An Analysis of Rainfall Weather Index Insurance: The Case of Forage Crops in Canada

by

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For my Grandfather, Dr. the Hon. Karl Wellington, OJ, CD.

Abstract

This study analyzes rainfall weather index insurance used for forage crops, in the Province of Ontario, Canada. The first objective of the study was to examine factors affecting the willingness of farmers to pay for forage rainfall index insurance, and a survey was undertaken. Some factors found to influence farmers' willingness to pay were knowledge and attitude regarding insurance, their risk profile, and socio-economic factors. A second objective of the study was to examine basis risk reduction approaches. Basis risk is the difference between the actual loss on a farm and the index measured loss payments that are determined by weather station data. The focus was to capture changing yield and weather relationships over crop growth stages. Using farm level forage yield and daily weather station data from Ontario, a multi-trigger index was designed using weighted crop cycle optimization, and results show that basis risk was substantially reduced.

Keywords: rainfall, weather index insurance, survey, temporal basis risk, forage, Canada.

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Chapter 1

Thesis Introduction

Weather index insurance for crops pays indemnities based on an underlying weather index that is correlated with actual losses, this differs from conventional indemnity-based insurance that pays indemnities according to a farmer's actual losses. There are many possible underlying indices for agricultural index insurance products, such as, area yield index, satellite vegetation index, etc.. However, weather indices, such as rainfall and temperature indices, are most commonly used. Weather index insurance has received considerable research attention in recent years as it overcomes many of the shortcomings of traditional, indemnity-based insurance, including expensive on site damage assessments, moral hazard, and adverse selection. Weather index insurance has been of particular interest in a number of developing countries, where farm sizes are small, making loss measurement and adjusting very costly.

Developing weather index insurance involves many complex parts including rate-making and calculating reserves. It is also important that those purchasing insurance be charged an acceptable price (acceptable premium). For example, if farmers are unable or unwilling to pay the actual cost of the insurance, then a government subsidy might be considered, which is often the case for agricultural insurance, when farmers' willingness to pay is more limited. Additionally, a new problem arises with weather index insurance, that of basis risk. In this paper, basis risk refers to the mismatch between payoffs based on the weather index, and actual losses on the farm.

As a result, this thesis, comprised of two main chapters, aims to first identify the factors that affect forage farmers' willingness to pay for forage index insurance (Chapter 2). Then, a new weighted multi-trigger rainfall index is developed with the aim of reducing basis risk (Chapter 3).

Thesis Organization

Chapter 2 focuses on the "Factors Affecting Willingness to Pay for Forage Index Insurance". The introductory sections describe forage insurance in Ontario, Canada along with a survey conducted with forage farmers in Ontario to elicit each farmer's willingness to pay for weather index insurance for forage. Descriptive statistics are then examined and ordered probit models are then utilized to understand the factors influencing forage producers' decision to purchase forage insurance and the amount each farmer would be willing to pay for this insurance.

In Chapter 3, a new weighted multi-trigger rainfall index is designed in order to increase demand for weather index insurance for forage, specifically by reducing temporal basis risk. Using farm yield and rainfall data, basis risk for the newly developed index is calculated and compared to the basis risk of existing rainfall indices offered in Ontario.

Factors Affecting Willingness to Pay for Forage Index Insurance

The objective of Chapter 2 is to examine factors that affect farmers' willingness to pay (WTP) for weather index insurance for forage in Ontario. First, a survey is conducted with forage farmers in Ontario. The questions included in the survey examine the knowledge and attitude of the farmers regarding index insurance, the risk profile of the farmers, as well as socio-economic factors. The survey also collects views on the current crop insurance program. The contingent valuation method is also used to elicit farmers' WTP for a weather index insurance for forage in Ontario.

An ordered probit regression is then fitted to determine the factors that determine a farmers' willingness to pay for forage index insurance. It is expected that farmers with a high level of knowledge and a positive attitude regarding index insurance will be willing to pay more for insurance. Additionally, it is expected that farmers who participate in alternative risk reduction strategies and those who feel that their forage production risk is low, will be willing to pay less for index insurance.

Temporal Basis Risk Reduction for Weather Index Insurance: A Weighted Multi-Trigger Index Approach

The objective of Chapter 3 is to examine basis risk reduction techniques and determine if a multi-trigger rainfall index can reduce temporal basis risk. Basis risk is often considered a main cause of low demand (Clarke, 2011). Temporal basis risk, the focus of this paper, occurs when timing of rainfall, regarding crop growth stages, is unaccounted for by the index. Therefore, there is a difference between the actual loss on the farm and index-measured loss. This is an area of research that has received considerably less attention relative to other types of basis risk, including spatial basis risk and variable basis risk.

Based on a survey conducted by the forage index insurance provider in Ontario, forage producers in the province identified drought as a main source of risk to forage yield. Excess rainfall during harvest was cited as the secondary main risk. Therefore, it is expected that a new multi-trigger index incorporating both insufficient rainfall risk and excess rainfall risk would likely reduce temporal basis risk, compared to existing insurance.

Chapter 2

Factors Affecting Willingness to Pay for Forage Index Insurance

2.1 Introduction and Background

Weather Index Insurance

Weather index insurance for crops pays indemnities based on an underlying weather index that is correlated with actual losses, this differs from conventional indemnity-based insurance that pays indemnities according to a farmers actual losses. There are many possible underlying indices for agricultural index insurance products, such as, area yield index, satellite vegetation index, etc. However, weather indices, such as rainfall and temperature indices, are most commonly used. Weather index insurance has received considerable research attention in recent years as a promising alternative to traditional, indemnity-based insurance for agriculture as it overcomes many of the shortcomings of traditional, indemnity-based insurance, including expensive on site damage assessments, moral hazard, and adverse selection. Weather index insurance has been of particular interest in a number of developing countries, where farm sizes are small, making loss measurement and adjusting very costly for traditional indemnity-based insurance.

Research Objective

The objective of this study is to better understand farmers' willingness to pay (WTP) for rainfall index insurance in Ontario, and the factors affecting WTP. This study will be among the first to examine willingness to pay for weather index insurance in a developed country. First, a survey is conducted with forage farmers in Ontario. The questions included in the survey examine the knowledge and attitude of the farmers regarding index insurance, the risk faced by the farmers, as well as risk management strategy and farm operation characteristics. A contingent valuation method is used to elicit the participants' willingness to pay for weather index insurance for forage in Ontario.

An ordered probit regression is then fitted to explain the factors affecting farmers' willingness to pay for weather index insurance for forage. It is expected that farmers with a high level of knowledge and a positive attitude regarding index insurance will be willing to pay more. Additionally, it is expected that a farmers who who feel that their forage production risk is high, will be willing to pay more for index insurance.

The remainder of this paper is organized as follows:this section describes the current crop insurance program in Canada and forage insurance in Ontario. The existing methods to elicit WTP, as well as determining the factors that influence and individual's WTP are then discussed. Following this, the data used in this research is described, including survey design and descriptive statistics, then the methodology of this research paper is highlighted and discussed. The results are then presented, followed by a summary of findings and possible future research.

Forage Insurance in Canada

In Canada, the main crop insurance program is a multi-peril crop insurance (MPC) program called AgriInsurance, which is delivered by each of the ten provincial government crop insurance organizations, in collaboration with the federal government, Agriculture and Agri-Food Canada. The program is subsidized, with farmers paying about 40% of the crop insurance premium, and 60% paid by federal and provincial governments. The federal government also provides a reinsurance arrangement (deficit financing) to provinces. Currently, five provinces (Alberta, Saskatchewan, Manitoba, New Brunswick and Nova Scotia) participate in the reinsurance arrangement.

Ontario was the first province to offer forage rainfall weather index insurance (pilot 2000-2002, product offered in 2005). This product has since been modified and adopted by other provinces as seen in Table 2.1. Participation is low across Canada despite the various insurance structures, which include measured yield (Manitoba, Saskatchewan, and British Columbia) simulated forage (Quebec), satellite based index (Alberta), and weather station based index (Nova-Scotia, PEI, and Ontario). In Ontario, farmers can insure against insufficient and/or excess rainfall with several options.

Customers identify their crop in proportions of hay and pastureland and value accordingly. A given contract payout is based on weather data professionally collected in one of over 300 stations across the province. Customers must select a station located in their township or one adjacent. Despite the flexibility of the program and several options available in Ontario, only 10% of forage acres are insured compared to 90% of annual crop acres insured. Of those who insure, the average customer selects 80% of available coverage.

National participation in forage insurance plans is also low with only 20% of all forage acres, and 12% of pasture acres being insured. See Table 2.1 for participation by province. The following subsection discusses methods used to elicit WTP, and identify the factors that determine WTP.

Table 2.1: Forage Insurance Participation By Province (Agricorp Technical Report, 2013)

Province	Coverage Type	Participation
BC	Establishment and forage supply (Yield)	11%
Alberta	Moisture Deficiency and export (Index, Yield, Satellite)	12%
Saskatchewan	Insufficient rainfall and establishment (Yield)	3%
Manitoba	Establishment (Yield)	12%
Ontario	Excess and Insufficient Rainfall (Index)	10%
Quebec	Simulated Yield (Satellite)	51%
Nova Scotia	Excess and Insufficient Rainfall, Establishment (Index)	9%
PEI	Excess and Insufficient Rainfall (Index)	15%

*Notes: This table shows the forage insurance participation rates by province as reported in the Agricorp Technical Report, 2013.

Eliciting Willingness to Pay

An individual or household's willingness to pay (WTP) refers to the amount he/she is willing to pay for a product or to participate in a program. This is sometimes considered in terms of factors such as wealth, socio-demographic characteristics and risk preferences. There are several ways to elicit WTP, known in literature as valuation methods. The main methods used to assess the value of non-market goods and services are revealed and stated preference methods. Revealed preference methods are based on the actual behavior reflecting utility maximization subject to constraint, while stated preference methods include creating a hypothetical market for the actual product and eliciting willingness to pay by asking direct questions about the value an individual places on the product (Freeman, 2003).

Contingent Valuation Method (CVM)

The most widely used stated preference determinant of WTP is the contingent valuation method (CVM), introduced by Davis (1963). There are many CVM formats which can be classified into several groups, the main being close-ended or bounded, and open-ended.

The open-ended models allow the individual to state the price he/she is willing to pay for a product. An example of an open CVM question is "What is the maximum amount you would be willing to pay for this product?". Close-ended processes offer a product to the potential customer at one price, or a series of pre-determined prices, where the "bounds" of the method refer to the maximum number of prices an individual may be offered in the process.

In a single bounded close ended format, a product is offered to the individual at a single price, then he/she decides whether or not to accept the offer. This approach tells the researcher whether the offered price is above or below the individual's WTP, and is thought to most closely mimic actual market situations, where consumers are offered one price and must decide whether or not to purchase (Hanemann et al., 1991). In the double-bounded close-ended model, the potential customer is offered an initial starting price. If the price is accepted/rejected, the individual is offered a second higher/lower price.

Another type of close-ended model is the iterative bidding model, where a range of prices is first predetermined, then the potential customer is offered an initial starting price. If the price is accepted/rejected, the individual is offered a higher/lower price until the offered price is rejected/accepted or the maximum/minimum price is accepted/rejected. These multiple-bounded models give the researcher the range within which the individual's WTP lies (usually between the highest accepted price and the highest rejected price).

Hanemann et al. (1991) show that a double-bounded dichotomous choice model, improves the statistical efficiency compared to the single-bounded equivalent. A dichotomous choice model only allows participants to respond with "yes" or "no" to questions asked as compared to a general discrete choice model which may include more choices, for example, "yes", "no", "probably yes" and "probably no". The close-ended CVM format is the preferred method for assessing WTP for insurance, however, it comes with a few limitations, including strategic, hypothetical, starting point and interviewer/respondent bias.

