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**THE EFFECT OF CLIMATE CHANGE ON THE PRICING OF WEATHER INDEX-BASED CROP
INSURANCE IN KENYA**

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DECLARATION

I declare that this work has not been previously submitted and approved for the award of a degree by this or any other University. To the best of my knowledge and belief, the Research Proposal contains no material previously published or written by another person except where due reference is made in the Research Proposal itself.

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1. INTRODUCTION

1.1 Background

1.1.1 Climate change risks faced by Agriculture in Kenya

The Agricultural sector is a pillar of the economies of many developing countries around the world. In Kenya, the sector contributes an average of 24% to the GDP directly and 27% indirectly through connection to other sectors e.g. manufacturing and distribution and accounts for about 60% of the total employment in the country. The agricultural sector also accounts for 70% of export earnings. Small-holder farmers are the main producers of agricultural output in Kenya constituting of 80% of all the farmers. (Ministry of Agriculture, 2009) The Government therefore places a high priority on Agriculture as an important tool for development.

The climatic conditions in Kenya have been changing over the years placing the agricultural sector at risk. The vulnerability of the sector to climate change is mainly due to the rain fed nature of Agriculture in the country. Increase in temperatures, change in rainfall patterns, severe weather conditions such as droughts and floods have been on the rise in the past few years .In 2009, Kenya experienced a major drought that affected all regions and led to starvation of close to 10 million people countrywide after poor harvest and crop failures. (Kenya Red Cross, 2009). This trend is projected to persist in future. According to the IPCC, it estimates that the adverse effects of climate change could lead to reduction in agricultural production yield by up to 50% in most Sub-Saharan countries(Kenya included)by 2020, decline in land suitable for crop production by 3% and by 2100 the crop net revenues will reduce by 90%. It is smallholder farmers who will suffer the brunt of this the most (Boko, 2007).In Kenya, it is the production of the four major staples; maize, wheat, groundnuts and irrigated rice that will be most affected (Herrero, et al., 2010).

Given the central role of Agriculture to the economy, a number of strategies have been developed to mitigate the negative effects of climate change. This includes strategies like growing drought resistant crops, improved management of water resources, and conservative agriculture among others. (Maina, Newsham, & Okoti, 2013). Also, the government and various stakeholders in the agricultural sector have been looking to insurance as a solution to curb the

negative effects of climate change. Various insurance products have been developed to help farmers manage weather risks.

Weather index-linked crop insurance is a risk management tool that has been gaining popularity over the past few years in many regions in Africa to help farmers cope with the effects of climate change.

1.1.2 Weather Index-linked Crop insurance in Kenya

Over the years, index-based weather insurance has been gaining interest as a suitable means to insure against weather risk as it addresses the challenges of traditional crop insurance.

Traditional crop insurance methods are dependent on direct measurement of the losses incurred by the farmer. However, with weather index-linked insurance, the insurance payouts are linked to objective measurable variables like rainfall and temperature. (IFAD, 2011) This helps eliminate moral hazard, the need for individualized loss assessment, adverse selection and collection of farm-level yield data, creating opportunities to insure crops that would have otherwise been too expensive to insure using conventional indemnity based insurance methods (Collier, Skees, & Barnett, 2009). Weather index-linked form of insurance is especially relevant to climate change as it insures against weather risks.

In Kenya, the first index-based weather insurance was initiated in Marsabit in 2009 to cover livestock mortality caused by drought. Pastoralists were indemnified when they lost their livestock to drought. That same year Kilimo-Salama another index-linked weather insurance product was also launched and targeted small-scale farmers covering a wide range of crops. To date over 47,000 smallholder farmers use the product and following its initial success of Kilimo Salama other insurance companies began offering index-based insurance products. (Sina, 2012)

1.1.3 Design of weather index-linked crop insurance

Weather index based insurance relies on historical data as the basis for product design and pricing. The index is based on climatic data collected over time at metrological stations such as

rainfall, temperature and windstorm. As was the case when designing Kilimo Salama, historical weather data of between 20 to 80 years was combined with agronomic data to design and price the product. (Sina, 2012) The index selected for weather index linked crop insurance has to be highly correlated with agricultural loss on the farms of the insured, for example water inadequacy is correlated with a drop in yield.

