COMPENSATION FOR THE EFFECTIVENESS OF RISK MITIGATION STRATEGIES FOR FUSARIUM HEAD BLIGHT (FHB) AND DEOXYNIVALENOL (DON)

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Nathalie Ndedi Lyonga

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Title

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

Food safety related problems are one of the biggest challenges worldwide. DON is produced by *Fusarium* species which causes the well-known Fusarium Head Blight (FHB) of wheat and barley. FHB outbreaks have led to variability in yield and revenue losses over the years. The main objective of my thesis was to quantify risk premiums at the farm level and with industry impact, to determine the effectiveness of FHB/DON mitigation strategies over time from 1997 to 2014. Data on revenue losses ($million) were obtained from USDA-ERS and was simulated using a risk analysis software called @RISK 7.5. The sample data was simulated 10,000 times to obtain a population. Risk premiums were calculated for each year and for each crop over time and graphs were plotted. Trends in risk premiums showed an overall decrease from 1997 to 2014, indicating that variability of losses have reduced and that the management practices have been effective.

ACKNOWLEDGEMENTS

I would like to express my earnest gratitude to my adviser, Dr. William Nganje for his wonderful support and his encouragements. My earnest gratitude goes to Dr. Paul Schwarz and Dr. Anuradha Vegi, who as the other members of my committee furnished my thesis with their remarks and contributions. I am also grateful to the entire food safety faculty, staff and the Department of Plant Sciences.

DEDICATION

I want to dedicate this thesis to my parents; Mr and Mrs R.C. Lyonga, my sister; Mrs Dorothy Efeti Lyonga Lambe and brother-in-law; Mr Shelly Molua Lambe.

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CHAPTER 1. INTRODUCTION

Food safety related problems are one of the biggest challenges worldwide. The Food and Agriculture Organization (FAO) estimates that 25% of the food crops worldwide are affected by mycotoxins annually (Alshannaq et al., 2017). Several fusarium head blight (FHB) outbreaks have occurred and characterized by high yield losses, that vary from year to year. Recalls of commercial pet food have also occurred in the US and other countries due to DON(Bischoff, 2013). In addition, discounts for DON are steep and variable at various grain elevators. In subsequent paragraphs we represent; the occurrence of FHB outbreaks, the variability of economic losses at the farm level, DON induced losses at the industry level, farm management practices to mitigate FHB losses, industry management practices to mitigate DON, the effectiveness of management practices using the risk premiums, the general objectives, the specific objectives and the contributions of our research.

1.1. FHB and DON Occurrences

In 1993, the FHB epidemic was described as “one regions ordeal” (McMullen et al., 1997). This epidemic affected several states in the US. It drastically reduced the yield in all wheat classes and malting barley and was recorded as one of the greatest farm losses in North America during that year (McMullen et al., 1997). Also, Rodriguez et al., (2012) analyzed different samples from the field to determine the rate of occurrence of DON in the Americas and Europe. In their study, a three-year survey was carried out on the occurrence of DON in soybeans, corn, wheat and Dried Distillers grains with solubles (DDGS) in North and South America. From their results of DON occurrence in these grains, North America, South America, Central Europe and Southern Europe had the highest number of positive corn samples. The least contaminated region was South America with only 17 positive corn samples out of a total of 322 tested from 2009- 2011. North America had the highest number of positive wheat samples. Based on their findings, DON was a major problem in these regions.

1.2. Economic Losses of FHB at the Farm Level

FHB/DON occurrences have led to high yield losses which in turn led to high costs incurred both at the farm level, industry level and the entire food grain supply chain. The economic impact of FHB in the United States between the periods 1993-2014 was studied by Wilson et al., (2017). In their study, the economic losses in terms of production losses in bushels and revenue losses in million US dollars were reported for hard red spring wheat, durum wheat, soft red winter wheat and barley. They estimated a total loss of approximately $1.47 billion in wheat and barley between 2015 and 2016 in the US. They developed models which estimated these costs for each of the wheat classes and for malting barley. The total costs for wheat was approximately $1.176 billion, with $186 million for Hard Red Spring wheat (HRS), $7 million for durum wheat, $568 million for Soft red winter wheat (SRW) and $415 million for Hard Red Winter Wheat (HRW).

Figure 1 and 2 shows the variability in production losses per thousand bushels and revenue losses in US dollars in soft wheats, hard wheats, durum wheat and barley respectively. The data presented in the figures are from Wilson et al., (2017). The graphs show that even though loses have declined, the variability of losses continue to pose major challenges. This trend is similar for yield and revenue losses. One interesting observation is that the trends coincide with the increased use of fungicides and resistant varieties developed thus far. Granite and Jensen are moderately resistant varieties of hard red winter wheat. The use of risk premiums could be used to evaluate the effectiveness of these mitigation strategies.

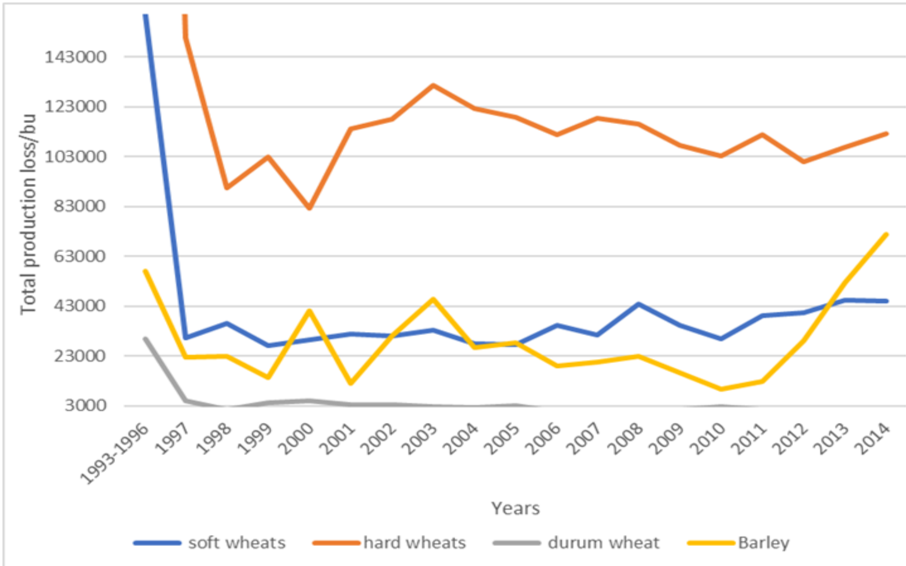

Figure 1. Total Production Losses/(1000 Bu) from 1996-2014.

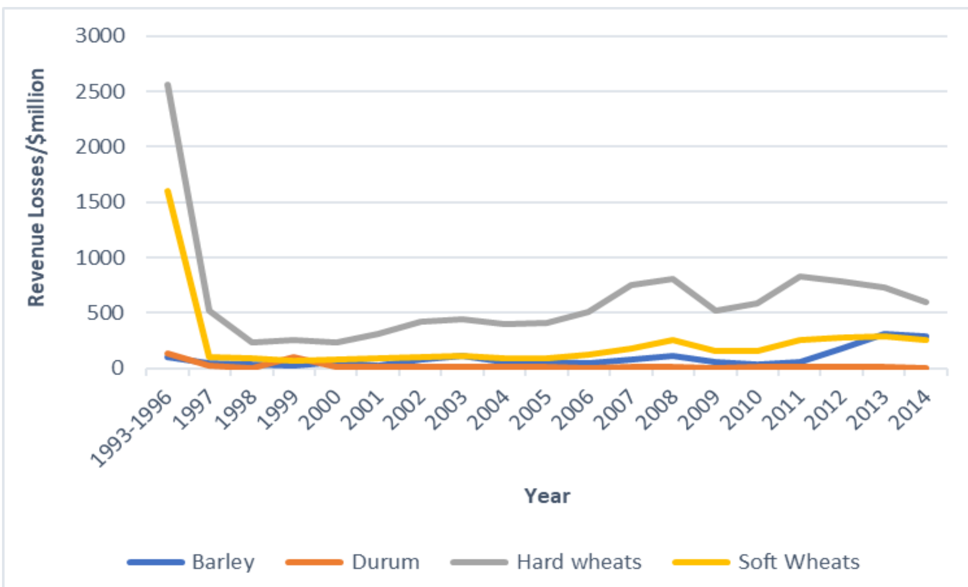

Figure 2. Total Revenue Losses ($ million) from 1996-2014.

1.3. Losses due to DON at the Industry Level

Costs accrued at the level of the industry because of DON, are in the form of recalls, discounts and liabilities (Bischoff, 2013). An example is the 1995 class II recall of commercial dog feed in the US (Bischoff, 2013). A recall is the withdrawal of a commodity from the market because it is adulterated and not fit for human or animal consumption. According to the FDA recall activities, 3 recall classes have been classified. Class I, II and III recalls. Class I recalls are those in which consumption of contaminated food products lead to illnesses or death. Class II recalls are those in which consumption of contaminated food products lead to temporary illnesses which are reversible but do not cause any serious health effects. Class III recalls are those which upon consumption of contaminated foods, do not pose any serious illnesses (FDA, 2018; Bischoff, 2013). Figure 3 below shows the trend of occurrence, based on the number of reported recalls in the US from 1991-2012.

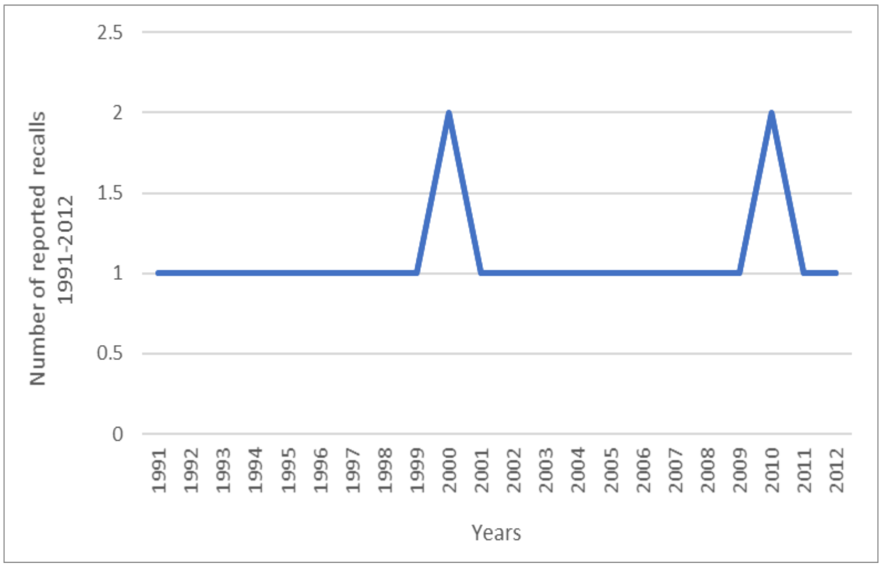

Figure 3. Number of Reported Recalls in the US between 1991 -2012.

DON recalls were compiled and rearranged according to the different years in which they occurred (McMullen et al.,1997; Bingham et al., 2004; Cowger et al., 2005; Maciel et al., 2011; Rumbeiha et al., 2011; Aquino et al., 2011; McMullen et al., 2012; Palazzini et al., 2015; European Commission, 2015; Yada et al., 2018). From figure 3, the number of recalls stayed constant in the nineties and then increased to a peak in year 2000. It further decreased till 2009, and then increased again in 2010, where it remained constant till recent years. Figure 3 shows that the variability of loses are still problematic even with increasing use of management practices by growers and industry practitioners (Wilson et al., 2017).