Contingent Valuation Method Bias

Strategic bias occurs when participants over or under-bid in hopes to influence the actual price of the product of interest. Hypothetical bias occurs when individuals do not consider all the information they have about their budget, available substitutes etc. when participating in a survey. As a result, their response in this created scenario may not be their response in the real world. Asking questions about this information before conducting the CVM can help reduce hypothetical bias (Bateman et al., 1994). Starting point bias occurs when the starting bid influences the individual's perception of the actual value of the product. For example, some studies show that the higher the starting bid, the higher an individual is willing to pay for a product (Dong, 2004). This bias can be reduced by randomizing starting points and including the effect of each starting point in the WTP model. Interviewer and respondent bias occurs when a participant's answers are influenced by the behavior of the interviewer. This may be reduced by conducting telephone or on-line surveys.

Determining the Factors that Affect Willingness to Pay

After choosing a model to elicit WTP, the independent variables, or factors that affect WTP, must be identified. The main groups of factors considered to affect willingness to pay in this study are attitude and knowledge, risk profile, and socio-economic factors.

Knowledge and Attitude

Regarding attitude and knowledge, increased trust and knowledge of the insurance product has been found to have a positive relationship with WTP. Lin et al. (2015) find that a positive attitude towards weather index insurance positively impacted willingness to pay for weather insurance in Hainan, China. In terms of exposure to risk, the higher the perceived chance of experiencing loss, the more likely it is that an individual will purchase insurance. Hill et al. (2013) estimate this value by recording the number of times in a 15 year period that the household's consumption fell below the long term average, and shows that WTP is significantly increasing in exposure to risk.

Risk Profile

Perceived exposure to risk also affects willingness to pay. If substitute products/methods of risk reduction exist, the less likely the individual will be willing to participate in insurance. Hill et al. (2013) assess whether other available risk reduction is seen as a substitute to index insurance or if it is an addition to a household's risk management portfolio. They find that households that self-insure have lower WTP for index insurance, while those in a large inter-dependent community are more likely to purchase index insurance. Sakurai and Reardon (1997) also show a negative relationship between WTP and alternative risk reduction, such as livestock holdings and public aid.

Socio-Economic Factors

Several socio-economic factors impact an individual's WTP. As a wealth measure, income has been seen to positively influence the amount individuals are willing to pay if index insurance is viewed as a normal good (Sakurai and Reardon, 1997). If it is viewed as an inferior good, there will be a negative relationship. Clarke (2011) shows that willingness to pay for index based insurance is negatively correlated with price and basis risk, and ambiguous with respect to wealth. He also shows that WTP increases and then decreases with risk aversion. Hill et al. (2013) disagree with the assumption in Clarke (2011) of well-informed consumers, stating that the assumption does not work in many situations where the financial product is new and/or complicated and, rather, compares WTP for index insurance to willingness to adopt new technology.

In the case of forage insurance in Ontario, the product is subsidized such that farmers only pay 40% of the fair premium, and all administration costs are subsidized. Despite this, the farmer participation rate for this insurance is approximately 10%, indicating that some farmers are unwilling to participate in the insurance even at rates substantially below the actuarially fair premium. Therefore, it is important to assess forage farmers' willing to pay (WTP).

2.2 Data

In this section, the survey from which data was collected is described and the data is summarized. Following this, the method for eliciting WTP is explained, including an outline of the product that was offered and the valuation process used to determine each participant's WTP.

An online survey was completed by 70 forage farmers in Ontario, Canada associated with the Forage Association of Ontario. The online survey was divided into three sections. First, the participants were asked questions to assess their risk preferences, knowledge and attitude regarding index insurance. The next section covered farming operations, including recent risk events and participation in risk reducing activities and existing, government agricultural programs. The final survey section asked questions regarding participants' and socio-economic characteristics.

Contingent Valuation Process

Survey participants' WTP was elicited for a particular index insurance product. The product presented to the respondents is based on one of the products currently available in Ontario as a part of the Forage Rainfall Plan in the province. Generally, if total rainfall for the growing season (May to August) at the chosen weather station is less than 85 percent of the historical average rainfall for that period, a payment is triggered.

Participants were first asked to consider the product and to state whether or not they would be willing to participate. WTP for the offered product was elicited using a multiple-bounded CV method, in which forage farmers were asked a sequence of dichotomous insurance questions. If respondents showed willingness to join the program, they were asked to consider if they were willing to pay at a specific price. The respondent was given the following scenario: Assume the insured amount of your forage is $100 per acre. Would you be willing to pay a premium of $X per acre for this insurance?, then a follow-up question with a higher (lower) price was then asked if they responded "yes" ("no") to the first question. The process continued until the WTP was classified into 6 different intervals using 5 prices (actuarial fair price minus subsidies, ±25% and ±50% of this price), resulting in a Likert scale where each respondent falls into one of 6 intervals. Starting bids were randomized and varied among respondents to reduce starting point bias. Table 2.2 summarizes the data collected in the survey as well as the WTP experiment.

2.3 Methodology

This section focuses on the methodology used to determine the factors that affect farmers' willingness to pay for weather index insurance for forage. Since the explanatory variables are all answered in an ordered categorical format, an ordered probit model is used (Lin et al., 2015).

A latent continuous variable y^* (which refers to WTP in this study) can be specified as (Greene and Hensher, 2010);

$$y_i^* = \mathbf{x}_i\boldsymbol{\beta} + \varepsilon_i, \qquad \varepsilon \sim N(0,1), \tag{2.1}$$

where $\mathbf{x}$ represents predictors (risk, production and socio-economic factors, in this case), the vector $\boldsymbol{\beta}$ includes the factor coefficients to be estimated, and ε is the error term.

$$y_i = j \Longleftrightarrow \mu_{j-1} < y_i^* \leq \mu_j, \qquad \forall i \in 1 \ldots N, \tag{2.2}$$

where y_i is the observed ordinal variable and takes on integers, N represents the sample size, $j = 0, \ldots, k$. Hence, k = 5 in the model estimating WTP.

The log likelihood function for an ordered probit model is then defined as:

$$logL = \sum_{i=1}^{n}\sum_{j=0}^{k} \Omega_{ij} \ln\left[\Phi(\mu_j - \mathbf{x}_i\boldsymbol{\beta}) - \Phi(\mu_{j-1} - \mathbf{x}_i\boldsymbol{\beta})\right], \tag{2.3}$$

where $\Omega_{ij} = 1$ if $y_i = j$ and 0 otherwise, and $\Phi(.)$ is the cumulative distribution function for the normal distribution.

2.4 Results

Survey Desctiptive Results

Despite index insurance being offered in Ontario since 2000, approximately 25% of farmers have a very low knowledge level regarding index insurance as can be seen in Figure 2.1. The average farmer has between a “neutral” and and “somewhat positive” attitude towards index insurance (Figure 2.2) but considers basis risk an “important” to “very important" factor in determining whether or not to purchase insurance (Table 2.2).

The weather event which occurred most frequently in recent years was too much rainfall during planned cutting, with 47% of respondents naming it as the most recent peril, while 35% named a lack of rainfall. However, the damage level caused by excess rainfall is, on average 20 - 40% of production, whereas lack of rainfall caused average loss of 40 - 60% of production. This information is summarized in Figure 2.3.

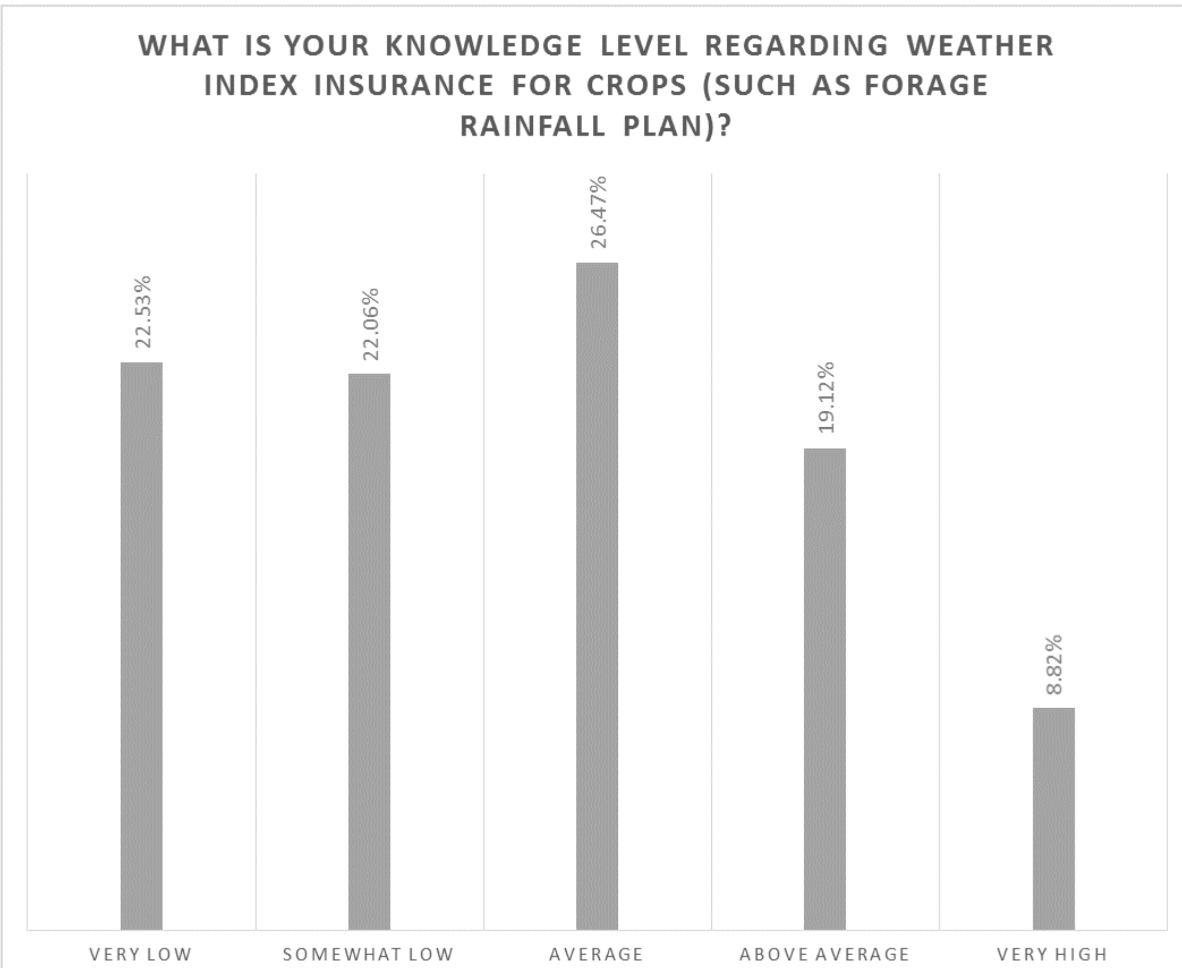
Fifty percent of farmers were between 56 and 70 years old, and over 50% had been farming for over 31 years at the time of the survey. Seventy percent of respondents participated in off-farm employment in 2014. When asked the percentage of income gained off farm, 30% of respondents stated above 75%. The average participant household in the survey makes between $110,000 and $125,000 in total income before taxes, however, approximately 30% of households make less than $70,000.

Willingness to Pay

Sixty-five percent of the respondents were willing to purchase the insurance product offered. The farmers who were not willing to purchase insurance were asked to state a maximum of two reasons, 50% said that forage was not important enough to their operation, 33.33% said they did not know enough about the product and 20% stated a main cause of basis risk.