The loss estimates are not dependent on the individual losses of a farmer but a proxy for losses instead. Therefore when the index does not meet a certain threshold, the proxy is triggered and all policyholders in the area covered by the insurance contract receive a payout. The payout itself is calculated based on pre agreed sum insured per unit of deviation of the observed index value from the threshold value that had been set. (Skees, Murphy, & Collier, Scaling up Index Insurance, 2007)

1.2 Problem statement

Traditionally, insurers have relied on historical data to price weather index-based insurance contracts. Climate change however poses significant difficulty for the pricing of weather index linked insurance as many climatic models predict that the frequency and severity of adverse weather conditions are likely to go on in future. This volatility of the weather and changing trends could result in products being either overpriced or underpriced and consequently result in losses for the insurer. The challenge therefore for insurers is to accurately incorporate this changing weather patterns when pricing weather index insurance products. Also with climate change, the complication of using historical data to predict future trends arises for insurers as the distribution of weather in the past is not expected to continue in future.

Given the lower administration costs and lower premiums of weather index-linked insurance compared to the traditional indemnity based contracts, it is attaining popularity as a suitable mechanism to transfer weather risks especially for developing countries. This study therefore seeks to quantify the difference in premium as a result of the increased risk brought about by climate change and also to investigate whether it is profitable for insurers to continue pricing weather-index linked crop insurance relying on historical data only, in the presence of changing risk.

1.3 Research Objectives

- i. To determine the effect of changing weather patterns brought about by climate change on weather index based crop insurance premiums.

1.4 Research Questions

- i. What is the relationship between crop yield and rainfall?
- ii. What is the effect of changing weather patterns brought about by climate change on weather index based crop insurance premiums?

1.5 Justification of the study

The goal of this research study is to determine the effect of changing weather patterns brought about by climate change will have on the pricing of weather index linked crop insurance. With index linked insurance gaining interest as a preferable means of insurance, it is important to determine whether the pricing strategies used by insurers are suitable in light of climate change.

The study will be important to insurers in Kenya offering index insurance or those planning to offer it in future. Through recognizing the impact of this changing weather patterns on their premium and payouts, insurers will be able to better price weather index linked contracts to incorporate climate change.

2 LITERATURE REVIEW

Climate change is defined as a change in the state of the climate that can be identified by changes in the mean and/or variability of its properties, and that persists for extended periods of time. (IPCC, 2007). Simply stated, climate change is the change in average weather. Climate change is expected to cause shifts in average climatic conditions and increases in the variability of weather and consequently a rise in the frequency and occurrence of extreme events. (Kapphan, Calanca, & Holzkaemper, 2012). Weather is an important factor in agricultural production while at the same time the least controllable source of risk in agriculture. It is expected that with climate change, weather risks will be exacerbated by increasing temperatures, irregular rainfall and the occurrence and severity of extreme weather events like droughts and floods (Heimfarth, Finger, & Mushoff, 2012). As a result of this, the adaptation of innovative weather index based insurance to help farmers cope with the negative effects of climate change has been on the rise.

As stated earlier, weather index based insurance is preferred to traditional indemnity based insurance as it addresses most of the challenges of traditional indemnity based insurance. However, a major challenge associated with weather-index based insurance is basis risk. Basis risk is defined as the variation in losses as measured by the index and the actual losses realized in the farm (Collier, Skees, & Barnett, 2009). The result of this is that a farmer could experience losses in yield but does not receive a payout, or a payout is triggered yet no crop losses have been experienced by the farmer. Basis risk is either geographical or structural. In geographical basis risk, a gap exists between where the weather readings are made and the farm insured, while in structural basis risk, a weather index insurance that is not suitable to a particular crop is created.