1.4. Farm Management Practices

These costs of FHB/DON to producers and processors can be managed using alternative strategies. These strategies used at the farm level are; fungicides applications and cultivation of resistant varieties, while cleaning and ozonation are used at the industry level. The cultivation of resistance varieties is a cost-effective strategy that has been used to mitigate FHB/DON (Wegulo et al., 2015; McMullen et al., 1997, 2012). The different types of FHB resistant traits were first described by Shroeder and Christensen (1963). The development of wheat/barley cultivars with FHB resistance traits is still a big challenge worldwide. This is because of its quantitative nature, i.e. the resistance trait is inherited and only prevents but doesn't eliminate the disease completely. In addition, it is very diverse with different biological bases (St Clair DA, 2010). However, despite these challenges, some cultivars have been released with fhb 1 resistance in spring wheat (McMullen et al., 2012). Several authors suggested that over 40% of the wheat cultivars in Minnesota, North Dakota and South Dakota had the fhb 1 resistance trait (Anderson et al., 2011; McMullen et al., 2012). They also mentioned that it had greatly reduced the amount of vulnerable wheat plants from 76% in 1999 to 31% in 2011. The United States Wheat and Barley Scab Initiative (USBWSI) have funded and is continuing to fund breeding programs in the US, to increase the amount of wheat and barley cultivars with moderate resistance (Wegulo et al., 2015).

The use of fungicides is another strategy that has been applied at the farm level. Fungicides are antifungal chemicals applied on plants to reduce/prevent fungi infestation, thereby preventing FHB/DON incidence. The most used group of fungicides are those that inhibit demethylation. Examples include: metconazole, propiconazole, prothioconazole and tebuconazole (Wegulo et al., 2015). In their study, these fungicides showed great reduction in

FHB/DON in wheat and barley. The application of prothioconazole/tebuconazole after the flowering stage in soft red winter wheat was also evaluated. It was discovered that the fungicide combination successfully eliminated FHB in wheat previously inoculated with *Fusarium graminearum* after 6 days (D'Angelo et al., 2014). They also concluded that the use of fungicides should be done either during the flowering stage or approximately after 6 days. This is because the plants are more vulnerable to FHB during the flowering stage (D'Angelo et al., 2014). The method of applying these fungicides on the grain crops is also important. Improper application will present little or no effects on mold infested plants.

Figure 3 and 4 below are graphs from Wilson et al., (2017) which shows the variability in the use of fungicides on Hard Red Spring (HRS) wheat and durum wheat in different states from 1990-2015 respectively. The use of fungicides has increased considerably over the years.

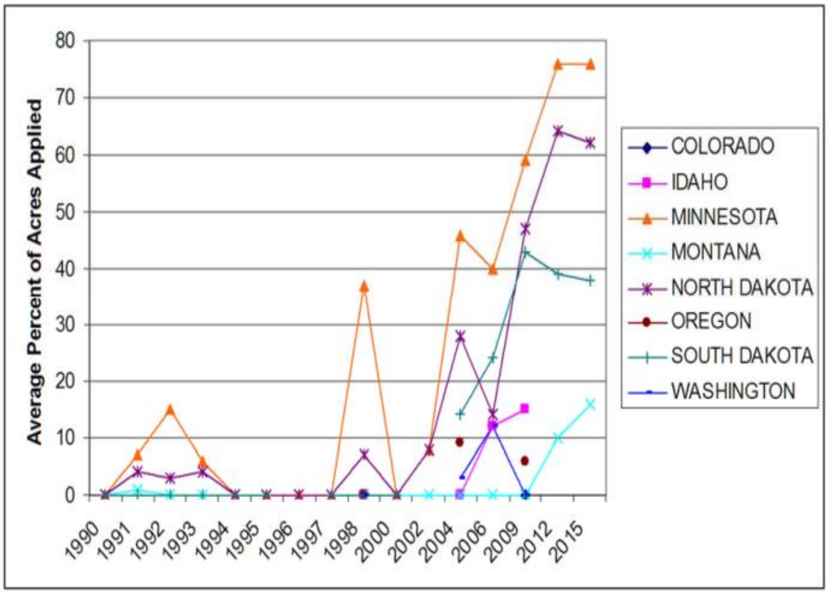

Figure 4. Use of Fungicides by State, 1990-2015 (Wilson et al., 2017)

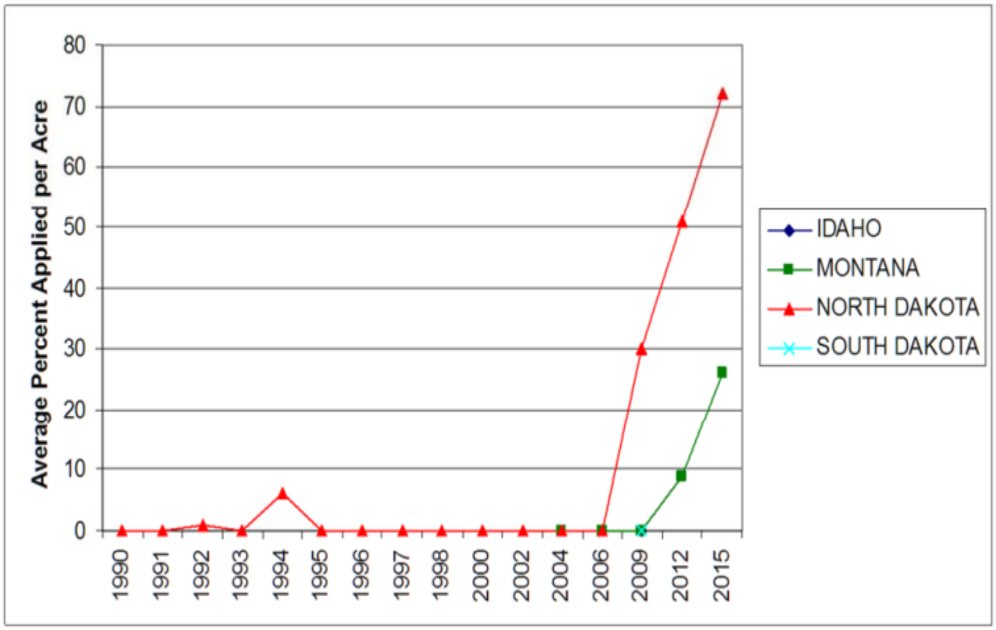

Figure 5. Durum Wheat Use of Fungicides by State, 1990-2015 (Wilson et al., 2017).

1.5. Industry Management Practices

At the level of the industry, food commodities are cleaned or treated with ozone to eliminate DON before they are transported to retailers (Wang et al., 2016). Ozone is a powerful chemical used in many food industries to preserve food. It is well known to preserve water in waste water treatment plants. Ozone is formed when free oxygen radicals produced by high electric discharge, react with the diatomic oxygen (O_2) molecule to form a triatomic molecule, ozone (O_3) (Tiwari et al., 2010). The breakage of this strong bond during free radical formation releases high amounts of energy. In the milling industry, DON levels in wheat are reduced by dehulling. This is because DON is usually accumulated on the outer surface layer of the kernel, the bran which is removed during this process (Karlovsky et al., 2016). Furthermore, incoming wheat grains are selected for low DON. Heavily contaminated grains are usually characterized with a low test weight, which constitutes the bulk of the damaged and broken kernels (Karlovsky et al., 2016). Also DON levels in barley are reduced during the steeping process and washing process. Karlovsky et al., (2016) shows that steeping and washing barley and corn in distilled water reduced their DON content by 65-69%.

1.6. Effectiveness of Management Practices using Risk Premiums

Risks are the variability of losses associated with FHB/DON. Risk premiums are the benefits of the investments to reduce risk. They are beneficial because they assess unexpected variability of losses. Risk premium is a product of risk reduction preference and the variability of losses, measured in terms of variance. This measure is used to estimate the true benefits of risk or losses, captures time variability of losses and evaluate losses in conjuncture with preferences for alternative management practices at the farm and industry impacts from recalls (Dahl et al., 2018).

1.7. General Objectives

The primary objective of this project is to quantify risk premiums and assess the true cost of risks for farmers and industry practitioners to invest in risks reducing management practices.

1.8. Specific Objectives

1.8.1. Objective 1

The first objective of this project is to quantify risk premiums at the farm level. At the farm level, if farmers invest in these management practices such as use of resistant cultivars, fungicides and good agricultural practices (tilling and early planting), the risk of losing their entire harvest to FHB will be reduced as compared to when nothing is done. The implementation of these strategies will significantly reduce DON levels (ppm) in the grains, as well as increase profit.

1.8.2. Objective 2

The second objective of this project is to quantify risk premiums with industry impacts from recalls. Technologies that will eliminate DON from food products, rendering them safe for human and animal consumption like ozone are evaluated. Without these technologies, processors will experience great losses because of recalls of contaminated products. These premiums and related returns will motivate processors to use these technologies even further to eliminate DON in foods, thereby reducing the risk of recalls and future losses.

1.8.3. Objective 3

The last objective of this thesis is to quantify a holistic risk premium and return on investment and to determine how beneficial it is to implement these practices simultaneously. Holistic risk premiums are the benefits of investing in risks mitigation strategies at the industry and farm levels. The benefits are the high returns farmers and processors will receive due to implementing alternative management practices.

1.9. Contributions

Previous studies have not addressed the true cost of risk (FHB/DON) which is captured by the risk premium. The risk premium is driven by 2 main factors; variability of FHB/DON losses over time and the aversion to risk which portrays how concerned growers and industries are managing these losses. Aversion to risk can be modeled as a scale from 0 to 0.1 i.e. from being risk neutral to highly risk averse respectively. Risk neutral growers and producers are those who show no concern to FHB/DON losses while those who are highly risk averse show more concern and are willing to invest in the different management practices, to mitigate FHB/DON at the farm and industry levels respectively. In addition, this research will also be beneficial to farmers, processors, biotechnologists and academia globally. No study to date has evaluated the impact of these management practices on the variability of crops or revenue losses. Declining variability and risk premium provide an effective framework to access the impacts of alternative risk management strategy. These frameworks have been used extensively in the economic literature.

CHAPTER 2. LITERATURE REVIEW

In this chapter we present a background on mycotoxins, deoxynivalenol (DON) and Fusarium Head Blight (FHB) as well as seven categories of factors that affect the variability of losses due to FHB/DON. First, a background on mycotoxins, DON and FHB will be discussed to give an insight of what DON is and how it is related to FHB, followed by seven factors which affect variability of losses due to FHB and DON.

2.1. Background on Mycotoxins, Deoxynivalenol(DON) and Fusarium Head Blight (FHB)

Mycotoxins are toxic secondary metabolites produced by certain fungi called molds which causes adverse health effects to humans, plants and animals. They are naturally occurring and very difficult to eliminate from the food supply chain. The Food and Agricultural Organization estimates that 25% of food crops worldwide are affected by mycotoxins annually (Alshannaq et al., 2017). Molds are multicellular microorganisms with thread like structures called hyphae. The main groups of molds usually associated with mycotoxin production in food crops and feed material belong to the genera: *Aspergillus, Penicillium* and *Fusarium* (Alshannaq et al., 2017). These molds attack a wide variety of cereal grains (such as oats, wheat, barley, sorghum, corn, rye, rice, peanuts etc.) in the field before harvest and during storage.

DON is a mycotoxin produced *Fusarium* which causes the well-known FHB of wheat and barley and is responsible for farm losses. Deoxynivalenol belongs to a group of mycotoxins called trichothecenes, particularly the type B group. It is produced by several species of *Fusarium* such as *Fusarium graminearum* and *Fusarium culmorum* (McMullen et al., 2012). These microorganisms produce DON under favorable conditions such as: high temperatures, excessive rainfall, as well as under stress conditions like drought. All the wheat classes and barley grains are susceptible to this disease (McMullen et al., 2012). Infested grains are pink in nature, a major characteristic of FHB, however not all of them have these symptoms which is the actual problem the industry faces. Petr Karlovsy (2011) mentioned that the common feature of all trichothecenes, the epoxide group is necessary for the inhibition of protein synthesis which is the main mechanism of action of these group of mycotoxins, hence the resulting adverse effects on animals/humans upon ingestion of contaminated food.

This epoxide group can be seen in the 2D chemical structure of DON as provided by ChemSpider is shown in figure 1 below.