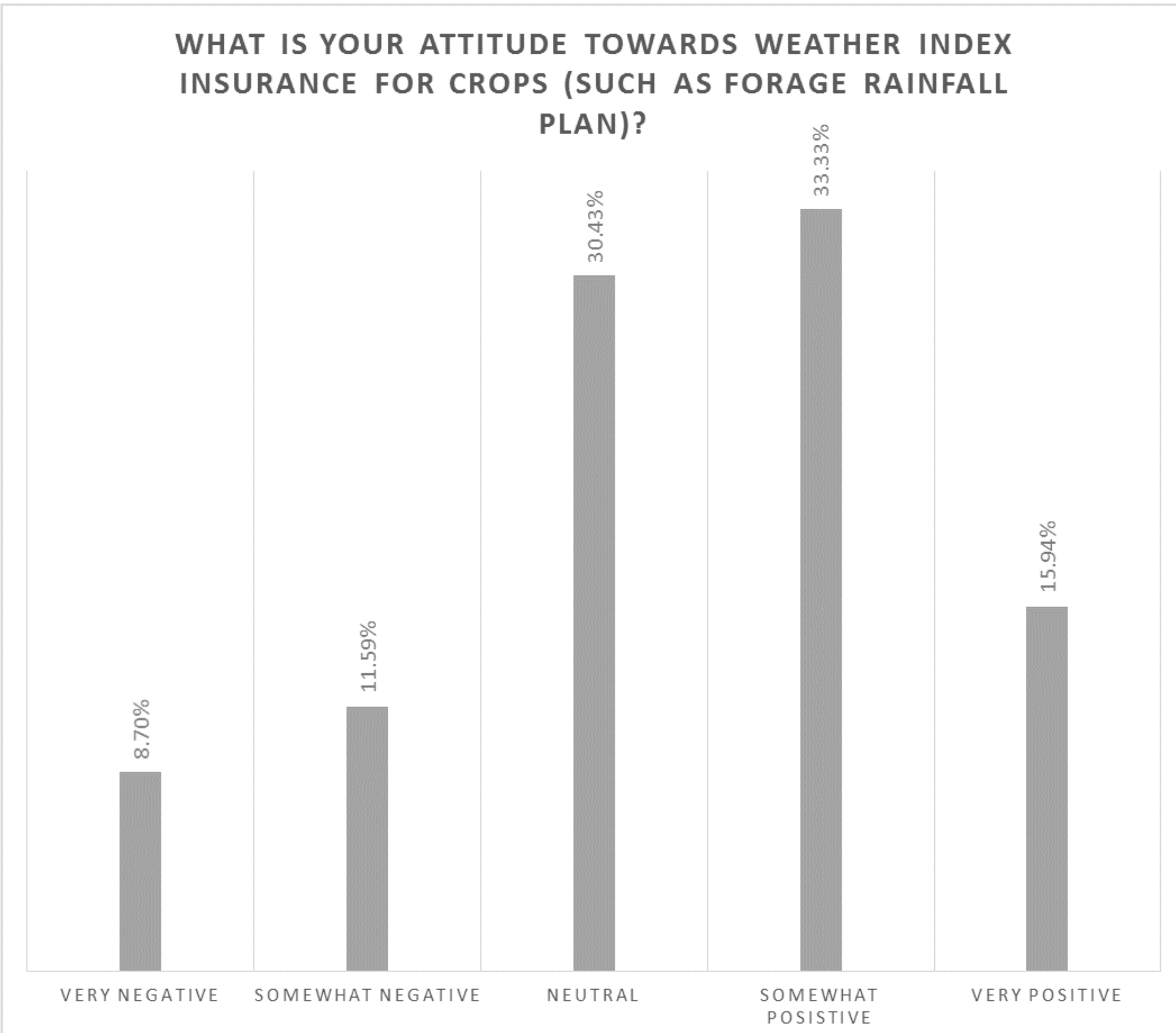
The amount farmers are willing to pay for the insurance is somewhat skewed. This can be explained by the maximum price offered being less than the actuarially fair premium due to subsidies offered to producers in Canada. Of those willing to pay the actuarially fair price or above, 0% had a very low knowledge level about the insurance product and only 20% had a below average knowledge level. In addition 60% had a positive attitude towards index insurance and 80% had insured at least two other crops.

Figure 2.1: Knowledge of Index Insurance



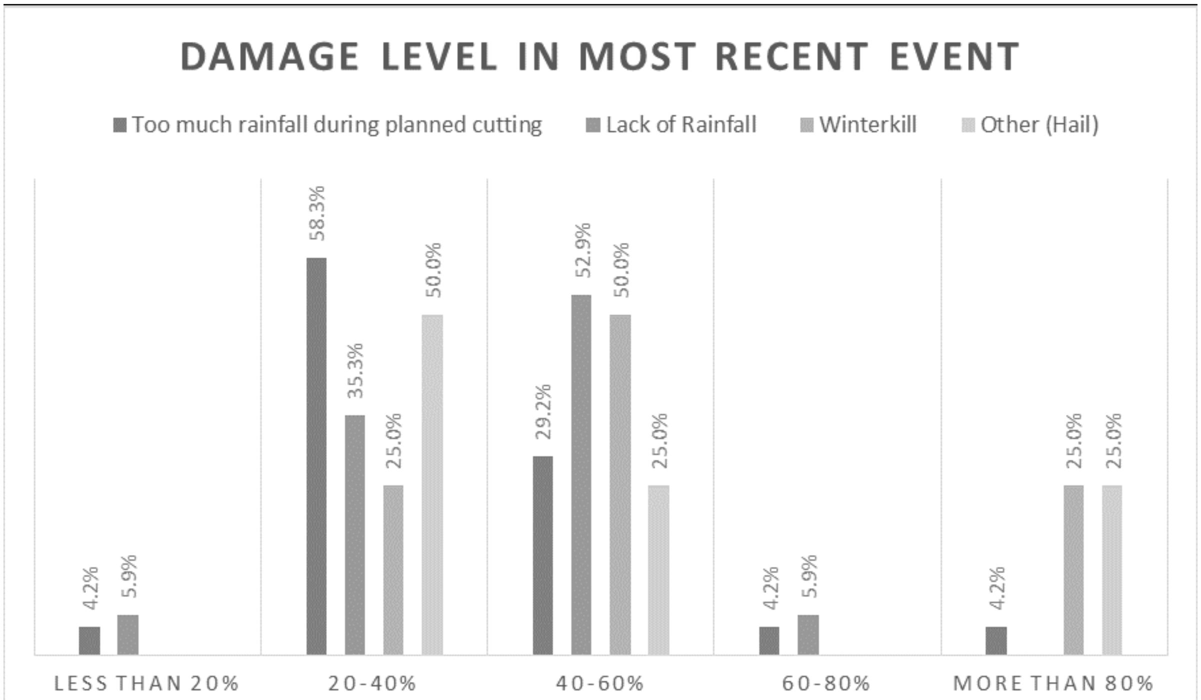
Notes: This figure shows the responses of survey participants when asked “What is your knowledge level regarding weather index insurance for crops?”

Figure 2.2: Attitude Towards Index Insurance



Notes: This figure shows the responses of survey participants when asked "What is your attitude towards weather index insurance?"

Figure 2.3: Damage Level of Most Recent Weather Risk



Notes: This figure shows the responses of survey participants when asked “Please specify the weather event that affected forage yield the most in your locality in the past 10 years and what extent was your forage yield affected during that weather event?”

Ordered Probit Model Results

In this section, the models used to determine the factors influencing how much a farmer is willing to pay for this insurance (WTP), is shown by Table 2.3. The model shows to what degree and in what manner attitude and knowledge, risk profile, as well as socio-economic factors affect WTP.

Knowledge and Attitude Results

Agreeing with previous literature, positive attitude towards index insurance and increased level of knowledge about index insurance have a positive and significant impact on WTP. This indicates that WTP may be improved significantly by employing methods to increase awareness and understanding of existing index insurance policies. In accordance with findings in Clarke (2011) and Carter et al. (2014), basis risk negatively impacts WTP. However, in this study, the impact of basis risk was not significant.

Risk Profile Results

As expected, factors that increase farmers' risk perceived risk exposure also increase the amount they are willing to pay for insurance, and vice versa. As can be seen in Table 2.3 the damage level of the most recent weather event had positive and significant impact on WTP. This agrees with Hill et al. (2013) who find that the higher the perceived chance of experiencing loss, the more likely it is that an individual will purchase insurance. Agreeing with Hill et al. (2013) and Sakurai and Reardon (1997), the level of participation in alternative risk reduction (farmers' level of self-insurance and the percentage of income gained off farm) significantly decreases the amount a farmer is willing to pay. The farmers' self assessed risk aversion also has a negative but insignificant relationship with WTP.

Socio - Economic Results

Total household income has a positive effect on WTP, indicating that the insurance product is seen as a normal good. However, the higher the percentage of income gained from other activities, the lower the amount a farmer is willing to pay for insurance. Therefore, the existence of other income sources acts as self-insurance for the farmer and thus decreases demand for formal insurance. The larger the household, the higher the WTP for insurance. This agrees with the findings of Hill et al. (2013) that members of larger inter-dependent communities are more likely to purchase insurance. Participants from the Western region of Ontario are most willing to show interest in the insurance product, while participants from both the Western and Eastern regions are willing to pay more for insurance. Interestingly, males are willing to pay significantly less for insurance than females.

Table 2.2: Descriptive Statistics of Survey Responses (n=70)

Variable Name	Mean Value	SE	Scale
Dependent Variables			
What price would you be willing to pay?	1.84	2.604	1 = low, 6 = high
Independent Variables			
Knowledge and Attitude			
Knowledge about weather index insurance	2.56	1.223	1 = very little, 5 = very much
Attitude towards weather index insurance	3.41	1.131	1 = very negative, 5 = very positive
Basis risk influence	4.30	0.685	1 = very little, 5 = very much
Risk Profile			
Risk aversion			
Damage from most recent weather event	2.55	0.923	1 = very little, 5 = very much
Level of self insurance	3.59	1.654	1 = very little, 5 = very much
Percentage of income gained off-farm	3.70	1.961	1 = very little - 6 = very much
Socio-economic			
Household size	2.54	0.676	1 = small, 5 = large
Household income	2.92	1.639	1 = low, 6 = high
Years of farming	3.45	0.832	1 = less than 10, 5 = more than 40
Gender	1.90	0.306	1 = female, 2 = male

*Notes: This table shows the descriptive statistics of select survey question responses

Table 2.3: Dependent Variable: Willingness to Pay (WTP)

Independent Variables	Estimate	SE	Significance
Knowledge and Attitude			
Knowledge level about weather index insurance	0.712**	.311	0.022
Attitude towards weather index insurance	1.075***	0.341	0.002
Basis risk influence	-.311	.542	.567
Risk Profile			
Risk aversion	-0.585	0.382	0.126
Damage level from most recent weather event	0.631*	0.338	0.062
Level of self-insurance	-0.305*	.165	.064
Percentage of income gained off-farm	-0.481***	0.168	0.004
Socio-economic			
Household income	0.287	0.180	0.110
Household size	0.856**	0.405	0.035
Years of farming	0.316	0.217	0.146
Gender	-2.203**	1.038	0.034
Pseudo R^2			
Cox and Snell	0.620		
Nagelkerke	0.655		
McFadden	0.331		
Notes: *, **, *** Significance level at 10, 5 and 1 percent, respectively			

*Notes: This table shows the results of the ordered probit regression model regarding the maximum price (0 =low, 6 = high) forage farmers are willing to pay (WTP) for weather index insurance in Ontario, Canada(n=70)

2.5 Summary

The objective of this paper is to examine and better understand the factors that affect willingness to pay (WTP) for forage index insurance. As a result, this research problem is of significant importance to producers, provincial crop insurance companies, federal and provincial governments, insurers and reinsurers.

This paper is the first to assess willingness to pay for forage insurance and is among the first to examine willingness to pay (WTP) for index insurance in a developed country. This study therefore adds to the literature by highlighting the similarities and differences in factors affecting WTP between developed and developing nations as well as between forage and non-forage producers.