2.1 Pricing weather index based insurance

The following equation summarizes the factors that insurers consider when pricing weather index based insurance (Collier, Skees, & Barnett, 2009)

$$\text{Price} = \text{Cost of the risk} + \text{Risk loading costs} + \text{Administrative Costs} \\ + \text{Cost of ready access to capital}$$

The expected cost of the loss (pure risk), is the likelihood and severity of a weather event. It is estimated through using historical weather data to develop a probability distribution of the underlying weather variable. Based on previous weather events and their consequent effects on factors like crop growth or household livelihoods, triggers and pay-out rates are determined.

Insurers also factor in ambiguity loading costs to account for the possibility that the insurer did not correctly estimate the pure risk associated with the weather risk. This incorrect estimation is usually likely due to insufficient data. Changing trends such as decreasing levels of rainfall contribute to ambiguity.

Catastrophic loads, which appreciate the probability that extreme weather events might occur in the first years when a product is initiated are also considered when pricing weather indexed products.

Administrative costs such as costs incurred when designing and selling the product, staff and office overheads area also included in the pricing of the product.

Given that weather index insurance involves underwriting correlated weather risks, the likelihood of experiencing losses that exceed the premiums in some years is high. To ensure that they have the capacity to pay for these losses insurers seek for a solution through reinsurance. This comes at high opportunity costs for the insurer. In developing countries like Kenya, insurers are not sufficiently exposed to reinsurance markets and this might increase the cost of capital. Consequently, this adds to the pricing of weather index insurance. (Skees, Barnett, & Collier, 2008)

2.2 Climate change and Weather Index-Insurance

Crop production is sensitive to weather variability and with climate change expected to cause unpredictable weather patterns, crop yields will consequently also be affected. (Kapphan, Calanca, & Holzkaemper, 2012) Literature on the hedging efficiency of weather index insurance

in light of climate change has been growing. Collier, Skees & Barnett (2009), observed that in regions where weather risk will increase as a result of climate change, insurers will respond by increasing insurance prices and at levels that will be too high for households. This increase in prices is attributed to increase in the pure risk, catastrophe loads and ambiguity of the risks. With climate change increasing uncertainties, insurers anticipate the worst of possible scenarios when determining catastrophe and ambiguity loads to add to the premium rates. The pure risk is affected by a change in the probability distributions of specific weather variables. Climate change will affect weather risk through shifts in the central tendency and an increase in the variability of weather events which in turn affects the variance of the distribution. The connection between climate change and weather index insurance is due to the fact that the pricing of the weather index product is done using historical burn analysis which is the use of historical data to estimate the fair premium of insurance. Therefore, with a change in trend of the data, a synonymous shift in the statistical parameters used in estimation will also occur (Adeyinka, Krishnamurti, Maraseni, & Chantarat, 2013).

Insurers have relied on the assumption that the underlying distributions of weather is stationary over time. However, studies have found that risk analysis in the face of climate change requires the use of distributions with non-stationary means and variances (McCarl, Villavicencio, & Wu, 2008). Further studies support this by concluding that the insurers expected profits increase by about 240% when they use adjusted contracts, while using non-adjusted contracts generate substantially smaller profits or even incur losses. An adjusted is a contract that has been derived using future projected yield and weather data to future weather conditions, while a non-adjusted contract is a contract that is designed using historical data. (Kapphan, Calanca, & Holzkaemper, 2012). Also, using multiple sources of climate information in the design phase of the product will lead to a more robust product.

2.3 Research Gap

Studies that have been conducted to determine the effect of climate change on the pricing of weather index based insurance are those that have been done considering the effect on

insurers on a global scale. This study seeks to identify the impact in the Kenyan context given its unique climate and insurance challenges so as to fully assess the impact on the Kenyan Insurer. Earlier studies also focused on weather index insurance in general. However, the focal point of this study will be determining how climate change will affect the pricing of weather index based crop insurance specifically.

3 METHODOLOGY

3.1 Introduction

This chapter presents the methodologies and data that were employed in the study.