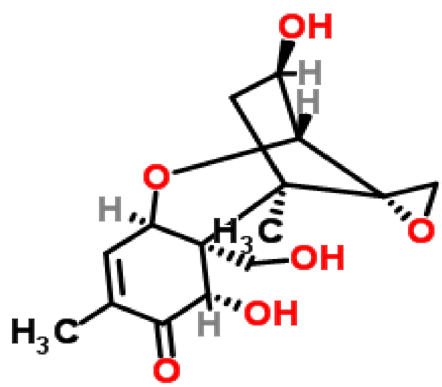

Figure 6. Chemical Structure of Deoxynivalenol

Petr Karlovsy (2011) suggested DON to be the most important toxin based on its economic impacts and the fact that it is very predominant in small grains. FHB causes losses in yield in wheat and barley, discount in prices for farmers, increase costs for farmers and low productivity in animals upon ingestion. Earlier studies by McMullen et al., (1997) extensively described the economic and social impacts of some FHB epidemics that occurred in North America and Canada, between the periods of 1991-1996. Within this time frame, they addressed the possible causes of these outbreaks and how growers, processors and scientists are all working together to manage this disease. The seven categories of factors that affect the variability of losses due to FHB/DON are: FHB occurrences, economic losses of FHB at the farm level, market cash discounts, DON losses at the industry level, farm management practices, industry management practices, and regulations in the US and EU.

2.2. Fusarium Head Blight Occurrences

McMullen et al., 1997; Nganje et al., 2004 extensively studied the economic impact of the 1993 FHB epidemic across three states in North America. The crops mainly affected in this study were wheat and malting barley. The wheat classes implicated were hard red spring wheat and durum wheat. FHB was severe in these areas leading to great losses in yield, as well as in grain quality with a monetary value of approximately $1 billion. The wheat yield losses in the affected areas were distributed as follows: 95 million bushels in North Dakota, 18 million bushels in South Dakota and 43 million bushels in Minnesota. The value of the above losses summed up to $ 704 million for all the wheat classes, while the total value for barley losses were $122 million. As mentioned in this study, the estimated yield losses and costs were made possible because of field surveys by the different agriculture departments in these states.

Due to losses in yield and grain quality, growers suffered high discount rates since most of their kernels had high DON concentrations and were low in test weight, which are qualities not acceptable by food processors. These also led to high prices with little or no marketability because of low supplies. All these triggered the Food and Drug Administration (FDA) to establish guidance levels for DON content in wheat and barley to 2 ppm for all raw grains for human consumption in 1993 (McMullen et al., 1997). After this guidance level was established, subsequent years showed low levels of DON contamination and low discount rates. This eventually led to the establishment of a final guidance level of 1 ppm of DON in finished flour as set up by the FDA. It also shifted the burden on growers to food processors and retailers, allowed farmers to blend high DON containing grains with healthy grains and reduced the risk of losing their entire yield to FHB (McMullen et al., 1997). The table is an extract from McMullen et al., (1997) and it shows the discount rates from 1993 to 1994 for hard red spring wheat at a Minneapolis Grain Exchange. These discount reductions were due the change of DON guidance levels from 2 ppm in raw grains to 1 ppm in finished products.

Table 1**.** Base Prices and Discounts for Hard Red Spring Wheat, Minneapolis Grain Exchange (McMullen et al., 1997).

Market/contract[a]	**1993 contract price ($/bu)**	**1993 vomitoxin discount($/bu)**	**1994 contract price($/bu)**	**1994 vomitoxin discount($/bu)**
Milling	5.36	0.96	4.50	0.25
Terminal, 2ppm	5.05	0.65	4.30	0.05
Terminal, 6ppm	4.40	1.59	4.25	1.20
Feed	2.81	NA[b]	3.05	NA

[a] Milling = highest grade
[b] NA = not applicable

Besides these risks or losses, McMullen et al., (1997) also addressed the negative impact of DON on health. They mentioned that the toxin DON, can cause vomiting and diarrhea in animals especially swine if fed with contaminated feed. This study suggested reasons that caused FHB severity in these regions and how it was managed accordingly; climatic conditions such as high rainfall, inadequate tilling and crop rotation. They also mentioned that the United States Department of Agriculture (USDA) discouraged farmers from rotating their crops, as they implemented a penalty on growers who did not have enough acres of wheat. However, because of this severity, management practices such as use of resistant cultivars and fungicides were used by farmers to manage the disease at the time. The outlook from this study was focused mainly on further development and improvement of breeding techniques, accurate planting time and application techniques of these chemicals to prevent and reduce FHB/DON incidence (McMullen et al., 1997). This has led to the development of new ideas resulting to subsequent publications on risks and costs of FHB, its economic impact as well as the different management practices.

2.3. Economic Losses of FHB at the Farm Level

A study carried out by Nganje et al., (2002) focused on the economic impact of Fusarium Head Blight in wheat and barley from 1998-2000. The main objective of their study was to analyze the impact of losses due to FHB on the economy in nine different US states with outbreak histories (Nganje et al., 2002). Three wheat classes were used in this study; hard red spring wheat, durum wheat and soft red winter wheat. The nine states with FHB histories were distributed based on the class of wheat involved in the outbreak. For example, for hard red spring wheat, the states of concern were: Minnesota, North Dakota, and South Dakota. They classified the losses into 2 groups; direct and secondary losses. Direct losses were in terms of the quantity lost due to FHB and price deviation from the normal expected price while secondary losses were in terms of macroeconomic impacts or multiplier effects (Nganje et al., 2002). These losses were estimated using data from Crop Reporting Districts (CRDs) of the affected states. Losses were estimated by obtaining the difference between the crop value with and without FHB. From their results, the direct losses for all the wheat classes summed up to 47.8 million bushels, with hard red spring wheat accounting for the highest losses. In addition, the secondary losses led to a multiplier effect in the different states. Costs accrued because of FHB for hard red spring wheat were approximately $330 million in North Dakota, South Dakota and Minnesota from 1998-2000 (Nganje et al., 2002). This study expanded the scope of the impact of management practices on losses.

Nganje et al., (2004) again studied the economic impacts of FHB in wheat and barley, but in this case within a time frame from 1993 to 2001. The focus of their study was to estimate the total losses, primary and secondary economic factors that affected yield and prices of wheat and barley across nine states in the US. Three wheat classes (hard red spring wheat, durum wheat and soft red spring wheat) and malting barley were analyzed. Of the nine states used in these study, hard red spring wheat, durum wheat and malting barley were mainly affected in North Dakota, Minnesota and South Dakota while soft red winter wheat was mainly affected in Illinois, Indiana, Kentucky, Michigan, Missouri and Ohio.

The primary factors that affected yield were measured in terms of production in bushels and expected price per bushel under disease-free conditions. The secondary factors and total economic effects of FHB were estimated using an input-output model. Production losses in bushels were estimated by wheat class and state. From their results, wheat and malting barley had the largest total losses in 1993, 1994 and 1997. The total losses in bushels for each wheat class were also estimated. A total production loss of 498.0 million bushels accounted for all the wheat classes. Of this total, hard red spring wheat had the largest loss, followed by soft red winter wheat and then durum wheat. North Dakota and Minnesota sustained the largest losses across all the nine states in their study. They concluded that FHB is still a major problem not only in the northern states, but in central states as well. Furthermore, they also mentioned that FHB affects grain producers and the entire economy, especially other sectors which rely on the revenues from the sale of these grains.

Dahl et al., (2018) studied risk premiums due to fusarium head blight in wheat and barley. The main objective of their study was to quantify risks premiums and related returns associated with the different alternative management practices to prevent FHB/DON. An analytical model was developed and was used to estimate these risks premiums. The models were simulated, and the results obtained measured the returns as the standard deviation for each strategy employed. The variables used were the different strategies employed by farmers for each wheat class (HRS, SRW and HRW) and malting barley which include use of no strategy, use of resistant cultivars, use of fungicides, and both resistant cultivars and fungicides. The distributions were further analyzed using Stochastic Efficiency with Respect to a Function (SERF). This system made it possible to rank the different strategies based on their returns for each wheat class. From their results, the use of both fungicides and moderately resistant cultivars had the highest returns for farmers relative to when no management practice was used. Hard red spring wheat had the highest return for the other three practices amongst the other wheat classes. They concluded that the practices used to mitigate FHB greatly reduces risks and increases returns for farmers as opposed to when no strategy was implemented. However they did not estimate how effective the strategies were overtime.

2.4. Market Cash Discounts

Several authors have described the importance of discounts in the cash market which usually occur because of increased FHB/DON incidence and serve as an indication to farmers and processors about the value of their products (Wilson et al., 2017; Dahl et al., 2018). In their study, they interviewed some country elevators on the sales and discounts of grains with different DON levels. Based on their survey, they concluded that the discounts in cash market for DON varies with time depending on the amount of DON in the grains. Also, no discounts are applied when the concentration of DON is 2 ppm, but above this level discounts apply. The table below summarizes the results from their survey, showing the discount prices of hard red spring wheat (HRS) in different crop years at a country elevator in North Dakota.

Table 2. Representative Cash Market Discounts at Country Elevator (Wilson et al., 2017)

Crop year	Specification limit(allowed) without discounts	Discount
2011	1	5c per1/2 ppm; > 5.1 = 60c
2012	2	0 -2.6 ppm =0; > 2.6 10c
2013	2	5c/ 1/2 ppm over 2
2014	2	10c/ ½ ppm
		5c/ ½ ppm for 2.1 to 4 ppm
2016	2	10c/ ½ ppm > 4.1 ppm

These discounts will have a negative impact on the variability of losses. High discounts will lead to an increase in variability of losses. Though FHB occurrence have seen a decrease over the years, the overall goal is to minimize variability of these FHB losses as much as possible.

2.5. Losses due to DON at the Industry Level

Bischoff, (2013) carried out a review on product safety and pet food recalls in the US from1996 to 2010. According to her review, most of the feed recalls in the US were due to natural contaminants such as mycotoxins. She further mentioned that these recurring feed recalls have raised government and pet owner's awareness over the years. Three classes of recalls were defined: class I, class II and class III. Class I recalls are very likely to cause illnesses or death; class II recalls cause illnesses but with little or no deaths; and class III recalls do not pose any illnesses if contaminated food is ingested. This study also reviewed the different classes of pet food recalls from 1996 to 2008 because of mycotoxins. Different types of mycotoxins were implicated but will focus on deoxynivalenol. An example of a pet food recall mentioned in this review was the 1995 dog food recall in the US due to DON. The grains used to produce dog food had high levels (30ppm) of DON. This was a class II recall because the resulting adverse health effects were reversible and did not lead to any deaths. She concluded that pet food manufacturers should continue to follow HACCP principles, to reduce risks of contamination.

2.6. Farm Management Practices

2.6.1. Cultivation of Resistant Varieties

From the above negative impacts of FHB, it is very important to adopt strategies to prevent this disease burden on growers and processors. FHB management practices at both levels will minimize variability of losses. Several authors have mentioned that the cultivation of resistance varieties is a cost-effective management practice to prevent FHB/DON (Wegulo et al., 2015; McMullen et al., 1997, 2012). Shroeder and Christensen (1963) first described the different types of FHB resistant cultivars. The development of FHB wheat/barley resistant cultivars has been a challenge worldwide. This is because the resistance trait is inherited and only prevents but does not eliminate FHB completely (St Clair DA, 2010).

However, regardless of these challenges some resistant cultivars have been successfully reported in some wheat classes as suggested by McMullen et al., (2012). It was stated in a study carried out by Anderson et al., (2011) and McMullen et al., (2012) that over 40% of the wheat cultivars in the Minnesota, North Dakota and South Dakota inherited the fhb 1 resistance trait. The amount of susceptible wheat plants decreased by 45% from 1999 to 2011 as mentioned in Wegulo et al., (2015). They also mentioned that for breeders to successfully obtain FHB resistant cultivars, the resistance traits must be coupled with other preventive traits such as herbicide and drought.