The method used to elicit WTP for insurance is a multiple-bounded dichotomous choice contingent valuation model. The insurance offered in the experiment is based on one of the forage index insurance policies currently available in Ontario. Then, using data collected through a survey with 70 forage farmers in Ontario, Canada, WTP is modeled using an ordered probit regression.

The results show that 65% of the respondents were willing to purchase the insurance product offered. For those farmers, the factors found to influence WTP included the farmer's household income, percentage of income earned off farm, attitude and knowledge of index insurance and participation in other risk reduction techniques. Additionally, the region in which the farm is located and household size were also found to play a significant role.

Three groups of factors were found to affect farmers' WTP. These included the farmer's knowledge and attitude regarding insurance, their risk profile, and socio-economic factors. Results show that as a farmer's level of knowledge and attitude regarding index insurance improved, the amount that the farmer was willing to pay increased. Additionally, farmers who participated in alternative risk reduction strategies and those who felt that their forage production risk was low, had a lower WTP. The relationship between basis risk and WTP was negative, as expected. However, an interesting result was that basis risk, which is considered to be a major factor in determining demand, did not have a statistically significant impact on willingness to pay in this paper.

Limitations of this study should also be discussed. The sample size of 70 farmers is relatively small, and this limited the number of factors that could be included in each model. Future research may include distributing the survey and experiment to a larger sample size and/or in another province to assess the robustness of results. Despite steps taken to minimize biases such as strategic and hypothetical bias, some bias may be present in the results. Using more complex methods to quantify these biases may be included in future work. Behavioral experiments to examine risk aversion, which were not included due to the online nature of the survey, may also be included in the future to get a better understanding of willingness to pay for index insurance.

Chapter 2 was focused on determining the factors that affect willingness to pay for weather index insurance. In Chapter 3, which follows, a new weighted multi-trigger rainfall index is designed in order to improve demand for weather index insurance for forage, specifically by reducing temporal basis risk. Using farm yield and rainfall data, basis risk for the newly developed index is calculated and compared to the basis risk of existing rainfall indices offered in Ontario.

Chapter 3

Temporal Basis Risk Reduction in Weather Index Insurance: A Weighted Multi-Trigger Approach

3.1 Introduction and Background

Weather Index Insurance

Weather index insurance for crops pays indemnities based on an underlying weather index that is correlated with actual losses, this differs from conventional indemnity-based insurance that pays indemnities according to a farmers actual losses. There are many possible underlying indices for agricultural index insurance products, such as, area yield index, satellite vegetation index, etc.. However, weather indices, such as rainfall and temperature indices, are most commonly used. Weather index insurance has received considerable research attention in recent years as a promising alternative to traditional, indemnity-based insurance for agriculture as it overcomes many of the shortcomings of traditional, indemnity-based insurance, including expensive on site damage assessments, moral hazard, and adverse selection. Weather index insurance has been of particular interest in a number of developing countries, where farm sizes are small, making loss measurement and adjusting very costly for traditional indemnity-based insurance.

However, a new problem arises with weather index insurance, that of basis risk. In this paper, basis risk refers to the mismatch between payoffs based on the weather index, and actual losses on the farm. In order for a weather index to be successful, basis risk must be minimized, that is, the weather index must exhibit high model effectiveness. A highly effective weather model is able to explain a high portion of the variability in crop production caused by weather. For example, an index which uses cumulative rainfall over a period to estimate crop growth in that period will only work properly if cumulative rainfall levels determine the growth of that crop to a large extent. However, if the rainfall index does not properly capture the effect of crop growth stages on yield, this results in a type of basis risk called temporal basis risk. This is assuming that the weather station is sufficiently close to the crop field (i.e. no spatial basis risk) and that rainfall is the sufficiently correct weather variable for the index, as opposed to sunshine or temperature etc. (i.e. no variable basis risk). Temporal, spatial and variable basis risk will be described later in this paper.

Crop Insurance in Canada

In Canada, crop insurance is delivered at the provincial level by government insurance corporations with oversight by the Federal Government. Premiums are government subsidized by 60% and farmers are responsible for the remaining 40%. Participation rates for most Canadian crop insurance are quite high with often more than 85% of producers insured. Forage insurance, however, has experienced considerable challenges across the country in achieving adequate participation, with only about 10% of producers insured. In an attempt to address the low demand, the province of Ontario developed a very flexible rainfall index insurance policy for forage. However, demand for rainfall index forage index insurance in Ontario remains low. Basis risk is often considered a main cause of this low demand (Clarke, 2011). Temporal basis risk, the focus of this paper, occurs when crop growth stages are not properly accounted for and there is a difference between the actual loss on the farm and index-measured loss. This is an area of research that has received considerably less attention relative to other types of basis risk, including spatial basis risk and variable basis risk.

Based on a survey conducted by the forage index insurance provider in Ontario, forage producers in the province identified drought as a main source of risk to forage yield. Excess rainfall during harvest was cited as the secondary main risk. Therefore, it is expected that a new multi-trigger design incorporating both insufficient rainfall risk and excess rainfall risk would likely reduce overall basis risk, through specifically reducing temporal basis risk.

Research Objective

The objective of this paper is to determine if a multi-trigger rainfall index can reduce temporal basis risk. In this multi-trigger index, the growing season is divided into different time periods, where higher weights are placed on periods in which rainfall is most important to forage crop growth, and consideration is made for both insufficient and excess rainfall risk. This index design is chosen because different forage plant growth stages have different needs. Therefore, it is possible to assume that a cumulative rainfall amount over the entire growing period may not completely frame the relationship between crop growth and rainfall, as timing of the rainfall is also important. It has been shown that a significant improvement in tracking the relationship between yield and rainfall can be achieved by assigning specific weights to the different growth stages (Stoppa and Hess, 2003). To overcome the basis risk limitation associated with the existing rainfall insurance policy offered in Ontario, a new multi-trigger rainfall index is proposed. In this index, the forage growing season is divided into different optimal time periods and consideration is made for both insufficient and excess rainfall risk. A comprehensive data set of forage yield and rainfall variables for the province of Ontario is used to empirically examine temporal basis risk and develop a new rainfall index structure. Temporal basis risk will then be calculated for the new index. A reduction in temporal basis risk will indicate increased effectiveness of the weather index model. Therefore, using this new weighted multi-trigger index may help to address the low demand of index-based insurance.

The remainder of this paper is organized as follows. In the next section, the relevant background regarding weather index design and basis risk is reviewed, followed by a description of the data used in this study. Next, the method of multi-trigger rainfall index design is explained as well as the method of assessing basis risk. The new proposed multi-trigger rainfall index is then constructed and the results regarding model effectiveness are presented. The final section provides concluding remarks, including an outline of major findings, limitations and suggestions for future research. Additional background information and results are provided in the Appendix.

Background: Existing Rainfall Index Designs

In this section, three existing rainfall index designs are explained, and the advantages and disadvantages of each design are highlighted.

Total Season Rainfall Index (Cumulative)

A cumulative rainfall index based contract triggers a payment if rainfall in the total growing season is under/over a given threshold. This design is widely used due to its simplicity, however, the impact of rainfall distribution on crop growth is ignored. For example, a dry spell during a certain period could be responsible for crop loss despite cumulative rainfall being within a normal range. Therefore, this design also does not consider rainfall timing within crop growth stages, i.e. rainfall in one period may be more important than rainfall in another period. The "Base" index in Ontario's existing forage rainfall policy is an example of a total season rainfall index.

Weighted Rainfall Index

The weighted rainfall index places different weights on multiple time periods within the total growing season. While this design is more flexible than the total season rainfall index, which imposes identical weights on each time period, it may lead to undesirable offsetting results. That is, excessive rain in a period with a low weight may still compensate for rainfall shortage in a period of high importance. Setting daily caps for rainfall can assist in overcoming this issue (Clarke, 2011). The “Monthly-Weighted” index in Ontario’s existing rainfall policy for forage is an example of a weighted rainfall index.

Multi-Period Rainfall Index

In a multi-period rainfall index, which is a special case multi-trigger index, the total crop growth season is divided into different time periods, with a different payout structure for each time period. Advantages of this contract type are that time periods typically correspond to crop stages, and payouts may be more timely since a payment may be triggered at the end of each time period. However, this design assumes the effect of rainfall on yield in a given time period is independent of rainfall in previous time periods. Therefore, an entire crop could be destroyed in one time period, but the payout would be less than the maximum possible payout if rainfall is within the normal range for subsequent time periods. One solution for this shortcoming is to consider soil moisture at the beginning of each time period in an effort to “roll over” the rainfall from the previous time period. Another alternative is to develop a sub-contract, which triggers a maximum payment if one or a few time periods exhibit extremely poor weather conditions. The Bi-Monthly index in Ontario’s existing rainfall policy for forage is an example of a multi-period rainfall index.

Background: Basis Risk

Basis risk refers to the risk that the underlying index is not perfectly correlated to actual losses, therefore a farmer will not be indemnified for actual losses, or will be paid indemnities despite having no actual losses (Elabed et al., 2013). While there are a number of possible explanations for low demand for weather index insurance contracts, such as lack of understanding or trust, the most prevalent is likely basis risk (Chantarat et al., 2013; Deng et al., 2007).

In order for an index to effectively reduce basis risk, there must be a clear relationship between the chosen index variable(s) (e.g. rainfall) and the loss exposure. Minimizing basis risk is crucial because farmers will not insure if basis risk is present even when premiums are actuarially sound (Mobarak and Rosenzweig, 2013). Also, if farmers exhibit ambiguity averse behavior, they are even less likely to purchase weather index insurance given that basis risk causes indemnities to be uncertain (Elabed and Carter, 2015). As a result, demand for weather index insurance, to date, has generally been much lower than expected. Also, in most cases, weather index insurance has not moved beyond the pilot stage, and the cost to producers is usually heavily subsidized. Basis risk is often considered the primary cause of this low demand for weather insurance (Clarke, 2011) and has been cited as a primary reason for limited implementation of commercial weather index insurance (Turvey, 2001; Brockett et al., 2005; Lin et al., 2015). The focus of this paper is temporal basis risk, though two other types of basis risk are typically discussed in literature, spatial basis risk and variable basis risk. Spatial basis risk relates to a mismatch between the weather observed on a farm and weather data obtained from the farm's reporting meteorological station. This mismatch occurs because of the distance between the the weather station and the farm and /or differences in geographical factors such as altitude. Variable basis risk is defined as the absence of a clear relationship between actual loss and the weather index due to the index having an incorrect or missing weather variable. For example, variable basis risk occurs when wind is used in an index when, instead, rainfall should be used. A description of temporal basis risk follows.

Definition: Temporal Basis Risk

Temporal basis risk, the focus of this paper, refers to a low correlation between a weather index and the crop losses due to the *timing* of the occurrence of the insured event (Skees et al., 2007). The temporal component of basis risk is related to the fact that sensitivity of yield to weather may vary over the stages of crop growth. During each stage, the amount of rainfall may have different effects on the yield. (Miranda and Gonzalez-Vega, 2010). This means that the weather insurance time periods are not temporally aligned with the intended crop growth stage. This may happen, for example, if a rainfall weather index does not take into account the key times at which rainfall is most needed by a crop, and instead relies on cumulative rainfall. Therefore, a crop may, in the germination stage, receive high rainfall which may flood the crop, then receive no rainfall during the main growing season, causing damage. In this case, the cumulative rainfall would be adequate (on average) although the timing of the rainfall was, in fact, destructive. Also, temporal basis risk may be viewed by some as a subset of variable basis risk, if the temporal element (time) is considered to be a variable.