3.2 Nature of the study

The nature of this study will be mainly quantitative as it aims to quantify the relationship between rainfall and yield and also to quantify the effect changing weather patterns will have on pricing index insurance.

3.3 Population and sampling

The population used in this research is the Kenyan rainfall data and maize yield data. Maize is selected as the crop to be used in this study as it is the staple crop of the country. Maize growing in Kenya is concentrated in Rift Valley regions of TransNzoia, Uasin Gishu and Nakuru. There are currently about 39 weather stations in Kenya located at different altitudes. The Nakuru weather station will be used as the source for the rainfall data and also the Nakuru area will be used for the maize yield data.

3.4 Data collection and data sources

Rainfall and yield data are quantitative data. The source of information for daily rainfall data will be obtained from the Kenya Meteorological department for the Nakuru weather station while the yield data will be obtained from Tegemeo Institute of Agricultural Policy and development which will be the kilograms of maize per hectare. The data that will be used will be that of the past 15 years (2000-2015) so as to sufficiently assess correlations between rainfall and maize yield.

3.5 Data Analysis

3.5.1 Estimating missing data

The missing data values were estimated using the simple arithmetic mean ratio. This involves

replacing the missing data records with the average value for a particular station. The arithmetic mean ratio formula is given by

$$Y_i = \frac{\bar{Y}}{\bar{X}} X_i$$

Where;

Y_i = is the month with the missing value

\bar{Y} = is the average monthly mean at the station with missing value

\bar{X} = is the average monthly mean at a nearby station

X_i = is a corresponding record of a nearby station

3.5.2 Homogeneity test

Homogeneity test to determine the consistency of the data will be carried out. This will be determined using the single mass curve which involves plotting the cumulative totals of rainfall and yield against time. Inconsistency will be observed through a break or a curve in the straight line

3.5.3 Obtaining the relationship between rainfall and yield

Correlation analysis will be used to determine the relationship between rainfall and yield. This is done using Pearson's coefficient formula that is given by;

$$r_{xy} = \frac{[\sum xy - \frac{\sum x \sum y}{n}]}{(\sum x^2 - \frac{(\sum x)^2}{n})(\sum y^2 - \frac{(\sum y)^2}{n})}$$

Where:

r=correlation coefficient

x=weather parameter

y=maize yield

n=number of years

3.5.4 Significance of Correlation Coefficient

The student's **t - test** was used to test the significance of the correlation coefficient.

The formula for **t - test** is given by;

$$t_{n-2} = \frac{r}{\sqrt{\frac{1-r^2}{n-2}}}$$

Where;

r = correlation coefficient

t= student's statistical test

n = number of observations

3.6 Payout structure

Consider a weather index insurance contract which pays the entire insured amount if the rainfall for the district R_A falls below the stop-loss rainfall R_S , where stop-loss is the value of the weather variable where the payout reaches its maximum value. Beyond the stop loss only the maximum value is paid out. The contract also pays out the proportion $IA\left(\frac{R_T - R_A}{R_T - R_S}\right)$ when the rainfall is between the stop loss rainfall R_S and the rainfall trigger R_T , and pays nothing when rainfall exceeds the trigger rainfall.

This can be expressed as follows;

$$\text{payout} \begin{cases} IA & \text{if } R_A \leq R_S \\ IA \left(\frac{R_T - R_A}{R_T - R_S} \right) & \text{if } R_S < R_A \leq R_T \\ 0 & \text{if } R_A > R_T \end{cases}$$

3.7 Calculation of pure premium

Numerical Integration will be used to determine the pure premium of the contract. The reason for using numerical integration is that it will provide an approximate solution to a definite integral.

The definite integral that will be approximated is

$$\text{Pure Premium} = \int_{x=0}^{\text{max}} f(x)y(x)dx$$

Where x= Rainfall values

f(x) =pdf of the fitted rainfall distribution

y(x) = payout for x mm of Rainfall

This is the product of the payout and the probability of the payout summed over all possibilities of rainfall.