2.6.2. Chemical Control (Use of Fungicides)

A study carried out by Wegulo et al., (2015) showed that the most widely used fungicides, were those that inhibited the demethylation process in plants. Examples include: metconazole, propiconazole, prothioconazole and tebuconazole. In addition, they mentioned that these fungicides have been used and have significantly reduced FHB/DON in wheat and barley.

Another study evaluated the application of prothioconazole/tebuconazole after the flowering stage in soft red winter wheat and found out that the application of these combination, eliminated FHB in wheat previously inoculated with the mold (*Fusarium graminearum)* after 6 days (D'Angelo et al., 2014). They concluded that application of fungicides should be done approximately 6 days after planting, since plants are more susceptible to FHB during this period. Despite the effectiveness of these fungicides, some difficulties were noted (McMullen et al., 2012). In their study, they stated that proper application of fungicides is necessary to ensure their efficacy in preventing FHB/DON. They further suggested that the use of nozzle sprayers effectively applies the fungicides to these plants.

Regardless of how promising the use of fungicides can be in reducing FHB/DON incidence, concerns about fungicides resistant fungi have been raised as well as the demand for the development of new fungicides with new targets. The discovery of a tebuconazole- resistant isolate of *Fusarium* fungus was reported in New York (Wegulo et al., 2015; Spolti et al., 2014). From the above report, more research needs to be done on resistant fungi alongside the development of novel fungicides with different targets.

2.6.3. Tillage and Crop Rotation

Good agricultural practices are very important when trying to prevent or reduce the incidence of FHB/DON. Crop rotation and tillage are very important especially after harvest on a previous scabby field. During harvest, infected kernel residues usually remain in the soil and as a result, can potentially contaminate newly planted grains on the same area if proper tilling is not done. Schatzmayr et al., (2013) reported that proper tilling and crop rotation on the field from which wheat was previously grown has lowered DON levels in subsequent crops. They also mentioned that early planting dates is also very important in reducing DON levels. If the grain crops are planted early, then farmers will not need to excessively irrigate their crops, which might lead to elevated moisture levels favorable for FHB/DON.

The effect of high moisture levels in increasing DON/FHB incidence is consistent with Wegulo et al., (2015); Cowger et al., (2009). In their field experiment, they studied the effects of increasing moisture levels during the flowering stage on FHB intensity, FDK and DON levels in soft red winter wheat cultivars inoculated with spores of *Fusarium graminearum*. After 10 to 20 days, they found out that the FHB intensity, Fusarium Damaged Kernels (FDK) and DON levels all increased significantly (Cowger et al., 2009). Based on these studies, it can be noted that moisture is a very crucial factor when mitigating DON/FHB.

At the level of growers, it is very difficult to manage FHB/DON. This is because of the inevitable climactic conditions such as excessive rainfall, which is very important in fungal growth and mycotoxin production. Predictive models such as DON cast as reported in Hooker and Schaafsma (2003) have been used to predict the risk of mycotoxin contamination, based on available weather information. This is very useful as it can keep growers and farmers informed on the risks of DON/FHB contamination under specific weather conditions.

2.7. Industry Management Practices: Practices used by Millers/Maltsters/Brewers and Ozonation

Karlovsky et al., (2016) mentioned different steps that are used to reduce DON levels in grains. Millers sort and sieve their grains before the actual milling process. They sort out grains with excessive mold growth as well as broken kernels. In their study, this process reduced DON contamination by 70- 80%. Furthermore, the actual milling process removes the bran which usually contains high DON levels. In addition to sorting/sieving, floating and density segregation was also used and they mentioned that the kernels which floated on both water and 30% sucrose reduced DON above 68% in wheat. DON levels in animal feed are reduced by treatment with sodium bisulfite and sodium metabisulfite. Another management practice they mentioned was enzymatic detoxification. This practice is beneficial for maltsters and brewers since beer is usually contaminated with DON (Karlovsky et al., 2016).

Even though there are limited studies on the effects of ozone on grains, a study investigated the efficacy of the anti-fungal properties of gaseous ozone in stored wheat (Wu et al., 2016). They used five different ozone concentrations on wheat samples with water activities of 0.90 for a period of 5 minutes. Their results showed an inactivation of 96% of fungal spores on the wheat samples. They further explained that the higher the ozone concentration, the more inactivation can be obtained. Another point noted in this study was the effect of water activity and temperature on the efficacy of ozone. They concluded that the efficacy of ozone increased with increase in temperature and water activity, making it more advantageous over other methods.

A review recently published by Zhu (2018), is consistent with the findings reported in Whu et al., (2016). This review supports the efficacy of ozone in inactivating *Fusarium graminearum* spores as in wheat flour. It is necessary to mention that the use of ozone in the food industry during grain processing to cereal products is efficient and safe for human consumption.

2.8. Regulations in the United States and European Union (EU)

2.8.1. USDA-FDA September 1993 Guidance Levels and Advisory Limits on DON

The FDA is a US government regulatory body under the USDA which ensures the safety of all food products including medical devices for its national consumers and users. Their primary goal is for the wellbeing of people, the environment and its natural resources. The concern of setting up regulations relating to DON started as early as 1982 (FDA, 2017). However, no regulations were set up due to lack of sufficient data on its toxicity and rates of occurrence. By September 1993, the FDA had obtained enough information to come up with guidance levels and advisory limits for DON in foods and feeds destined for human and animal consumption respectively. These regulations were later documented in June 2010 and covers the maximum levels of DON in finished wheat products and distillers' grains to be used as swine, cattle and chicken feed as seen in table 3 below (NGFA, 2010).

Table 3. FDA Advisory Levels for DON (NGFA, 2010)

Intended Use	**Grain or Grain By- Products**	**DON Levels in Grains or Grain By- Products and Complete Diet** (parts per million (p.p.m)**
Human consumption	Finished wheat products	1 p.p.m
Swine	Grain and grain by- product not to exceed 20%	5 p.p.m. (1 p.p.m) **
Chickens	Grain and grain by- products not exceed 50% of diet	10 p.p.m. (5 p.p.m) **
Ruminating beef and feedlot cattle older than 4 months	Grain and grain by-products*	10 p.p.m. (10 p.p.m.) **

*88% dry matter basis **Complete diet figures in parentheses

2.8.2. Regulations in the European Union (EU)

Regulatory bodies of most European countries are quite different from those in the United States. Regulations in the EU are very elaborate and have shown to evolve gradually as the years go by. The first EU regulation concerning mycotoxins in food began in 1998, expanded in 2006 and enforced in 2007 (Egmond et al., 2007). This regulation was enforced successfully with the aid of risk assessments carried out by the European Food Safety Authority (EFSA) (Egmond et al., 2007). Regarding the *Fusarium* toxin DON, the European Union commission created a commission together with guidelines for all its member states to comply. They regulate the amount of DON in grains intended for animal, infant and human consumption.

2.8.3. The December 19^{th}, 2006 Commission Regulation for Maximum Levels of DON in Foodstuffs.

This regulation encompasses cereals such as durum wheat and oats, unprocessed maize, cereal related products such as pasta & bread and other cereal based products for infant consumption. The table below shows the maximum limits of DON in the different foodstuffs intended for human and infant consumption.

Table 4. Guidance Values for Deoxynivalenol in the EU intended for Human Consumption (European Commission, 2006)

Deoxynivalenol	**Maximum Levels (ppm)**
Unprocessed cereals other than durum wheat, oats and maize	1.25 ppm
Unprocessed maize	1.75 ppm.
Cereals intended for direct human consumption, cereal flour (including maize) flour, maize meal and grits, bran as product marketed for direct human consumption and germ except for foodstuffs.	0.75 ppm
Unprocessed durum wheat and oats	1.75 ppm
Pasta dry	0.75 ppm
Bread (including small bakery wares), pastries, biscuits, cereal snacks and breakfast cereals.	0.5 ppm
Processed cereal based foods and baby foods for infants and young children	0.2 ppm

FHB and DON remains a big burden to farmers and processors. Based on the negative economic impacts as reviewed by previous studies above, it is very important farmers and processors adopt these management practices to reduce these risks or losses. Risk premiums are the costs or investments incurred in mitigating FHB/DON losses at the farm and industry levels respectively. Farmers and processors will obtain high profits for using these alternative practices (Dahl et al., 2018). This thesis is geared at estimating the true cost effectiveness of alternative management practices at the farm and industry. The analytical model to be used, is reviewed in the methodology section.

CHAPTER 3. METHODOLOGY AND DATA

3.1. The Impact of FHB and DON on Revenue

FHB and DON impact producers and industry in several ways: 1) create significant loss of revenue; 2) affect the production of crops with varying degree, up to complete abandonment of certain variety like two row barley; 3) increase the variability in revenue loss, and 4) complete shutdown of businesses in the case of major food recalls. In this chapter, we focus on the importance of increasing variability of revenue and risks. Upward variability of revenue is not risky, it could occur from increased prices due to limited supply of good quality grains from FHB (see Figure 7). Figures 7 provides an illustration of the potential impacts of FHB on producer revenue. It is assumed that the price received by producers is higher than normal due to FHB-related production shortfalls. Thus, ps > pn, where ps is scab related price and pn are prices in normal years. The change in producer revenue due to scab is given by;

$$\mathbf{\Delta R = (ps \times qs) - (pn \times qn)} \qquad (1)$$

Producer revenue in a scab year is given by areas A + C, while producer revenue in a normal year is given by areas C + D. The change in revenue is A - D. Thus, producers would lose revenue if the positive price impact is less than the value of lost production (i.e., if A < D). Another negative revenue situation occurs if quantity declines and price remain constant and the producer losses area D. A worse revenue situation is downward variability of revenue, when price and quantity decrease simultaneously. Producers and industry do not like revenue to vary significantly year after year. This creates difficulty with budget planning, obtaining bank loans, and operating a business efficiently. To mitigate FHB and DON risks, growers and industry participants have adopted varying strategies (e.g., more resistant varieties, applying fungicide, adopting crop rotations, cleaning, and the use of Ozone). The effect of these strategies is to reduce risk and increase/stabilize returns. When these risk mitigation strategies are effective, the market compensate producers and industry participants with higher prices and revenues. A good example is when management practices lead to more grains for human consumption and less feed grain, resulting in a premium of area A +B.

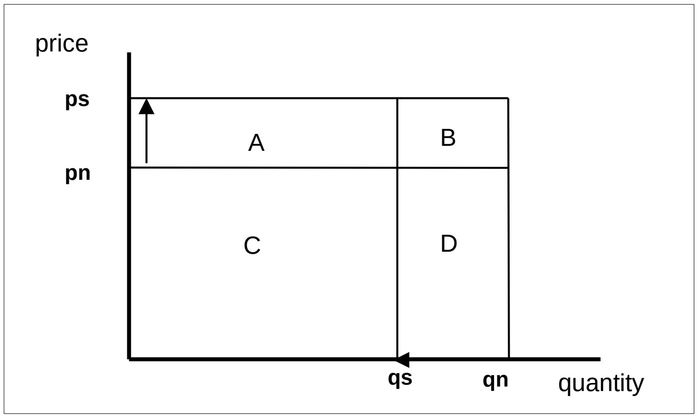

Figure 7. Change in Crop Value When Net Price Impact Is Positive (Johnson et al. (1998)

This compensation is commonly referred to as the 'risk premium.' Wilson, Bruce, and Nganje (2018) indicated that the technologies or strategies that have been adopted to respond to the risk of FHB and DON have resulted to increase revenue to producers and industry with the compensation of the 'risk premium.' The next section develops an analytical model to evaluate these issues and to quantify the risk premiums.