Existing Literature: Temporal Basis Risk

Some papers have focused on temporal basis risk, including Stoppa and Hess (2003) and Lin et al. (2009). Stoppa and Hess (2003) significantly reduce the temporal basis risk of rainfall weather index insurance in Morocco by applying optimized weights to growth stages to create a weighted rainfall index which gives more weight to crop growth stages that are more important for determining crop yield and vice versa. In Lin et al. (2009), the impact of temporal basis risk is assessed by allowing separate rainfall insurance contracts to be purchased for different periods during the crop cycle in the state of Georgia, USA. Multi-trigger index insurance is currently offered in several developing and developed countries in an effort to reduce temporal basis risk. However, a positive relationship is always assumed between rainfall and crop yield, without considering the adverse effects of excess rain or ill-timed rainfall. Therefore this research aims to determine if a multi-trigger rainfall index may improve temporal basis risk, by assigning rainfall triggers to each crop growth stage and considering the effects of both excess and insufficient rainfall. In this analysis, temporal basis risk is examined using a dataset from Ontario, Canada for forage, regarding rainfall.

3.2 Data

The data used are farm-level first-cut forage yields for 1999-2003, for Timothy and Alfalfa. Ontario consists of more than fifty census divisions, and in this study, data were obtained for sixteen of the census divisions. These census divisions have three types; single and upper-tier municipalities, as well as districts. Historical farm-level yield data was collected by the provincial crop insurance organization in Ontario for 200 farmers, as well as corresponding daily rainfall data within the 16 census divisions, which was obtained from a third-party provider. This resulted in a total of 448 observations as data were not available for each farmer every year (i.e. an uneven panel dataset was used).

Forage Production in Ontario

The major forage crops in Ontario are perennial legumes and grasses, with the most popular legume being Alfalfa, and the most popular grass being Timothy. These crops can be insured under the rainfall index insurance policy offered in Ontario. This insurance policy is called the Ontario Forage Rainfall Plan, a detailed description of which may be found in Appendix A. In Ontario, forage is grown from about from May to August, and most farmers use a three-cut system, cutting approximately every 6 weeks starting at the beginning of June.

3.3 Methodology: Multi-Trigger Index Design Elements

In this section, the methods used to design the newly proposed multi-trigger index are outlined. The relationship between rainfall and forage yield is examined as the proposed index is focused on basis risk reduction. In this index, the season is divided into different time periods, where period weights are selected to optimize the correlation between rainfall and yield. It is expected that higher weights will be placed on periods in which rainfall is most important to forage crop growth, and consideration is made for both insufficient and excess rainfall risk. Triggered payments are, therefore, more dependent on the rainfall occurring in different crop growth stages than in commonly used cumulative rainfall indices.

A step by step process is used to determine the most accurate index design to reduce basis risk. The elements to be considered when designing this weather index are: (i) the locations of the weather stations used for reporting (e.g. farm X's yield will be estimated using rainfall data from the Y closest weather stations within a Z km radius), (ii) the time period that the index will cover (e.g. coverage for this insurance will span the crop growth season which lasts from month A to B), (iii) the definition of effective rainfall and the optimization of rainfall weights (e.g. rainfall above V mm will not be included in calculations and the rainfall in time periods $a, \ldots, k$ will be given weights $w_a, ..., w_k$, respectively), (iv) the trigger variables that will be included in the index (e.g. a payment will be triggered if there is *excess rainfall* in period Q and *insufficient rainfall* in period P) and, (v) the strike values that trigger payment (e.g. if rainfall in time-period L is less than $N\%$ of the long-term average rainfall in that period, this is considered insufficient rainfall for that period and, therefore, a payment will be triggered).

Determining the Weather Station Used for Reporting

The first step for designing the new multi-trigger rainfall index is determining which weather stations to use in providing rainfall information for each farm. In this paper, only farms less than 5 km away from a weather station with continuous rainfall data are considered. This way, any difference between the estimated loss and the actual loss can mostly be attributed to non-spatial factors, such as index design.

Determining the Index Insurance Coverage Period

The second step for designing the new multi-trigger rainfall index is determining the total time period which the index will cover. The typical growing season for forage extends from May to August. However, as previously discussed, only first-cut yield data is available, and not the second and third-cut data which, together, corresponds to the total yield over the growing period. However, first-cut data typically represents about 60 - 65% of the total yield. The fisrt-cut of forage happens by the end of June. Therefore, the multi-trigger index will cover only the months of May and June.

Defining Effective Rainfall and Optimizing Rainfall Weights

The third step for designing the new multi-trigger index is defining effective rainfall, that is, rainfall that is actually useful to the crop in question, and determining the weights that maximize the correlation between effective rainfall and yield. First, a rainfall "capping" procedure is introduced to account for the fact that water in excess of storage capacity is lost and does not contribute to plant growth. Similarly, daily rainfall below a certain level is lost to evaporation. Consultation with Ontario's forage specialist estimates that, for the average conditions in the province, soil maximum daily retention capacity is 50mm, and daily rainfall below 1mm is lost to evaporation. As a result, if considering Ontario, daily effective rainfall on day d in year t, r_{dt}, is defined as:

$$r_{dt} = \begin{cases} \min[r^*_{dt}, 50mm] & r^*_{dt} \geq 1mm \\ 0mm, & otherwise \end{cases} \tag{3.1}$$

where r^*_{dt} is the actual rainfall on day d in year t. Therefore, for a period i, containing p days in year t, the total effective rainfall is given by:

$$r_{it} = \sum_{d=1}^{p} r_{dt}, \tag{3.2}$$

In order to find the most suitable periods for each trigger, rainfall is aggregated in monthly, ten-day and five-day periods. Then, using the model in Stoppa and Hess (2003), rainfall in the index design is defined using the "effective factor totals", F_t, for year, t to determine the weights to be used for each period.

The effective factor totals in year t, F_t, which corresponds to the weighted average of rainfall, is then defined as:

$$F_t = \sum_{i=1}^{n} \omega_i r_{it}, \tag{3.3}$$

where n is the total number of periods in the growing season, ω_i is the weight assigned to the rainfall in period i of the growing season, and r_{it} is the total useful rainfall in period i of year t. Note that the effective factor totals depends on the weights and these weights, in turn, play a crucial role in the design of the multi-trigger design for reducing basis risk. To reduce the temporal basis, the weights, ω_i, are then chosen to maximize the sample correlation between the index and yield. Also note that ω_i may be negative since excess rainfall in some periods may be negatively correlated with yield.

Let Y_t denote the yield in year t, and $\bar{Y}$ and $\bar{R}$ denote the sample means of yield and factors, respectively. Then, the optimal weights are chosen by solving (Stoppa and Hess, 2003):

$$\max_{\omega_i} corr(F, Y) = \frac{\sum_{t=0}^{n} (F_t - \bar{F})(Y_t - \bar{Y})}{\left[\sum_{t=0}^{n} (F_t - \bar{F})^2\right]^{1/2} \left[\sum_{t=0}^{n} (Y_t - \bar{Y})^2\right]^{1/2}}. \tag{3.4}$$

In our empirical studies, we examine three possible periods of aggregating rainfall (i..e monthly, ten-day and five-day). The ten-day periods of rainfall (Stoppa and Hess, 2003) are found to be the most suitable measurement period for estimating yield, compared to monthly cumulative rainfall and five-day cumulative rainfall. Therefore, the insufficient rainfall trigger is a weighted rainfall index determined by the ten-day period weights.

Determining the Rainfall Index Triggers

The fourth step for designing the newly proposed multi-trigger index is determining the triggers to be included in the index. The intent of developing a multi-trigger rainfall index is to consider both the weather risks of insufficient rainfall and excess rainfall, in order to offset any potential basis risk caused by failing to acknowledge both risks simultaneously. The contract designed in this paper therefore includes triggers for both insufficient and excess rainfall. A sub-contract trigger is also included to account for extreme weather. As a result, the multi-trigger rainfall index is defined as:

$$P_{xyz} = \begin{cases} 0 & \text{if } x \text{ or } y \\ L & \text{if } x \text{ and } y \\ L_{+} & \text{if } z \end{cases} \tag{3.5}$$

where $P_{xyz} \geq 0$ is the payment triggered, x is the insufficient rainfall trigger, y is the excess rainfall trigger and z represents the sub-contract trigger. L is the assumed loss under the main contract, and L_{+} is the assumed loss under the sub-contract. Therefore, a payment is triggered if x and y happen simultaneously, or if z occurs.

A New Weighted Multi-Trigger Rainfall Index - Insufficient Rainfall Trigger

Based on the results of the weighted optimization, ten-day period weighting performed the best among the compared monthly and five-day periods. Therefore, the insufficient rainfall trigger is a weighted rainfall index determined by ten-day period weights. More specifically, the that portion of the index will "trigger" if there is a shortfall in the season's ten-day-weighted cumulative rainfall for the months of May and June.

A New Weighted Multi-Trigger Rainfall Index - Excess Rainfall Trigger

The excess rainfall trigger is designed as follows. Given a rainfall threshold (currently 5mm or 7mm), if there are no consecutive five-day windows in the intended harvest period with less rainfall than the threshold, a claim will be paid. A farmer may choose one of the following harvest period options based on the typical harvest period for first cut of forage, including, May 22-31, June 1-10, June 11-20, June 21-30 or July 1-10.

A New Weighted Multi-Trigger Rainfall Index - Sub-Contract Rainfall Trigger

The combination of the insufficient rainfall trigger and the excess rainfall trigger results in a multi-period index. This design assumes the effect of rainfall on yield in a given time period is independent of rainfall in previous time periods. Therefore, an entire crop could be destroyed in one time period, but the payout would be less than the maximum possible payout if rainfall is within the normal range for subsequent time periods. To account for this possibility, a sub-contract is included in the index which triggers a maximum payment if one or a few time periods which are critical to crop growth exhibit extremely poor weather conditions. Given that ten-day periods were found to be most optimal for estimating yield, the two most ten-day periods with the highest weights are used to determine the time periods of the sub-contract.

Determining the Strike Values that Trigger Payment

The fifth and final step for designing the new multi-trigger rainfall index is determining the strike values at which each part of the index will trigger. To determine the most optimal index, several index designs are tested, with a focus placed on contract simplicity.