The probability density function of the rainfall distribution will be fitted using the easy fit software.

3.8 Climate Change Simulations

After estimating the premium under the normal climate scenario. The study assumed uniform climate change scenarios of a decrease in precipitation levels between 2.5%-20%. Under this scenario, it is assumed that only one aspect of climate changes and that change is uniform across the country.

Using the above formula the premium will be determined for the obtained rainfall values. Rainfall values for different rainfall scenarios under climate change will be simulated and the premium under these circumstances determined

The difference between this premium and the premium obtained from the actual rainfall values will be determined so as to quantify the difference in premium that arises as a result of climate change.

Administrative and insurance costs are also usually loaded when determining the premium but in this study only the pure premium will be taken into consideration.

4 DATA ANALYSIS

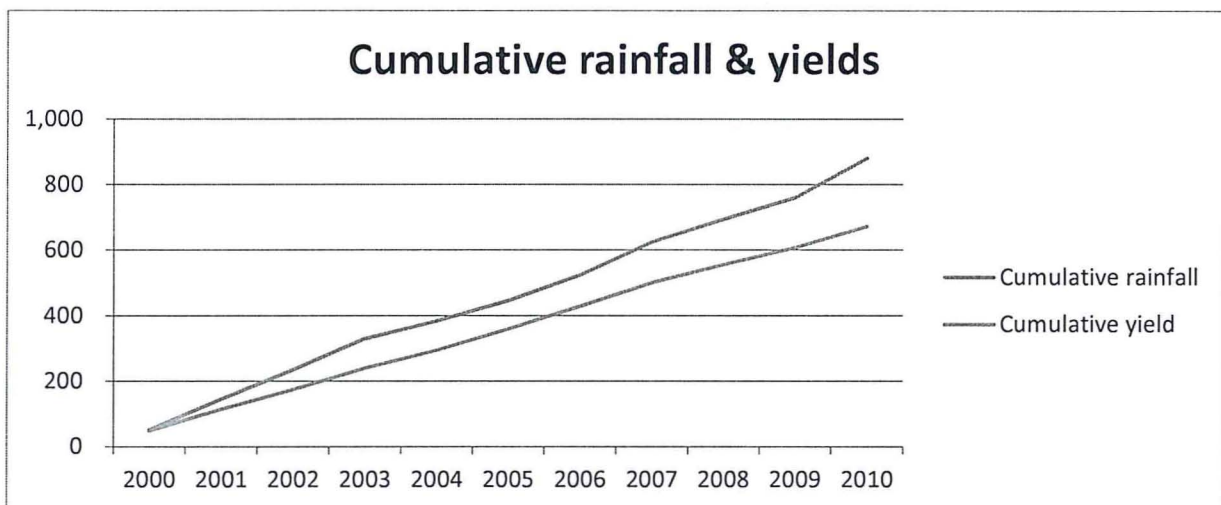
4.1 Introduction

This chapter presents the results of the study. The results from the test for homogeneity of the data are first presented in section 4.2. This is followed by a test for the correlation of the rainfall and yield parameters in section 4.3. The payout structure, distribution of rainfall were determined and the premium calculated in sections 4.4, 4.5 and 4.6 respectively. Finally the effect of climate change is discussed in section 4.7.

4.2 Testing for homogeneity

A test for homogeneity was carried out to determine the consistency of the data. This was through plotting the cumulative totals of rainfall and yield against time. The yield data displayed more consistency as the line was straight without any breaks or curves. The rainfall data was also consistent although it had slight bends. This therefore demonstrates that the data is reliable.

Figure 1: Single Mass Curve of Rainfall and Yield against time



4.3 Determining the correlation between rainfall and yield.

The relationship between rainfall and maize was determined using correlation analysis. The results indicated that rainfall and yield have a strong correlation at 0.67 as presented in table 1. This is important because weather index insurance requires that a strong correlation between the weather parameter and yield exist for it to be effective.