3.2. Theoretical Foundations to Measure the Risk Premiums

The theoretical measure of the risk premium is the difference between expected or average returns ($\bar{X}$) on a risky investment and a certain return from a risk-free investment (e.g., Treasury Bill, Note, or Bond), as in equation 2. Another measure of a certain return is a guaranteed price floor (e.g., the Loan Rate for farmers). A certain return is called certainty equivalent (CE). This mathematical relationship presented in equation 2 is the foundation of risk analysis (Robinson and Barry, 1999). If there is no difference between the expected revenue of a risky investment and a certain return, then investments to mitigate risk are not justified.

$$\boldsymbol{\pi} = \bar{X} - CE \quad (2)$$

Where; $\boldsymbol{\pi}$ is the risk premium

From equation 1, the utility of the certainty equivalent could be measured as in Equation 3.

$$\text{U}(\textbf{CE}) = \bar{X} - \boldsymbol{\pi} \quad (3)$$

The risk premium can further be decomposed as half the product of risk preference (aversion to risk) and the variability of returns, as in equation 4. An example of risk preference is "risk neutral," when growers and processors show no concern to FHB/DON losses and do not invest in any mitigation strategy or "risk averse," if they are willing to invest in alternative management practices to avoid FHB/DON losses. The magnitude of the risk premium depends on the level of risk aversion i.e. either highly risk averse or risk neutral and the variability of losses, depicted by the variance.

$$\text{Max U}(\textbf{CE}) = \bar{X} - \frac{\gamma}{2}\,\sigma^2 \quad (4)$$

Where;

$\frac{\gamma}{2}$ is the aversion to risk and σ^2 is the variability of returns over time.

The risk premium also reveals the true cost of FHB/DON risks over time. Losses at the farm and industry levels is a product of the risk reduction preferences (highly risk averse or risk neutral) and the variability of losses, measured in variance over time. Aversion for risk could be measured with the Arrow-Pratt approximation of the utility function using Taylor expansion series.

$$\gamma = -\frac{U''}{U'} \quad (5)$$

Equation 5 show the risk aversion parameter could be estimated by dividing the second derivative and the first derivative of the utility function U(CE).

3.3. Empirical Model at Farm Level

The empirical model we used in this thesis is an expansion of the model developed by Dahl and Wilson (2018). The model is based on a characteristic farm returns to labor and management. In equation 6, we present the model.

$$\boldsymbol{R_{i,t}} = \sum \boldsymbol{\widehat{Y}_{i,t}} \times \left(\boldsymbol{\widehat{P}_t} - \boldsymbol{\widehat{D}_{i,t}}\right) - \boldsymbol{F_{i,t}} - \boldsymbol{ODC_t} - \boldsymbol{FC_t} + \boldsymbol{rc_t} \qquad (6)$$

Where;

$$\boldsymbol{\widehat{Y}_{i,t}} = \boldsymbol{\widehat{Y}LD_t} - \boldsymbol{LN(DON)_t} * \boldsymbol{\widehat{DON}_t} - \boldsymbol{\widehat{Severity}_{i,t}} * \boldsymbol{Arcsign\ Severity} * \boldsymbol{t_t}$$

Given $t_t = 1$ if t = t;

$\boldsymbol{R_{i,t}}$ is returns to labor and management using technology choice i and wheat class/barley t;

$\widehat{Y}_{i,t}$ is adjusted yield for FHB/DON mitigation strategy for alternative i and wheat class/barley t;

$\widehat{Y}LD_t$ is base random yield for wheat class/barley t;

$\widehat{P}_t$ random price for wheat class/barley t;

$\widehat{D}_{i,t}$ is the random discount for DON alternative i and wheat class/barley t;

$F_{i,t}$ is fungicide cost for alternative i and wheat class/barley t;

FC_t is fixed cost for wheat class/barley t;

ODC_t is other direct costs for wheat class/barley t;

Rc_t is recalls reduction benefits for wheat class/barley t;

$\widehat{DON}_t$ is the random draw for DON for wheat class/barley t;

$LN(DON)_t$ is beta for the log transformation of DON;

$Severity_{i,t}$ is the random variable for severity;

Arcsign Severity $_{i,t}$ is the beta for the arc sign transformation

The model used for our analysis is an extension of the Dahl and Wilson (2018) model, to estimate system wide risk premiums for a combination of management practices, including benefits for reduction in recalls. The rational is that efforts to mitigate FHB and DON involves private-public partnerships. Also, studies have shown that mitigation strategies that reduces food recalls from industry have significant impacts on commodity prices and revenue (Mejia et al. (2010). The analysis was based on derived farm revenues with farm level mitigation strategies and additional revenues from industry efforts, for each year. Separate specifications were made to allow different strategies including adopting more moderately resistant (MR) varieties, fungicide or both. In addition, the impact of reduction in recalls from industry management strategies (e.g., Ozone or cleaning) were incorporated (Equation 7).

$$\mathbf{LN}\ (\boldsymbol{R_{i,t}}) = \mathbf{-\ 0.97 \quad + \quad 0.21(\#Recalls) + E} \tag{7}$$

$$\mathbf{(0.28)\ ***\ (0.44)**}$$

$$\mathbf{R^2 = 5\%}$$

$$\mathbf{N = 10000\ (simulated)}$$

3.4. Data and Data Sources

Data on crop budgets for all wheat and barley classes are provided by NDSU Extension Swenson (2015) and USDA-ERS (2016). This database includes the output variables used in our analysis, returns to labor and management. Some of the variables were specified as being risky, with distribution functions. Distribution functions enable us to develop a population distribution from a sample data. All variables in equation 6 include: yields for normal production, DON severity, discounts for excessive DON levels, severity of SCAB infestations, price, fungicide use and cost, revenue variability and savings from FHB/DON mitigation strategies and recalls due to DON outbreaks. The distribution for fungicide use, price, direct and fixed costs, recalls are presented in Table 5. DON maximum limits were assumed to be 2 ppm. Discounts of $0.05/bu.

or $0.10/bu. per ppm were applied. These discounts are representative of those at country elevators. Yields adjusted for alternative FHB management practices and distributions of FHB severity and DON were adopted from Nganje et al., (2014).

Table 5. Fitted Distributions for Fungicide Use, Recalls and Revenue

	Fitted Distributions
Recalls	Risk Pareto (11.542, 1)
Returns	Risk Uniform (0.26933,0.79067)
DON	Exponential (8.9433, -0.009)
Fungicides	Uniform (0.03333, 1.867)

Data on returns to management and labor for all wheat and barley producing regions affected by FHB/DON were adopted from Wilson et al. (2017). Returns were due to the use of farm level mitigation strategies such as; fungicides and the use of resistant cultivars. The returns for hard wheats, soft wheats and malting barley were estimated for each crop reporting district (CRDs) in the different states (table 6 to table 9).

Table 6. Returns for Barley ($) from 1997 - 2014

Years	**MD**	**NY**	**ND**	**MN**	**VA**	**Grand Total**
1997	40,1268	0	0	0	0	401268
1998	902,783	46,427	0	0	2782357	3731567
1999	1,223,894	109,744	1089095	0	2992807	5415539
2000	0	34,045	0	2654335	2867104	5555484
2001	891,921	0	0	3249935	3030087	7171942
2002	0	95,292	0	0	1687386	1782678
2003	666,270	29,213	0	0	2921356	3616839
2004	0	0	0	0	3571940	3571940
2005	0	15,841	0	518817	3057852	3592510
2006	688,286	0	0	0	0	688286
2007	356,669	0	0	0	0	356669
2008	0	0	0	0	1749215	1749215
2009	1,032,431	0	0	0	2998560	4030991
2010	488,732	0	0	19259	2818769	3326760
2011	0	0	0	0	0	0
2012	0	0	0	0	0	0
2013	0	0	0	0	0	0
2014	0	0	0	0	0	0
Mean	369,570	18,365	60505	357908	1693191	2499538
STDEV	431,184	33,844	256702	957059	1454878	2251230
Total($million)	**6,652,255**	**330,562**	**1,089,095**	**6,442,346**	**30,477,431**	**44,991,689**

Table 7. Returns for Durum Wheat ($) from 1997- 2014

Year	ND	MN	Grand Total
1997	11,752,880	615,052	12,367,933
1998	29,225,537	575,052	29,800,590
1999	0	611,247	611,247
2000	18,679,572	514,687	19,194,259
2001	23,647,658	615,052	24,262,710
2002	19,824,258	549,532	20,373,790
2003	21,951,598	609,344	22,560,942
2004	24,308,406	577,150	24,885,555
2005	22,563,488	573,677	23,137,165
2006	29,328,119	568,804	29,896,924
2007	23,380,578	492,227	23,872,806
2008	20,591,458	514,772	21,106,230
2009	26,839,089	562,564	27,401,653
2010	18,114,542	544,052	$18,658,594
2011	22,368,761	509,620	$22,878,381
2012	23,714,875	529,015	$24,243,890
2013	24,907,934	532,926	$25,440,860
2014	23,941,237	533,059	$24,474,296
Mean	21,396,666	557,102	$21,953,768
STDEV	6,730,913	38,939	$6,718,787
Total ($million)	**385,139,991**	**10,027,834**	**$395,167,825**

Table 8. Returns for Hard Wheats ($million) from 1997- 2014

Year	ND	SD	KS	NE	MN	MT	Grand Total
1997	0	8,268,102	82,603,925	28,447,112	7,353,475	0	126,672,614
1998	117,368,337	11,657,099	127,584,252	43,808,328	99,976,513	3,435,302	403,829,831
1999	123,411,259	12,381,086	156,605,261	45,399,962	97,739,930	$0	435,537,498
2000	106,411,056	12,381,086	132,259,651	47,514,950	98,613,255	$13,926,322	411,106,321
2001	96,575,725	12,381,086	96,690,579	43,449,421	66,769,357	$11,664,736	327,530,904
2002	44,384,626	10,085,096	93,738,626	35,995,475	34,750,983	0	218,954,805
2003	26,807,159	9,029,335	79,538,766	25,971,623	48,151,537	11,129,504	200,627,925
2004	59,720,460	9,541,291	78,358,118	24,517,246	57,569,965	8,414,087	238,121,167
2005	55,964,485	8,648,778	86,358,301	20,409,925	49,005,601	12,136,114	232,523,203
2006	49,191,534	8,500,569	17,029,104	4,704,008	46,928,379	8,205,369	134,558,964
2007	0	7,390,805	0	0	0	895,275	8,286,080
2008	0	6,065,478	0	0	0	0	6,065,478
2009	38,452,151	7,452,308	38,076,032	0	37,769,064	8,104,751	129,854,306
2010	1,870,098	8,785,697	47,676,215	0	14,459,622	0	72,791,632
2011	0	8,202,748	0	0	0	0	8,202,748
2012	27,284,634	9,439,567	0	0	2,634,550	0	39,358,752
2013	42,525,279	8,482,809	0	0	15,828,506	0	66,836,594
2014	30,711,126	9,170,005	0	0	27,407,025	27,685,772	94,973,927
Mean	45,593,218	9,325,719	57,584,379	17,789,892	39,164,320	5,866,513	175,324,042
STDEV	41,319,112	1,824,553	52,861,995	19,171,717	34,525,808	7,532,630	142,714,512
Total	**820,677,930**	**167,862,947**	**1,036,518,830**	**320,218,051**	**704,957,763**	**105,597,231**	**3.155,382,750**