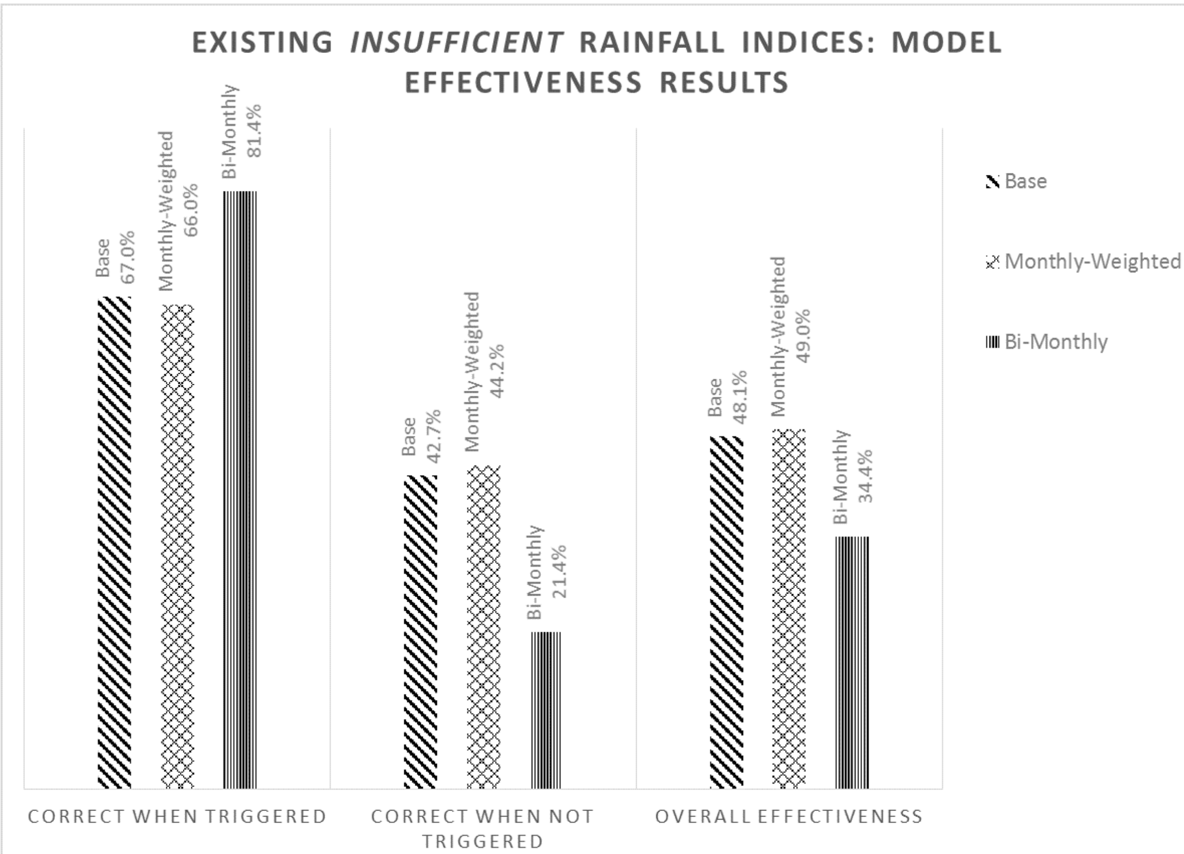
Insufficient rainfall thresholds of 50 % to 90% of the long-term average (in increments of 10%) are considered. Excess rainfall thresholds of 2mm, 5mm or 7mm are then each considered as a possible portion of the multi-trigger rainfall index. Each county was found to have at least two ten-day periods with significant weights. This is also the motivation for incorporating the "sub-contract" in our design in order to capture short periods of extreme weather in these periods. The triggers considered for this sub-contract include when the effective rainfall for any of the two most"important" ten-day periods in the respective county is less than 50, 60 or 70% of the long term average. As a result, a total of 65 index designs are tested. The results of the new proposed multi-trigger rainfall index are in the section that follows.

3.4 Model Results for Rainfall Index Effectiveness

In this section, the effectiveness of the new weighted multi-trigger rainfall index is compared to the effectiveness of the benchmark contracts used to replicate Ontario's existing insufficient and excess rainfall indices. A further description of these benchmark contracts may be found in Appendix B. The intent is to examine the "predicted" loss, which refers to whether or not a payment would have triggered for each farmer in each year. This "predicted" loss is then compared to the "actual" loss experienced on the farm. The basis risk contained in the product is therefore the mismatch between the "predicted" loss and "actual" loss. More specifically, false positive basis risk refers to the probability that the index predicts a loss when there is no actual loss, while false negative basis risk refers to the probability that the index does not predict a loss, when there is an actual loss. Clearly, an index that leads to a high false positive probability and high false negative probability is inadequate as it leads to high basis risk. For this reason, we measure the model effectiveness by focusing on the the probability that a model is "correct when triggered" when there is actual loss (the opposite of false negative basis risk) and "correct when not triggered" when there is no actual loss (the opposite of false positive basis risk).

It is expected that considering forage crop growth stages as in Stoppa and Hess (2003) as well as considering the impact of both insufficient and excess rainfall risk will substantially improve the effectiveness of these contracts (i.e. reduce both false positive and false negative temporal basis risk), and therefore increase demand for forage insurance.

Figure 3.1: Existing *Insufficient* Rainfall Indices: Model Effectiveness Results



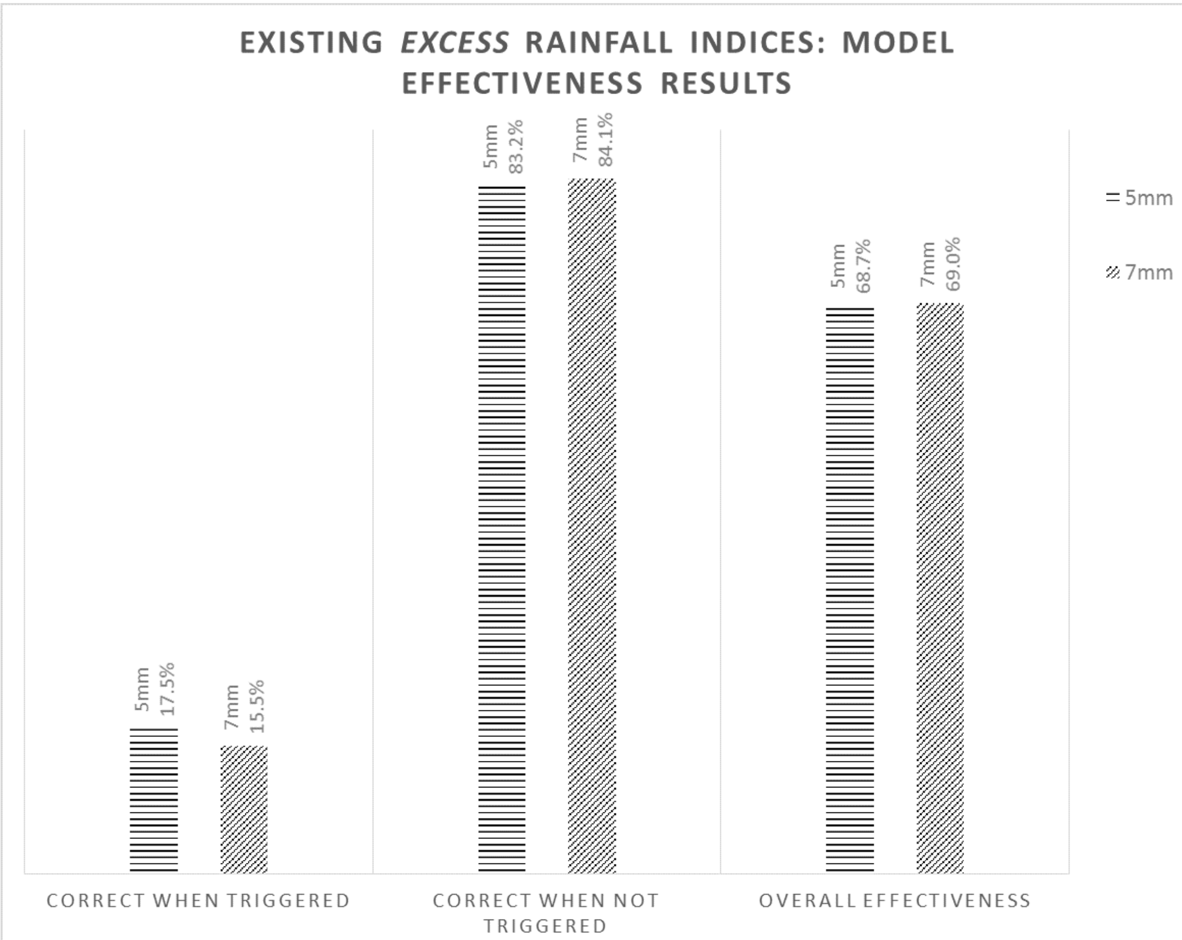
Notes: This figure summarizes the performance of the existing insufficient rainfall indices offered in Ontario. An index is "correct when triggered" if the index predicts a loss when actual loss occurs and is "correct when not triggered" if no loss is predicted given that no actual loss occurred. Overall effectiveness is calculated as follows: (correct when triggered x probability of actual loss) + (correct when not triggered x (1-probability of actual loss)), where probability of actual loss is 22%.

Existing *Insufficient* Rainfall Indices: Model Effectiveness Results

Figure 1 demonstrates the effectiveness of the existing insufficient rainfall indices, namely, the base, monthly-weighted and bi-monthly coverage alternatives. The left-most panel of Figure 1 shows how often the existing insufficient rainfall indices are correct when triggered. For example, the graph shows that the Base alternative correctly predicts loss 67% of the time that there is actual loss. Conversely, as can be seen in the center panel of Figure 1, the Base alternative correctly predicts no loss 42.7% of the time that there is no actual loss on the farm. As a result, the overall effectiveness of the index (right-most panel) is 48.1% and is calculated as (correct when triggered x (probability of actual loss)) + (correct when not triggered x (1 - probability of actual loss)), where the probability of actual loss is 22%.

As a whole, Figure 1 shows that the benchmark contracts for Ontario's current insufficient rainfall alternatives have substantial basis risk. More specifically, all three insufficient rainfall contracts demonstrate large false positive basis risk, which means the index is likely to trigger a payment when there is no actual loss. This can be potentially good for the insured farmer but can create substantial loss for the insurer, who determines premium based on the probability of actual loss. Since the index triggers a payout more often than actual loss is incurred, there will be severe losses to the insurer, in this case, the government. As can be seen in the center panel of Figure 3.1, the probability of correctly not triggering a payment is as low as 22% for the bi-monthly coverage alternative. The contract that exhibits the highest overall effectiveness is the monthly-weighted coverage alternative, with an overall effectiveness of 49%. There is, therefore, a demonstrated need for an improved index, since correctly triggering/not triggering 50% of the time is equivalent to flipping a fair coin to determine payouts.

Figure 3.2: Existing *Excess* Rainfall Indices: Model Effectiveness Results



Notes: This figure summarizes the performance of the existing excess rainfall indices offered in Ontario. An index is "correct when triggered" if the index predicts a loss when actual loss occurs and "correct when not triggered" if no loss is predicted given that no actual loss occurred. Overall effectiveness is calculated as follows: (correct when triggered x probability of actual loss) + (correct when not triggered (1-probability of actual loss)), where probability of actual loss is 22%.

Existing *Excess* Rainfall Indices: Model Effectiveness Results

Figure 2 demonstrates the effectiveness of the existing excess rainfall indices, namely, the 5mm and 7mm coverage alternatives. The left-most panel of Figure 2 shows how often the existing excess rainfall indices are correct when triggered. For example, the graph shows that the 5mm alternative correctly predicts loss 17.5% of the time that there is actual loss, and correctly predicts no loss 83.2% of the time that there is no actual loss on the farm (center panel). As a result, the overall effectiveness of the 5mm index (right-most panel) is 68.7%

As a whole, Figure 2 shows that the benchmark contracts for Ontario's excess rainfall alternatives show substantial false negative basis risk. This means that the index is not likely to trigger a payment when there is an actual loss. This can be potentially good for the insurer but can be devastating for the farmer, who, not only incurred an actual loss, but also paid a premium cost to insure against this loss. The probability of correctly triggering payment is less than 20% for both excess coverage alternatives, as is seen in Figure 3.2 . The 7mm alternative slightly outperforms the 5mm alternative, with overall effectiveness of 69%.