A t- test to test the significance of the correlation coefficient was also carried out at a 5 % level of significance giving a p value of 0.02254 leading to the conclusion that a linear relationship exists between rainfall and yield.

Table 1: The Correlation Between rainfall and Yield

	<i>Rainfall</i>	<i>Yield</i>
<i>Rainfall</i>	1	
<i>Yield</i>	0.675503922	1

4.4 Payout Structure

The stop loss and trigger levels of the payout structure are determined to be used in the calculation of the premium amount. The trigger rainfall value(x_t) was determined using regression analysis and was set as the value corresponding to the long term average maize yield(y). The results of the regression analysis are presented in table 2.

Table 2: Summary Output of Regression analysis

	<i>Coefficients</i>	<i>Standard Error</i>
<i>Intercept</i>	1047.469789	180.5450039
<i>X Variable 1</i>	6.00373368	2.184488385

The long term average of the crop yield was determined to be 1637.922 kg/ha and using the regression coefficients, the trigger rainfall level was calculated to be 98.18mm. Given that the average rainfall is 61.87mm, the trigger rainfall level determined is sufficient for the pricing of weather index crop insurance.

The stop loss rainfall level is assumed to be a percentage of the trigger rainfall amount and is set at 30%. This is because the weather index insurance contract is insuring against drought and therefore the stop loss value has to be less than both the average rainfall and trigger rainfall. The value is set at 30% because the insurer would prefer to pay the full insured amount only when the rainfall values are as minimum as possible. This gives a stop loss value of 26.18mm, which is the value at which the payout maximum limit is reached.

Consider a weather index crop insurance product for an insured amount of 100 currency units, the payout structure can then be represented as;

$$payout \begin{cases} 100 & \text{if } R_A \leq 26.18 \\ 100 \left(\frac{87.26 - R_A}{87.26 - 26.18} \right) & \text{If } 26.18 \leq R_A \leq 87.26 \\ 0 & \text{if } R_A > 87.26 \end{cases}$$

4.5 Determining the distribution of rainfall

The rainfall data is fitted to an appropriate probability distribution for accurate pricing and estimation of the premium rate. The normal, lognormal and gamma distributions were tested using the easy fit software to determine which one provided the best fit to the rainfall data. The software uses the Anderson Darling test to determine the best fit. A further chi square test of goodness of fit was then carried out to determine which of the three distributions provided the best fit. The results of the test are presented in table 3.

Table 3: Anderson Darling Test results at $\alpha=5\%$

<i>Distribution</i>	<i>Observed test</i>	
	<i>statistic A^2</i>	<i>Critical Value</i>
Normal	1.4881	2.5018
Gamma	28.443	2.5018
Lognormal	34.443	2.5018

The Observed test statistics for both the gamma and log-normal distribution are much greater than the critical value of 2.5018 and they are both rejected. However, the normal distribution's test statistic of 1.4881 is less than the critical value of 2.5018 and is therefore accepted as a good fit to the data at a significance level of 5% under the Anderson darling test

Table 4: Chi-Square test at $\alpha=5\%$

<i>Distribution</i>	<i>Observed test</i>	
	<i>statistic</i>	<i>Critical Value</i>
Normal	10.853	14.067
Gamma	29.245	14.067
Lognormal	53.524	14.067

Under the Chi-Square test, the normal distribution is again validated as the best fit to the data as the test statistic of 10.853 is less than the critical value at 14.067 at a 5% significance level. The test statistic values of the Gamma and Lognormal distributions are greater than the critical values and are therefore rejected.

The mean rainfall amount under the normal distribution is determined to be 61.865mm and the standard deviation 85.854mm.

4.6 Calculation of the Premium Amount

Using the payout structure and the fitted normal distribution, the premium amount is then determined. Rainfall values of between 1mm to a maximum of 267mm are generated and the probability of each rainfall amount occurring together with its corresponding payout is then determined. The premium is then calculated by summing the product of the payout and the pdf values for each value of the rainfall. The premium amount is determined to be 24.28 currency units for a sum insured of 100 currency units.