Table 9. Returns for Soft Red Winter Wheat ($billion) from 1997-2014

Year	IL	IN	MI	MO	OH	KY	NY	AR	Grand Total
1997	15.7	256.64	3.26	6.28	12.86	0.04	0.06	0.46	346.36
1998	10.81	143.02	2.10	5.62	9.90	0.00	0.53	0.74	298.11
1999	15.30	238.38	2.21	5.99	12.64	0.00	0.56	2.18	427.91
2000	14.83	245.55	1.94	4.93	12.86	0.00	0.52	0.00	444.22
2001	14.81	251.29	1.81	4.08	11.24	0.00	0.43	0.00	414.94
2002	14.44	255.57	0.00	5.63	10.75	0.00	0.29	0.00	386.03
2003	13.54	254.26	0.00	6.18	8.45	0.00	0.54	0.00	377.95
2004	12.61	255.30	0.00	5.87	10.87	0.00	0.56	1.46	394.58
2005	14.31	255.51	0.00	6.10	10.91	0.00	0.47	3.24	407.63
2006	13.84	254.41	0.00	5.52	10.49	0.00	0.12	4.53	338.31
2007	13.06	254.98	0.00	3.15	8.91	0.00	0.00	0.00	281.31
2008	11.41	241.50	0.00	5.64	8.32	0.00	0.00	0.00	268.25
2009	12.52	253.54	0.00	5.51	9.84	0.00	0.00	0.00	308.70
2010	14.62	255.57	0.00	5.28	9.98	0.00	0.00	2.21	292.83
2011	13.19	254.57	0.00	4.97	8.58	0.00	0.00	0.00	281.31
2012	12.57	253.80	0.00	5.62	9.03	0.00	0.00	0.00	281.01
2013	11.40	252.66	0.00	5.62	9.71	0.00	0.00	0.00	279.39
2014	11.77	247.71	0.00	5.23	2.78	0.00	0.00	0.00	267.48
Mean	13.38	245.79	0.40	5.40	9.90	0.00	0.23	0.82	338.69
STDEV	1.46	26.17	1.19	0.77	2.28	0.01	0.25	1.36	61.71
Total	**240.81**	**4,424.25**	**7.11**	**97.23**	**178.11**	**0.04**	**$4.07**	**14.82**	**6,096.35**

Year	GA	MD	NC	VA	PA	OR	LA	Grand Total
1997	0.25	0.17	0.00	0.84	0.36	8.19	33.04	346.36
1998	4.23	0.00	2.86	2.60	2.15	17.69	71.73	298.11
1999	6.30	0.00	6.29	3.30	1.58	23.91	76.94	427.91
2000	5.02	0.00	7.18	4.44	2.66	23.37	88.64	444.22
2001	5.56	0.00	3.14	3.58	1.62	18.61	72.47	414.94
2002	6.06	1.16	4.68	2.37	0.00	12.03	53.97	386.03
2003	3.08	2.93	6.86	3.93	0.54	4.98	57.86	377.95
2004	3.21	2.97	4.97	3.55	1.90	15.23	63.25	394.58
2005	4.24	3.22	4.89	3.28	1.08	14.84	68.29	407.63
2006	5.71	0.00	1.99	1.35	0.48	11.00	25.50	338.31
2007	0.00	1.21	0.00	0.00	0.00	0.00	0.00	281.31
2008	0.00	1.37	0.00	0.00	0.00	0.00	0.00	268.25
2009	0.00	0.50	0.00	0.00	0.00	4.12	22.68	308.70
2010	4.14	1.03	0.00	0.00	0.00	0.00	0.00	292.83
2011	0.00	0.00	0.00	0.00	0.00	0.00	0.00	281.31
2012	0.00	0.00	0.00	0.00	0.00	0.00	0.00	281.01
2013	0.00	0.00	0.00	0.00	0.00	0.00	0.00	279.39
2014	0.00	0.00	0.00	0.00	0.00	0.00	0.00	267.48
Mean	2.66	0.81	2.38	1.62	0.69	8.55	35.24	338.69
STDEV	2.56	1.14	2.75	1.71	0.90	8.70	33.43	61.71
Total	47.8	14.56	42.85	29.24	12.36	153.96	634.37	6,096.35

3.4.1. Hard Wheats

Returns from hard wheats were approximately $3.16 billion in North Dakota, Minnesota, South Dakota, Kansas, Nebraska, and Montana 1997 to 2014. The hard wheats accounted for was Hard Red Winter Wheat (HRW).

3.4.2. Malting Barley

The total returns from barley were estimated at $45 million in North Dakota, Maryland, New York, and Virginia from 1997 to 2014.

3.4.3. Soft Wheats

The returns from soft wheats particularly Soft Red Winter Wheat (SRW), was estimated to a total of $6.1 billion in Illinois, Indiana, Michigan, Missouri, Ohio, Kentucky, New York, Arkansas, Georgia, Louisiana, Maryland, North Carolina, Virginia, Pennsylvania, and Oregon. Revenue savings for SRW were highest amongst the other crops.

3.4.4. Durum Wheat

Returns for labor and management practices from durum wheat were estimated at $395 million in North Dakota, Montana and Minnesota. North Dakota showed the highest savings amongst the other crop reporting districts.

3.5. Affected Regions and Data on Returns due to FHB

Data on revenue savings ($ million) for the different wheat types (hard wheats, soft wheats and durum wheat) and malting barley were adopted from Wilson et al., (2017). The returns for the different Crop Reporting Districts (CRDs) in the affected states for each wheat type were obtained for 1993 to 2014. Soft wheats were mainly affected in (Maryland, Virginia, Illinois, Indiana, Kentucky, Michigan, Missouri, Ohio, Arkansas, Georgia, Los Angeles, North Carolina, Pennsylvania, Oregon, New York), hard wheats were affected in (Kansas, Nebraska, North Carolina, South Dakota, Minnesota, Montana), durum wheat was affected in (North Dakota, Minnesota, Montana) and malting barley was affected in (Maryland, Minnesota, North Dakota, Virginia, New York). These regions are highlighted as shown in figure 8 below.

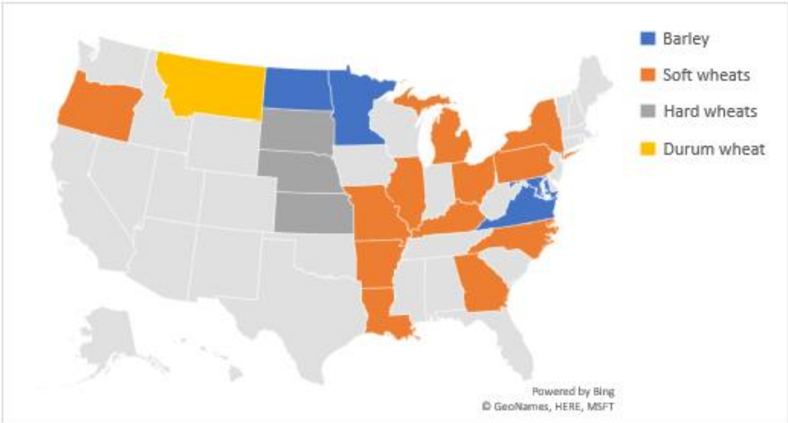

Figure 8. FHB Affected States for the Different Wheat Types and Malting Barley in the US from 1996-2014 (Wilson et al., 2017)

From the figure above, soft wheats had the highest number of affected states in the US, followed by hard wheats. Malting barley and hard wheats were mainly affected in the northern and mid-western states.

CHAPTER 4. SIMULATION PROCEDURES AND RESULTS

4.1. Simulation Procedure

Data was entered in @RISK 7.5 to simulate and get a population distribution from the sample data from 1993 to 2014. @RISK 7.5 is a risk analysis software which fits probability distributions to sample data in order to have more robust results and precise predictions. Five steps to this approach were used: 1) data was entered in @RISK; 2) distributions were fitted to specify the data for each year, 3) outputs were added to the different distributions obtained in each year; this step tells the software the number of times you want to simulate your data. (The larger the number of simulations, the better the results); 4) the number of iterations were chosen, which in this case was 10000; and 5) the mean, standard deviation, and other moments of the distribution were obtained for the population. Other parameters like the coefficient of variation and risk premiums were calculated using the distribution parameters (e.g. mean and standard deviation). The coefficient of variation is the ratio of the standard deviation and the mean and it useful in comparing the degree of variation between data sets of different sizes and magnitude. The smaller the coefficient of variation, the smaller the risk an investor is likely to have in a risky investment. The risk premiums were also calculated for each year and for each crop from 1997 to 2014, following equations 4, 5, and 6.

4.2. Results of Objective 1

The risk premium at the farm level was quantified using the data on returns in $million dollars for each crop (malting barley, hard wheat, soft wheat and durum wheat) and each year from 1997 to 2014 and for all the crops. Tables for the mean, standard deviation, coefficient of variation, sensitivity with respect to risk aversion and risk premiums of all the crops were also generated for each year. Graphs were plotted to show trends of the risk premiums for each year and each crop from 1997 to 2014.

Figure 9 below shows the trends in risk premiums for all the crops from 1997 to 2014. The risk premiums received by farmers ranged from $80 to $120 million across the years. The trends were relatively stable from 1999 to 2005, with sharp declines in later years. This stability in earlier years as seen in the graphs, can be accounted for the fact that farm management practices are beneficial but much work needs to be done. The sharp declines from 1997 to 1998, 2006 to 2007 and 2009 to 2011 are all due to the fact that significant variability in losses continued to exist. However, a sharp increase is seen in 2014, showing that farmers are investing in these practices and are being compensated by the market in the form of the high returns they receive. The more these practices are being implemented by farmers, the more profit they will receive.

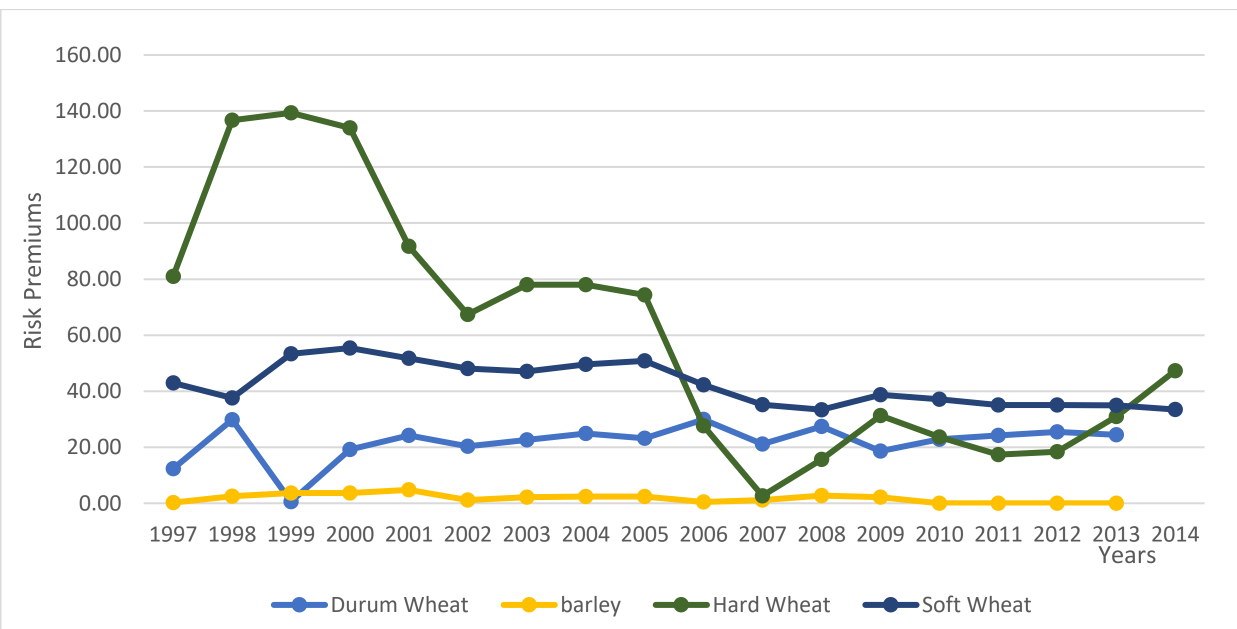

Figure 9. Risk Premiums vs Years for all the Wheat Types and Malting Barley from 1997 to 2014.