New Weighted Multi-Trigger Index: Model Effectiveness Results

Based on the highest performing multi-trigger rainfall index developed in this paper, the forage index triggers a payment if

- **Insufficient Rainfall Trigger:** Weighted Rainfall for the entire growing season (May and June) is less than 70% of long term average (x), AND
- **Excess Rainfall Trigger:** There are no five day windows in a ten-day harvest period with less than 7mm rainfall (y), OR
- **Sub-Contract/Extreme Weather Trigger:** The cumulative rainfall in any of

the county's two most "important" ten day periods is less than 50% of long term average (z)

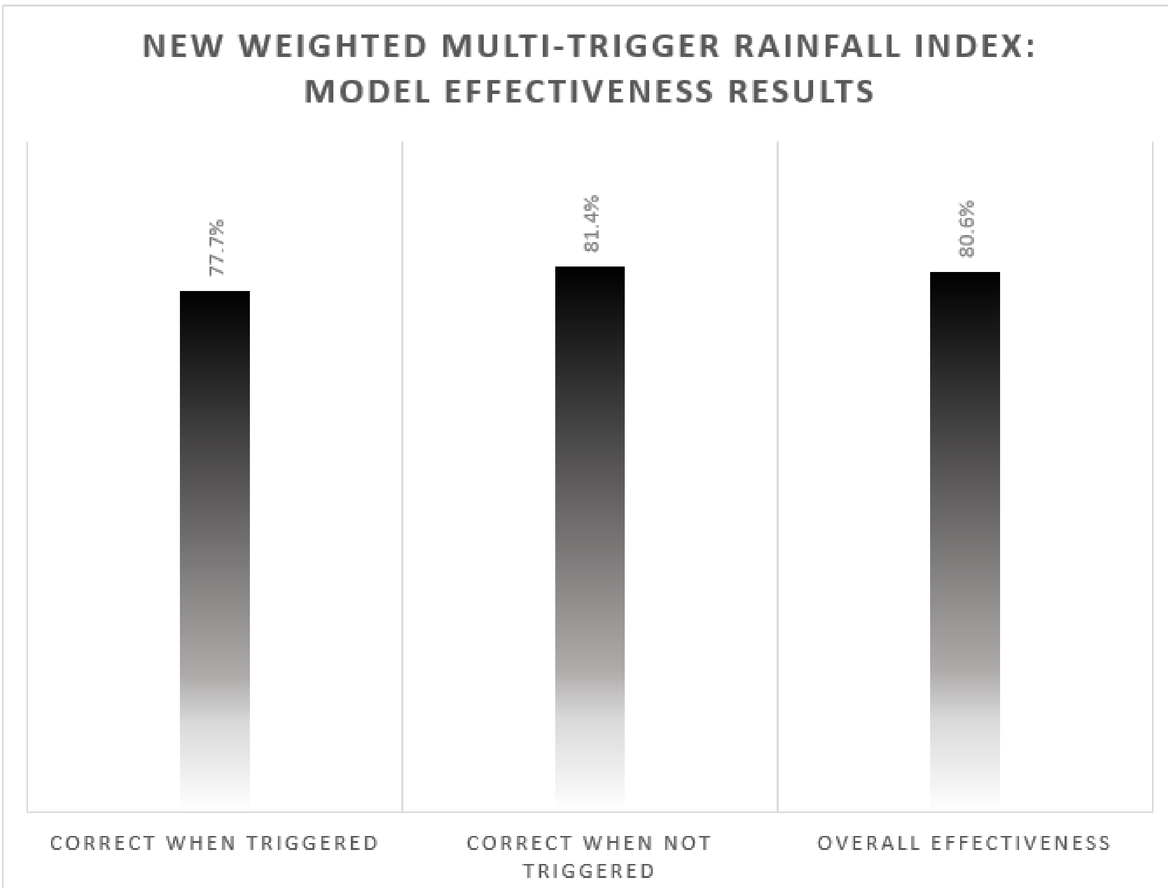
In summary, the new weighted multi-trigger index includes an insufficient rainfall trigger, an excess rainfall trigger and a trigger for extreme impact conditions. Figure 3 demonstrates the effectiveness of the newly developed index. The left-most panel of Figure 3 hows how often the new multi-trigger index is correct when triggered. For example, the graph shows that the new index correctly predicts loss 77.7% of the time that there is actual loss and correctly predicts no loss 81.4% of the time that there is no actual loss on the farm (center panel), resulting in an overall effectiveness (right-most panel) of 80.6%.

As a whole, Figure 3 shows that the new proposed multi-trigger rainfall index developed in this paper substantially improves effectiveness when compared to the existing insufficient and excess rainfall indices. Compared to the insufficient rainfall indices in Figure 3.1, the new weighted multi-trigger index (Figure 3.3) correctly predicts no loss an additional 45% of the time that there is no actual loss. The new multi-trigger index also correctly predicts loss 78% of the time that there is an actual loss, which is better than both the existing base and monthly-weighted indices. As a result, the overall effectiveness of the new proposed multi-trigger index is 81%. This is an improvement of about 30% compared to the existing monthly-weighted index, which was found to be the most effective among the insufficient rainfall indices offered in Ontario (Figure 3.1).

Compared to the existing excess rainfall indices in Figure 3.2, the new index correctly predicts loss an additional 60% of the time that there is actual loss. The overall effectiveness of the new proposed multi-trigger rainfall index is more than 10% higher than each of the existing excess rainfall indices (Figure 3.2).

The existing insufficient rainfall indices exhibit high false positive basis risk, while the existing excess rainfall indices exhibit high false negative basis risk. Considering

Figure 3.3: New Weighted Multi-Trigger Index: Model Effectiveness Results



Notes: This figure summarizes the performance of the new weighted multi-trigger rainfall indices offered in Ontario. An index is "correct when triggered" if the index predicts a loss when actual loss occurs and is "correct when not triggered" if no loss is predicted given that no actual loss occurred. Overall effectiveness is calculated as follows: (correct when triggered x probability of actual loss) + (correct when not triggered x (1-probability of actual loss)), where probability of actual loss is 22%.

times when there is actual loss, the new weighted multi-trigger index correctly triggers a payment more often, which is of concern to farmers. Similarly, considering times when there is no actual loss, the new weighted multi-trigger index more frequently correctly does not trigger a payment, which is of concern to insurers. As a result, combining the excess and insufficient rainfall indices at different strike levels and adding a sub-contract to account for extreme weather conditions, as is done in the new proposed multi-trigger rainfall index designed in this paper, significantly improves model effectiveness.

The results of the McNemar tests in Table 3.1 show that there is a positive significant difference between the new multi-trigger index and each of the existing indices, meaning that the new proposed multi-trigger rainfall index developed in this paper is significantly more effective than the existing insufficient and excess rainfall indices. The odds ratios show that the new multi-trigger performs between 1.80 and 3.97 times better than the existing indices offer in Ontario. For example, the results imply that the mean effectiveness of the new multi-trigger index is 11.38% higher than that of the 5mm excess rainfall alternative. The results also show that the new multi-trigger index is twice as likely to be correct in predicting loss, given the odds ratio of 2.

3.5 Summary

Despite considerable subsidization, forage insurance has experienced considerable challenges across the Canada in achieving adequate participation, with only about 10% of producers insured. The most prevalent explanation for lack of demand is basis risk. Reducing basis risk makes these products more accurate and trusted by farmers, and is a necessary step to improve the performance and demand for index insurance products. Temporal basis risk is a topic yet to be studied in Canada and with little research worldwide. It occurs when there is a difference between the actual loss on the farm and index-measured loss, due the timing of the index (e.g. rainfall) not being considered at

Table 3.1: Testing Significance of Improvement in Effectiveness: McNemar Test

Control Index	Difference in Effectiveness	McNemar's Chi^2	P-Value	Odds Ratio
Existing Insufficient Rainfall Index				
Base	0.3170	66.76	0.0000	2.8205
Monthly-Weighted	0.3058	63.20	0.0000	2.7125
Bi-Monthly	0.4576	122.52	0.0000	3.9710
Existing Excess Rainfall Index				
5mm	0.1138	17.00	0.0000	2.0000
7mm	0.1094	14.04	0.0002	1.8033
N = 448				

*Notes: This table shows the results of the McNemar Tests comparing the effectiveness of the new weighted multi-trigger index to the existing insufficent and excess rainfall indices. These result show that there is a positive significant difference between the new multi-trigger index and each of the existing indices (p-values ¡ 0.05), meaning that the new proposed multi-trigger rainfall index developed in this paper is significantly more effective than the existing insufficient and excess rainfall indices. The odds ratios show that the new multi-trigger performs between 1.80 and 3.97 times better than the existing indices offer in Ontario. Similar results of a more well-known test, the paired t-test, can be found in Appendix D.

different crop growth stages. The objective of this paper is to determine if a multi-trigger rainfall index can reduce temporal basis risk, and thus improve the effectiveness of index insurance. As a result, this research problem is of significant importance to agricultural producers, provincial crop insurance companies, federal and provincial governments, insurers and reinsurers.

The method used to reduce temporal basis risk in this paper is through the development of a new proposed multi-trigger rainfall index design. The methodology included using optimal weighting, multiple triggers and by testing combinations of trigger levels. In this index, consideration is made for both insufficient and excess rainfall risk. The season is divided into different time periods, where higher weights are placed on periods in which rainfall is most important to forage crop growth. Triggered payments are, therefore, more dependent on the rainfall occurring in different crop growth stages than in commonly used cumulative rainfall indices. The results of the new proposed multi-trigger rainfall index were compared to the existing forage rainfall index insurance being offered in the province of Ontario, Canada, using a unique data set from the province, including farm level yield data and corresponding weather data.

The results show that the new proposed multi-trigger rainfall index developed is substantially more effective when compared to the existing forage rainfall indices offered in Ontario. The new multi-trigger rainfall index increases the overall effectiveness of the best performing existing insufficient rainfall index by 30%. Considering growth stages in weather index insurance design improves the performance of the index in accordance with Stoppa and Hess (2003). Specifically, compared to existing excess rainfall indices offered in Ontario, the probability of correctly triggering a payment is increased by an average of 60% and compared to existing insufficient rainfall indices offered in Ontario. The probability of correctly not triggering a payment is improved by an average of 45%. The results of McNemar tests indicate that the new weighted multi-trigger index is a significant improvement in overall effectiveness compared to existing insufficient and excess rainfall indices offered.

A number of limitations of the study should also be considered. First, only first-cut forage data was available, when there are traditionally three cuts of forage. Despite first-cut data being approximately 65% of total production, this limitation may cause an over or underestimation of actual loss. Second, the data from 1981 to 2004 may not represent the current relationship between rainfall and forage loss, given technological improvements. Additionally, a lack of sufficient data prevented an out-of-sample test to be conducted. As a result, the model may be over-fitted, thus overestimating the effectiveness of the multi-trigger index that was developed. In the future, a more recent data set could be compared to the findings of this paper. Future research could also determine payout values and pricing of the new multi-trigger index insurance, which was beyond the scope of this paper.

Chapter 4

Thesis Summary

Forage insurance has experienced considerable challenges across the Canada in achieving adequate participation, with only about 10% of producers insured. This lack of participation may be due to several factors, since developing weather index insurance involves many complex parts. It is important that those purchasing insurance be charged an acceptable price (acceptable premium). Additionally, a new problem arises with weather index insurance, that of basis risk. In this thesis, basis risk refers to the mismatch between payoffs based on the weather index, and actual losses on the farm.

As a result, this thesis study, which includes two papers, aims to first identify the factors that affect forage farmers' willingness to pay for forage index insurance (Chapter 2). Then, a new weighted, multi-trigger rainfall index is developed with the aim of reducing basis risk (Chapter 3).

Factors Affecting Willingness to Pay for Forage Index Insurance

The objective of the first paper in this thesis (Chapter 2) is to examine the factors that affect willingness to pay (WTP) for forage index insurance. As a result, this research problem should be of interest to agricultural producers, provincial crop insurance companies, federal and provincial governments, insurers and reinsurers.

The method used to elicit WTP for insurance is a multiple-bounded dichotomous choice contingent valuation model. The insurance offered is based on one of the forage index insurance policies currently available in Ontario. Then, using data collected through a survey with 70 forage farmers in Ontario, WTP is modeled using an ordered probit regression.

Three groups of factors were found to affect farmers' WTP. These included the farmer's knowledge and attitude regarding insurance, their risk profile, and socio-economic factors. Results show that as a farmer's level of knowledge and positive attitude regarding index insurance increased, the amount that the farmer was willing to pay increased. Additionally, farmers who used self insurance had a lower WTP. The relationship between basis risk and WTP was negative, but not statistically significant.