4.7 The impact of climate change

In this section, the study simulates the expected future impact of climate change on the premium amount using a Uniform Climate Change Scenario where the study assumes that precipitation levels shall change uniformly across the region. To get the impact of climate change, precipitation is adjusted to different climate scenarios and the premium amount under these scenarios is then determined.

The results for the impact of climate change under uniform climate scenario are presented in table 5. Uniform change assumes that only one climate variable changes and such change is uniform across the region. The Uniform scenario changes are a decrease in precipitation by 2.5%, 5%, 10%, 15% and 20%. The corresponding mean and standard deviation of rainfall under each rainfall scenario is presented in table

Table 5: Estimated Changes in the mean and standard deviation of rainfall amounts under climate change

<i>Climate Scenario</i>	μ	σ	% change in mean rainfall amount
2.5% decrease in Precipitation	56.0301	35.108	5.83%
5% decrease in precipitation	47.0904	33.069	14.77%
10% decrease in precipitation	30.8035	28.958	31.06%
15% decrease in precipitation	25.9546	32.609	35.91%
20% decrease in precipitation	20.4351	32.205	41.43%

The premium amount under the different climate scenarios is then determined and the results as presented in table 6 indicated a decrease of precipitation amounts will cause a significant rise in the premium amount.

Table 6: Uniform Climate Change Scenarios Impacts on the Premium

<i>Climate Scenario</i>	% change in premium
2.5% decrease in Precipitation	22%
5% decrease in precipitation	53%
10% decrease in precipitation	131%
15% decrease in precipitation	134%
20% decrease in precipitation	150%

5 Summary, Conclusions and Recommendations

5.1 Summary

This study analyzed the effect that climate change will have on the pricing of weather index based crop insurance. The data for this study was based on a period of 15 years (2000-2014). The rainfall data was obtained from the Kenya Meteorological Department. Yield data used in this study was sourced from Tegemeo Institute of Agricultural Policy and Development.

The general objective of this study was to conduct an assessment of the impact that climate change will have on the premiums of weather index crop insurance in Kenya. Five climate scenarios were simulated under a uniform climate change scenario that were used to analyze the effect that climate change will have on the premiums charged on weather index crop insurance. The study assumed a decrease in precipitation at different levels and determined the premium amounts under these climate scenarios.

The results of the study indicate that climate change has a significant effect on the premiums of weather index based crop insurance. The mean rainfall amount will decrease at 31% and 41% when the rainfall amount decreases by only 10% and 20% respectively. A slight decrease in rainfall by 2.5% causes a rise in premiums by 22% while decreases in rainfall at higher levels of 10% and 20% causes a sharp rise in premiums by 131% and 150%. The high levels of premiums will in turn affect the marketability of weather index insurance products and consequently it will be unprofitable for insurers to continue offering them. This results supports findings by Collier, Skees and Barnett (2009), who found that that in regions where weather risk will increase as a result of climate change, insurers will respond by increasing insurance prices and at levels that will be too high for households.

5.2 Conclusion.

In conclusion, it is clear that climate change will have an adverse effect on the pricing of weather index crop insurance. If the products continue being priced relying on historical weather patterns only, Insurers will suffer significant losses. It is therefore important for insurers to consider other pricing approaches and other factors to include when pricing weather index insurance products in Kenya. Given the heavy reliance on rain fed agriculture in Kenya, proper pricing of these products will offer an opportunity for insurers to make profit and for farmers to be protected from losses caused by adverse weather conditions.

5.3 Recommendations and areas of further research

This study recommends that future studies on the effect of climate change on weather index insurance take into consideration a longer time period than the one adopted by this research. Also, increasing the number of regions and number of weather stations studied will benefit future studies. This is because this information will facilitate better analysis and modelling of the effect that climate change will have on weather index based crop insurance. Also, the use of other climate scenarios as generated by the Global Circulation Model for example the Parallel Climate model (PCM) and Coupled General Circulation Model (CGCM), will improve the results of future studies.

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