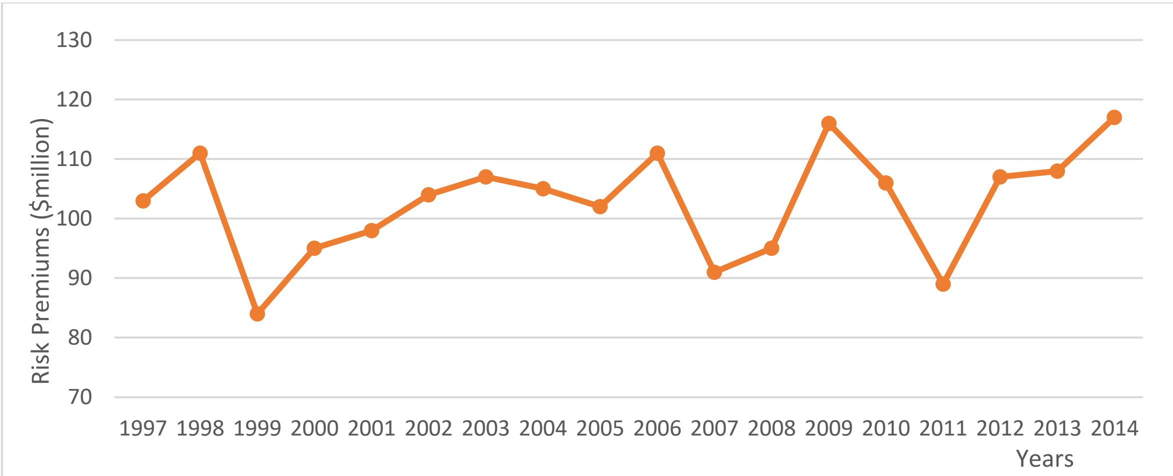

Figure 10. Risk Premiums vs Years for Barley, Durum Wheat, Hard Wheat and Soft Wheat from 1997 to 2014.

Figure 10 above shows an overall decrease in risk premiums received by farmers over time. This decrease can be accounted for the fact that management practices are effective overall, and risks associated FHB yield losses are reducing.

The risk premium for barley was relatively stable across the years because no resistant varieties have been adopted, hence little or no benefits are received by farmers. When farmers invest in fungicides but do not use resistant cultivars, they are not able to produce high quality grains, as the prices for such grains are low (due to discounts for higher level DON), and as a result little or no benefits earned by the farmers. Another explanation is that, certain varieties of barley could be less susceptible to FHB as compared to the other wheat varieties. Farmers do not effectively control for FHB/DON because of limited availability of mitigation strategies. The risk premiums for durum wheat and soft wheat decreased over time but were higher than that for barleys'. Durum wheat and soft wheat were affected in more states compared to barley in magnitude and implemented more management strategies, a possible reason why the risk premiums received for both crops were higher than that received by barley producers. The rate of the crops susceptibility to FHB and related yield losses will determine the implementation of these risk management practices.

Hard red winter wheat has been the most implicated in many FHB outbreaks in the US. (McMullen et al., 1997; Wilson et al., 2018). The risk premiums for hard wheats were greater in early years and declined sharply over the years. This wheat type showed the greatest losses in returns, hence causing farmers to continue investing in these practices. Table 10 below shows how sensitivity with respect to risk aversion changes with risk premiums over time. As earlier mentioned in previous chapters, risk aversion assesses farmers/industry processors attitude towards FHB and related risks. It ranges from 0 to 0.1, i.e. zero being risk neutral to 0.1 being highly risk averse. Highly risk averse farmers are willing to implement these practices to combat FHB, meanwhile risk neutral individuals show little concern and not willing to invest in such practices, hence they receive less compensation for mitigating risks. For example, highly risk averse producers receive higher compensation for mitigating risks, ranging from $285.33 million to $621.29 million.

Table 10. Sensitivity with respect to Risk Aversion (λ) and Risk Premiums ($million) from 1997 to 2014.

risk aversion	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
0.1	285.33	283.35	621.29	464.57	473.82	363.49	341.62	381.75	394.63
0.05	142.66	162.66	310.64	232.28	236.91	181.75	170.81	190.87	197.32
0.005	14.27	16.45	31.06	23.23	23.69	18.17	17.08	19.09	19.73
0.0005	1.43	1.65	3.11	2.32	2.37	1.82	1.71	1.91	1.97
0	0	0	0	0	0	0	0	0	0
0.1	300.33	332.35	761.29	3564.57	473.82	363.49	341.62	341.75	381.75
0.05	142.66	162.66	310.64	252.28	245.91	160.11	175.51	190.87	200.57
0.005	12.27	14.45	35.06	27.34	28.87	17.19	19.08	19.09	19.05
0.0005	1.67	1.63	3.50	2.25	2.6	1.54	1.76	1.92	1.97
0	0	0	0	0	0	0	0	0	0

From the results obtained in table 10, it clearly shows that risk neutral individuals will not receive any additional benefits in forms of returns when they do not implement these strategies. The variance of the returns in ($million) were obtained and the risk premiums were calculated using equation 4 in chapter 3. Risk premiums increases as the individual becomes more risk averse and is willing to invest in FHB management practices. The highest additional benefits are obtained by highly risk averse individuals, as they get compensated by the high prices the market has to pay for their high-quality grains. It is therefore important for farmers to continue to implement these practices to combat FHB.

Table 11**.** Means, Standard Deviations, Coefficient of Variation and Risk Premiums of Returns for all the Wheat Types and Barley from 1997 to 2014.

	1997	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Mean	6.19	14.90	0.31	9.59	12.13	10.19	11.28	12.44	11.57
Stdev	7.87	20.25	0.43	12.84	16.28	13.63	15.09	16.78	15.55
CV	1.27	1.36	1.41	1.34	1.34	1.34	1.34	1.35	1.34
RP	12.37	29.80	0.61	19.18	24.26	20.37	22.56	24.89	23.13
	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Mean	14.95	11.94	10.55	13.70	9.33	11.44	12.12	12.72	12.24
Stdev	20.33	16.19	14.20	18.58	12.42	15.46	16.39	17.24	16.55
CV	1.36	1.36	1.35	1.36	1.33	1.35	1.35	1.36	1.35
RP	29.89	16.19	21.10	27.39	18.65	22.88	24.24	25.44	24.47

The coefficient of variation was also calculated as seen in table 11 above. As earlier mentioned, the coefficient of variation is the ratio of the standard deviation to the mean. It determines the degree of variation in data sets. This parameter decreased over the years from 1997 to 2014. The smaller the coefficient of variation the lower the risk. This still shows that farmers need to continue to invest in these practices in order to reduce variability of revenue.

4.3. Results of Objective 2

The risk premiums ($million) with industry impacts was quantified. The use of ozone is a great way to eliminate DON from food products in industries before they are retailed out to consumers. Data on recalls in the US from 1991 to 2012 was used to run a regression using excel. From the regression equation, we determined that a 1% decrease in recalls (one recall) would lead to a 21% increase in revenue. This increase in revenue trickle to all members along the supply chain including farmers. The coefficient of determination, R^2 (5%) was obtained from the regression equation. It is important because it explains the amount of variability induced by the independent variables. The outcome was that decreasing the number of recalls would increase producers' revenue.

Data on returns at the farm level was converted to returns on recalls data by adding 21% of the mean for each year to each data point from 1997 to 2014. Data was entered in @RISK 7.5 to obtain the fitted distributions, the mean and standard deviation. Data was simulated to obtain 10,000 iterations. Again, the risk premiums and coefficient of variation were calculated using excel. Tables for the mean, standard deviation, coefficient of variation, and risk premiums of all the crops were also generated for each year. Graphs were plotted to show trends of the risk premiums for each year and for each crop from 1997 to 2014.

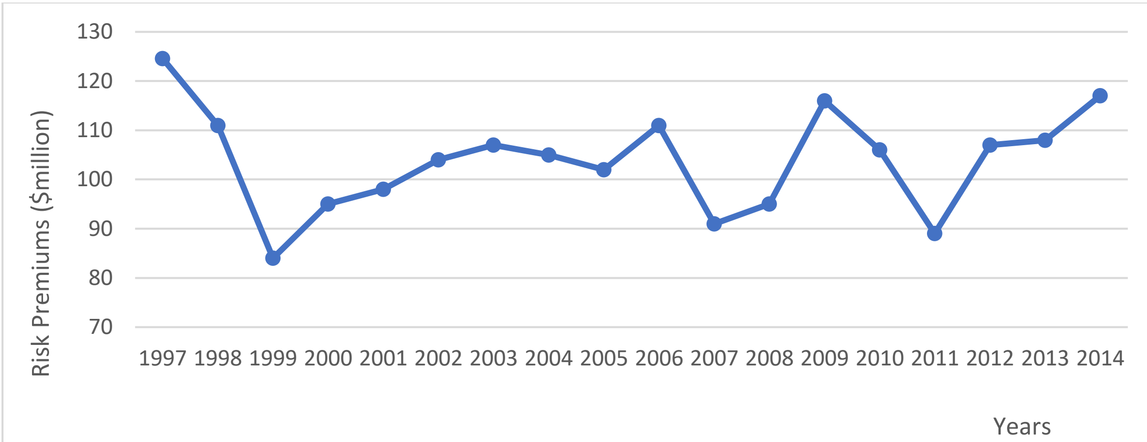

Figure 11. Risk Premiums vs Years for all the Wheat Types and Barley Commodities in the Industry from 1997 to 2014**.**

The trends varied significantly but was relatively stable from 2000 to 2005, with increase variability in later years. This variability suggest that industry management practices such as use of ozone were not frequently used and therefore the returns varied significantly. The sharp declines from 1997 to 1999, 2006 to 2007 and 2009 to 2011 could be due to the fact that less industry processors invested in this mitigation technology because of the losses associated with DON recalls, which might lead to shut down of businesses, leading to little or no benefits. However, a sharp increase is seen in 2014, showing that food processors are investing in these practices and are being compensated by the market in the form of the high prices they receive. Food processors are encouraged to invest in technologies such as; use of ozone and UV light to prevent major DON-associated recalls and further business shut down.

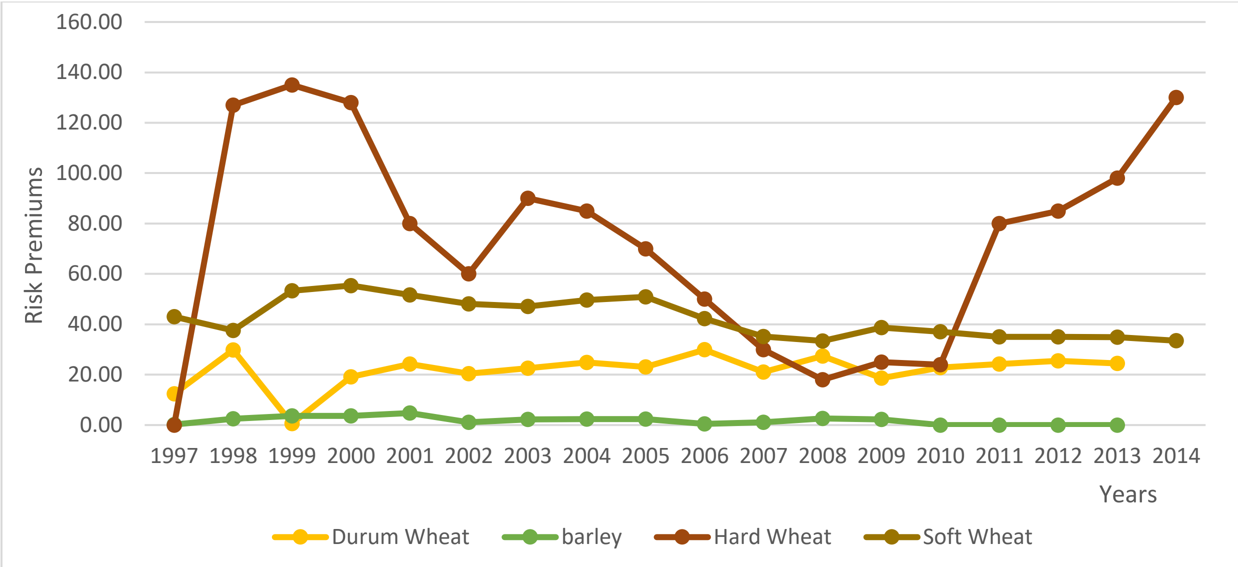

Figure 12. Risk Premiums vs Years for each Wheat Type and Barley Commodities in the Industry from 1997 to 2014.