Temporal Basis Risk Reduction for Weather Index Insurance: A Weighted Multi-Trigger Index Approach

The objective of the second paper in this thesis (Chapter 3) is to determine if a multi-trigger rainfall index can reduce temporal basis risk, and thus improve the effectiveness of index insurance. As a result, this research problem is of significant importance to producers, provincial crop insurance companies, federal and provincial governments, insurers and reinsurers.

The method used to reduce temporal basis risk in this paper is through the development of a new proposed multi-trigger rainfall index design. The methodology included using optimal weighting, multiple triggers and by testing combinations of trigger levels. In this index, consideration is made for both insufficient and excess rainfall risk. The season is divided into different time periods, where higher weights are placed on periods in which rainfall is most important to forage crop growth. Triggered payments are, therefore, more dependent on the rainfall occurring in different crop growth stages than in commonly used cumulative rainfall indices. The results of the new proposed multi-trigger rainfall index were compared to the existing forage rainfall index insurance being offered in the province of Ontario, Canada, using a unique data set from the province, including farm level yield data and corresponding weather data.

The results show that the new proposed multi-trigger rainfall index developed is substantially more effective when compared to the existing forage rainfall indices offered in Ontario. The new multi-trigger rainfall index increases the overall effectiveness of the best performing existing insufficient rainfall index by 30%. By considering crop growth stages in weather index insurance design, the performance of the index is improved in accordance with Stoppa and Hess (2003). Specifically, compared to existing excess rainfall indices offered in Ontario, the probability of correctly triggering a payment is increased by an average of 60% and compared to existing insufficient rainfall indices offered in Ontario, and the probability of correctly not triggering a payment is improved by an average of 45%. The results of McNemar tests indicate that the new weighted multi-trigger index is a significant improvement in overall effectiveness compared to existing insufficient and excess rainfall indices offered.

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Appendices

Appendix A

Weather Index Insurance: Ontario Forage Rainfall Plan (Existing Insurance)

The Ontario Forage Rainfall Plan was introduced to assist forage producers in managing their risk of insufficient rainfall and excess rainfall during harvest. Indemnity payments are made based on outcomes compared to historical averages, as is typical with weather index insurance. There is no minimum farm size required to purchase the insurance, but there is a minimum coverage value, which is discussed later. Insurance coverage is restricted to the summer growing season, corresponding to the period from May to August. Farmers must insure their full forage crop.

A professional weather service provides rainfall data from a network of 350 rainfall collection stations across Ontario. Similar to other crop insurance, producers pay 40% of the premium cost, and together the federal and provincial governments contribute the other 60%, with administrative costs fully funded by both levels of government. To obtain this rainfall index insurance, producers must first specify coverage value, coverage level, coverage alternative, rainfall threshold and harvest period. Below, each of these insurance policy terms are explained.

- *Coverage value:* The determined dollar value for each forage stand multiplied by the number of stands covered. A forage stand is a single plot of land being used for planting forage.
- *Coverage level:* Producers may choose to insure forage from a minimum of $2,000 (total) up to a maximum that is equal to the total forage crop value.
- *Coverage alternative:* The coverage alternatives from which the producer may choose are the base, monthly-weighting, bi-monthly and three month alternatives.
- *Rainfall thresholds:* excess rainfall coverage alternatives include either 5mm, or 7mm. If there are no consecutive five-day periods in a farmer's intended harvest period with less rainfall than the chosen threshold, a claim is paid.
- *Harvest period:* Farmers may choose one of the available harvest period options based on when they typically harvest their first cut hay or haylage. The 10-day harvest period options are: May 22-31, June 1-10, June 11-20, June 21-30 or July 1-10

Appendix B

Developing a Benchmark for Existing Rainfall Index Insurance

In order to demonstrate the expected improvement in basis risk caused by the new multi-trigger index design, the basis risk for the existing rainfall index insurance policies must be ascertained. The insufficient rainfall policies, as well as the excess rainfall policies offered in Ontario are described here. The focus is the methodology associated with benchmarking the forage rainfall policies given the data limitation, which restricts analysis to first-cut forage yields. This benchmarking is necessary to compare the basis risk of the existing rainfall policies in Ontario to the basis risk of the new proposed multi-trigger index developed in this paper.

Description: Existing Insufficient Rainfall Index Insurance in Ontario

When considering the existing insufficient rainfall indices for the province of Ontario, a farmer's coverage depends on: (i) the value of the farmer's forage crop, (ii) the farmer's chosen coverage level; and (iii) the coverage alternative chosen by the farmer. This section focuses mainly on the coverage alternatives, since the measurement of basis risk used in this paper does not consider crop value or level of coverage. There are four coverage policy alternatives under the insufficient rainfall policy from which each farmer can choose one, and each alternative measures the rainfall differently. a) The base coverage alternative considers the cumulative rainfall for the crop growing season, while b) the monthly-weighted alternative places a different weight on each month in the growing season. There is also c) a bi-monthly index, which separates the growing season into two parts and d) a three month index which does not consider rainfall in the final month of the growing season. However, in each of the four coverage alternatives, the measured rainfall must be less than 85 per cent of the historical average. Further, based on agronomic research in Ontario, daily and monthly caps are places on rainfall. The daily rainfall is capped at 50 mm, and each month's rainfall is capped at 125 per cent of the long-term average for that county to recognize the maximum capacity of soil moisture. Days with less than 1mm of rainfall are counted as 0mm towards the monthly total to recognize the small amounts of rainfall are lost to evaporation. The coverage alternatives available to the farmer, and measurement of rainfall are summarized in Table B.1.

Table B.1: Ontario Forage Rainfall Policy: Insufficient Rainfall Coverage Alternatives

Coverage	May Weight	June Weight	July Weight	August Weight
Base	1	1	1	1
Monthly-Weighting	1.3	1.2	0.8	0.7
Bi-Monthly	May and June 60% of coverage		July and August 40% of coverage	
Three-Month	1	1	1	0

[1]Note: This table summarizes the four insufficient rainfall indices for the province of Ontario, Canada.It represents the weights used to calculate rainfall index for each season. For example, the rainfall index using the monthly-weighted alternative is calculated as (May Rainfall x 1.3) + (June Rainfall x 1.2) + (July Rainfall x 0.8) + (August Rainfall x 0.7)

Description: Existing Excess Rainfall Index Insurance in Ontario

When considering the existing excess rainfall indices in the province of Ontario, Canada, a farmer's coverage depends on: (i) the value of the farmer's forage crop, (ii) the coverage level chosen by the farmer, (iii) the rainfall threshold chosen by the farmer; and (iii) the harvest window chosen by the farmer. As in the insufficient rainfall alternatives, this paper will focus mainly on the rainfall threshold and the harvest window chosen, since the measurement of basis risk used in this paper does not consider crop value or level of coverage. A farmer can select a rainfall threshold of 5mm or 7mm, and if there are no consecutive five-day windows in the intended harvest period with less rainfall than the chosen threshold, a claim will be paid. A farmer may choose one of the following harvest period options based on the typical harvest period for first cut of forage, including, May 22-31, June 1-10, June 11-20, June 21-30 or July 1-10.

Description: Benchmarking the Ontario Forage Rainfall Policy Using Only First-Cut Data - Considering Only May and June Rainfall

Given the data limitation that restricts analysis to first-cut forage yield, which is reaped by the end of June each crop season, the focus here is on developing a suitable benchmark which only considers the months of May and June. These benchmark index structures are based on the existing insufficient and excess rainfall index insurance alternatives offered in Ontario. Using the benchmark indices, the 2014 policy is replicated using farm level and census division level data from 1997 to 2004. The intent is to examine the "contractual" loss, which refers to whether or not a payment would have triggered for each farmer in each year. This "contractual loss" is then compared to the "actual loss" experienced on the farm. The difference between the "contractual loss" and "actual loss" is the basis risk contained in the product. As in the existing rainfall policy, the "measuring stick for actual yield loss will be long term average yield for the county. That is, "actual loss" on a farm is calculated by comparing the yield on that farm to the long term average yield of the county in which it is located. This definition of loss is used because the "contractual loss" is measured by comparing the rainfall data collected at a chosen weather station to the long term average rainfall of the county in which the station is located.

A main issue with with replicating the existing insufficient rainfall index insurance alternatives is that only first-cut yield data is available. As a result, only the first-cut yield is considered and rainfall in the months of May and June are used to replicate a " half policy". The assumed coverage alternatives and measurement of rainfall based on a "half policy" are summarized in Table B.2.

Table B.2: Insufficient Rainfall Benchmark Coverage Alternatives

Coverage	May Weight	June Weight
Base	1	1
Monthly-Weighting	1.1	0.9
Bi-Monthly	May 50% of coverage	June 50% of coverage

*Notes: This table summarizes the coverage alternatives and measurement of rainfall based on a "half-contract", which is necessary given the data limitations in this study, where only first-cut data corresponding to the months of May and June are available. It represents the weights used to calculate rainfall index for each season. For example, the rainfall index using the monthly-weighted alternative is calculated as (May Rainfall x 1.1) + (June Rainfall x 0.9)

Appendix C

Conceptual Framework and Theoretical Definition of Basis Risk

The theoretical definition of basis risk used in this paper is based on Elabed et al. (2013). The payoff structure of an index insurance contract is as follows; each year, every individual farmer will have favorable yields with a probability, g, and will suffer yield loss, L, with a probability, 1-g. The individual has initial income Y_0, pays a premium, ϕ, for insurance in hopes of receiving a payout, π, if she incurs loss, L.

- If the individual experiences poor yields, there is a probability, p, that the index will predict those poor yields and the insurance will trigger a payoff, resulting in an income, $(Y_0 - \phi - L + \pi)$. This is equal to the net income under bad yields, less the insurance premium, plus the value of the insurance indemnity payment.
- However, there is a probability, $1 - p$, (false negative basis risk) that conditional on poor yields, the index fails to predict the loss and the insurance contract fails to payoff. In this case, the individual receives a net income, $Y_0 - \phi - L$, (equal to the net income under bad yields minus the insurance premium).
- If the individual yields are good, there is a probability, q, that the index is correctly not triggered. In this case, no insurance payments are made and the individual receives an income equal to the net income under good yields, less the insurance premium, $(Y_0 - \phi)$.
- However, there is a probability, $1 - q$, that the index incorrectly predicts loss and the insurance triggers a payoff (false positive basis risk), resulting in an income, $(Y_c - \phi + \pi)$. This is equal to the net income under good yields plus the value of the insurance indemnity payment, deducting the insurance premium.

Table C.1 shows this framework and Table C.2 illustrates the "ideal" index contract, i.e. a contract without basis risk.

Table C.1: Index Insurance Framework

		Predicted	
		Loss	No Loss
Observed	Loss	p	$1-p$
	No Loss	$1-q$	q

*Notes: This table defines the basis risk framework, where p is the probability that the index predicts loss when a loss is observed, and q is the probability that the index predicts no loss when no loss is observed.

Table C.2: Ideal Contract

		Predicted	
		Loss	No Loss
Observed	Loss	100%	0%
	No Loss	0%	100%

*Notes: This table shows the "ideal" index contract (i.e. a contract without basis risk), where a loss is predicted only when a loss is observed, and no loss is predicted only when there is no observed loss.

Appendix D

Testing Significance of Improvement in Effectiveness: Paired t-test

Table D.1: Paired t-test

Control Index	Difference in Effectiveness	t	P-Value
Existing Insufficient Rainfall Index			
Base	0.3170	8.9177	0.0000
Monthly-Weighted	0.3058	8.5679	0.0000
Bi-Monthly	0.4576	12.9718	0.0000
Existing Excess Rainfall Index			
5mm	0.1138	4.1989	0.0000
7mm	0.1094	3.8030	0.0001
N = 448			
H_o = Difference = 0			
H_a = Difference > 0			

*Notes: This table shows the results of the Paired t-tests comparing the effectiveness of the new weighted multi-trigger index to the existing insufficent and excess rainfall indices.