Figure 12 above shows an overall decrease in risk premiums received over time. This trend is similar to risk premiums quantified without recall impacts. This decrease is due to the fact that processors are reluctant to invest in or implement these technologies due to the fact that the cost might be prohibitive and not everyone is mandated to implement such technologies.

The risk premium for barley was relatively stable across the years because no moderate resistant varieties has been implemented, and it has not been associated with major food recalls; hence little or no benefits received by processors. Another explanation could be that, some barley varieties are not very susceptible to DON as compared to the different wheat varieties. Food processors do not find it necessary to implement these practices since no major recalls have occurred. The risk premiums for durum wheat and soft wheat still decreased over time but were higher than that for barleys. A possible explanation could be that the management practices were effective.

The trends for hard wheats decreased significantly over time, but with an increase in variability observed in recent years (2014). A possible explanation for the overall decrease could be the reduction in FHB/DON risks. The increase in variability in recent years is due to the increase variability in the weather and seasonal changes (Scala et al., 2016). Scala et al., (2016) have shown that environmental and weather conditions play a role in FHB occurrence.

4.4. Results of Objective 3: Holistic Risk Premiums and Returns on Investment

Holistic risk premiums are the returns at the farm level and to industry to reduce FHB/DON risks respectively. These returns were quantified and graphs of total returns/risk premiums for each crop were plotted over time. The graphs below show how the total returns and risk premiums vary at both the farm and industry level for each crop. The more farmers and food processors invest in such practices/ technologies the more revenue they will receive. Figure 13 below shows that the risk premium and total returns are changing over time. Risk premiums and total returns were increasing until a sharp decrease in 2006 and 2011. This is an indication that other factors like humidity could cause unanticipated variability in returns. For example in 2001, producers received in premiums $4million from management practices and received a total of $14 million in returns. Total returns decreased as risk premiums decrease as seen in 2006 and 2014. This indicates that lower compensations are gained from lower risk reduction. In 2014, risk premiums remained stable as well as total returns.

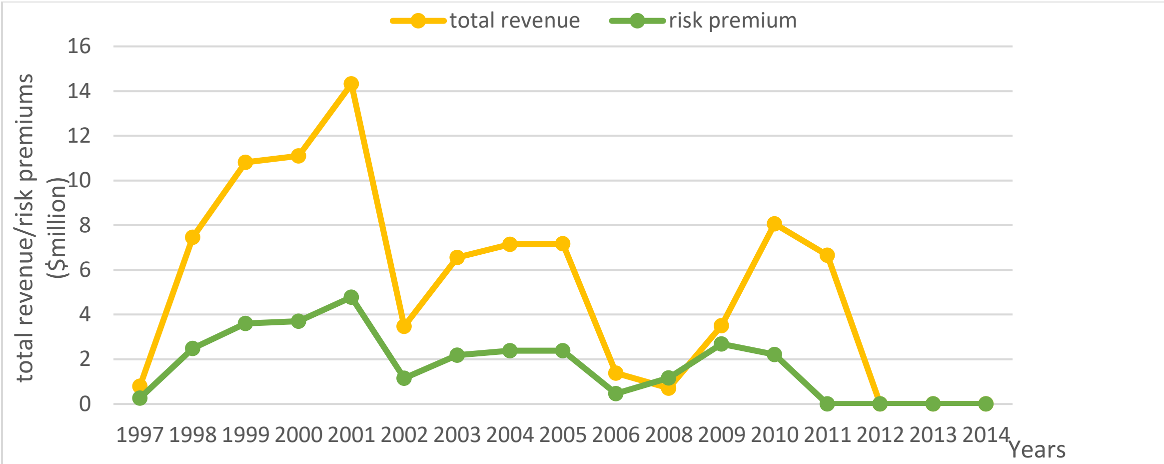

Figure 13. Risk Premiums and Total Revenue over Time for Barley Commodities in the Industry and Farm Levels.

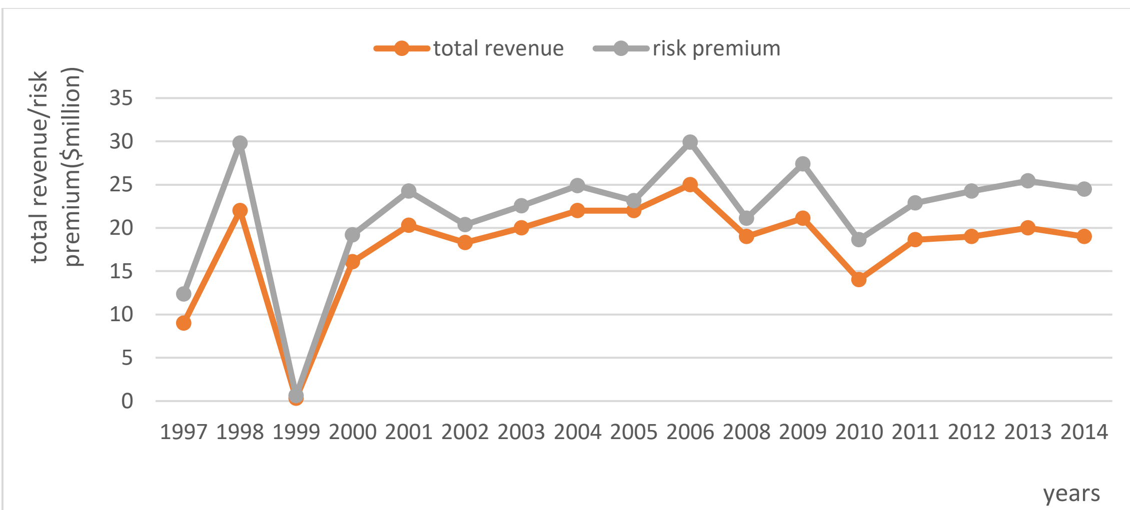

Figure 14. Risk Premiums and Total Revenue over Time for Durum Wheat and Related Commodities at the Farm and Industry Levels**.**

Durum wheat showed a different trend from barley as seen in figure 14 above. In this case, the risk premiums were higher than the total returns by the farmers and food processors. A possible explanation to this result is that the management strategies invested by farmers and processors were very effective. In this case the potential to increase returns from investing in mitigation strategies have huge upside.

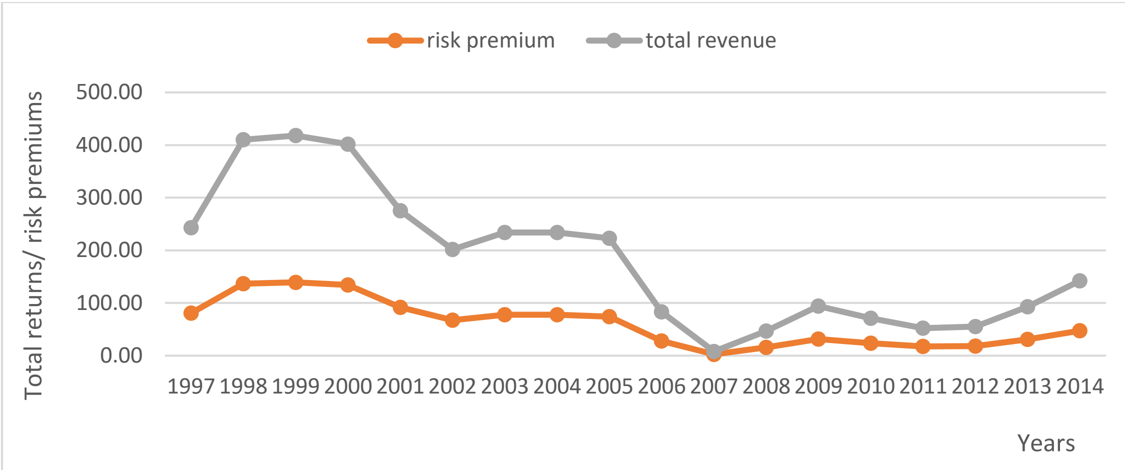

Figure 15. Risk Premiums and Total Revenue over Time for Hard Wheat and Related Commodities in the Farm and Industry Levels.

The trends of risk premiums and total revenue for hard wheat as shown above are similar to that of barley. The total revenue increases as the risk premium increases over the years. An overall decrease in returns was observed from 1997 to 2014. Farmers and processors continued to invest in these practices in later years. This can be accounted for the gradual increase in total returns and risk premiums from 2010 to 2014.

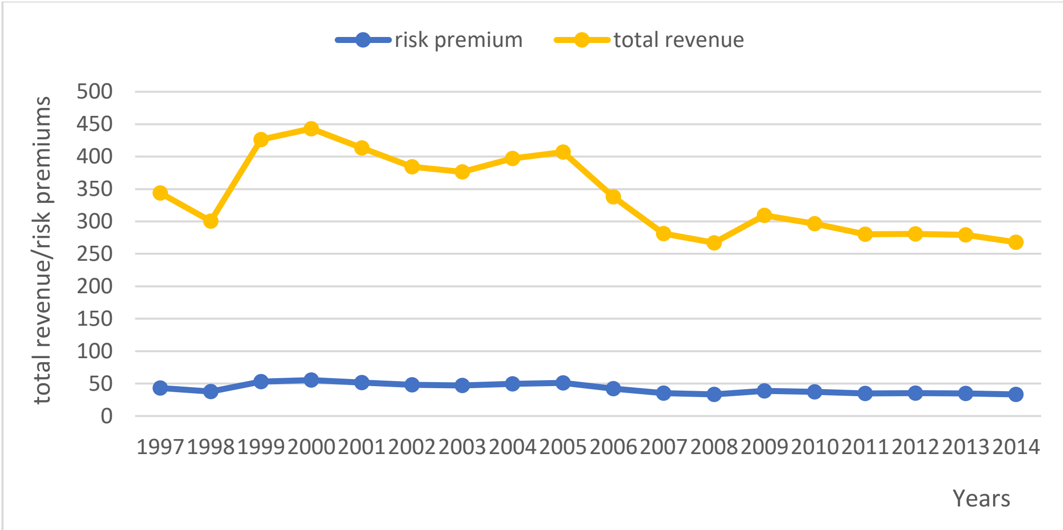

Figure 16. Risk Premiums and Total Revenue over Time for Soft Wheat and Related Commodities in the Farm and Industry Levels.

Figure 16 above shows a relatively stable risk premiums over the years, but with increase in total returns. This could be accounted for the fact that resistant varieties have not been adopted for soft wheats, so farmers especially rely on spraying their farms and hence only invests in one type of management practice. An increase in total returns despite these little investments could be due to overall effectiveness of risk management practices.

CHAPTER 5. CONCLUSION

Risk premiums were quantified and the true benefits of risks for farmers and industry practitioners investing in FHB/DON management strategies were assessed. The risk premium which measures the returns of investing in these practices in the form of additional benefits farmers and industry practitioners receive were quantified at both the farm and industry impacts from recalls. Generally, trends for risk premiums (or compensation for reducing risk due to FHB/DON) showed an increase over time for all the crops. This indicates that these management practices are being used effectively over time. The assessment of different crops however showed slightly different results over the years. This accounts for the alternative mix of resistant varieties, fungicide application and other risk mitigation strategies. The risk attitudes of farmers vary and not all farmers are willing to invest in these practices. Results from the sensitivity test show that farmers/processors who do not invest in these practices will not receive additional benefits or compensation for reducing risks.

Results from the total returns and risk premium trends still supports the fact that farmers and industry practitioners should continue to invest in these management practices. The additional benefits received, accounts for the cost incurred and the high prices of the high-quality crops and alternative commodities produced. This thesis provides firm basis to encourage farmers and industry practitioners to continue investing in management practices to combat FHB/DON. Consistent implementation of these strategies reduces variability of losses over time and increase returns on investment.

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