



**Strathmore**  
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**PRICING OF CLIMATE CHANGE CATASTROPHE BONDS IN KENYA**

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## **ABSTRACT**

Catastrophe bonds have become popular with insurance companies, world over, since their invention in 1996 because of their ability to hedge the insurer against catastrophic risks. With increasing cost and burden on the public budget due to catastrophic disasters in developing countries, a government issued catastrophe bond can be suggested as a timely solution (Mahul & Cummins 2008).

Since the financial impact of drought in Kenya has been regarded as catastrophic over the years, this research sought to find out what the price of a drought linked zero coupon CAT bond issued by the Kenyan government would be. Single trigger zero coupon catastrophe bonds launched on 1st August 2017 and set to have varying maturities of 91 days, 182 days and one year were priced under various contract terms. The underlying trigger chosen was drought, which was defined as rainfall amounts falling below the long term average of 47.90 millimeters.

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### ABBREVIATIONS

CAT Bond- catastrophe bond

LIBOR Rate- London Interbank Offered Rate

SPV- Special Purpose Vehicle

MM- millimeters

Ksh. -Kenya Shillings

## CHAPTER 1

### INTRODUCTION

#### 1.1 Background

Catastrophe bonds are risk linked securities used to transfer a specified set of risks from the issuer to investors. These catastrophes range from natural disasters such as hurricanes, floods, tsunamis and adverse climatic conditions such as drought to man-made disasters such as terrorism and oil disasters. The investors take on the risks of a specified catastrophe occurring in return for attractive rates of investment. Upon occurrence of the qualifying catastrophe, investors lose the principal they invested and the issuer receives the money to cover their losses (Edesedd, 2014).

In the aftermath of Hurricane Andrew and the Northridge earthquake in the mid-1990s, insurance companies in the United States began to look for alternative methods to hedge their risks and catastrophe bonds were born (Carayannopoulos, Kovacs, & Leadbetter, 2003). CAT bonds provide a series of coupon payments and return of capital to an investor, contingent on a trigger event not occurring. The trigger event is defined to be where a measurable quantity related to an underlying insured risk exceeds a predetermined level. This trigger could be based on modeled losses, industry losses or the severity of a natural disaster exceeding a specified limit. The bonds usually have a short term to maturity of three or five years (Haslip & Kaishev, 2010). These bonds therefore became popular with insurance companies as they served as a form of reinsurance in which insurance firms were able to offset financial risks from both the natural and man-made catastrophes (Kish, 2016).

Edesedd(2014) notes that CAT bonds are attractive to investors because they are virtually uncorrelated with the other risks that investors assume such as the risk of equity market fluctuations, credit risk and interest rate risk hence offering an opportunity for diversification. Another attractive feature of catastrophe bonds is that they offer high yields relative to their risk. This is why the CAT bond market has grown rapidly since their introduction twenty years ago with rates of return averaged in the range of 7-9% annually since 2002 (Edesedd, 2014).

Although common with insurance companies, governments have also issued these bonds. The Mexican government, for example, issued a \$160 million CAT bond with a maturity term of three years in 2006 and was the first sovereign to do so. The government's objective in so doing was to transfer earthquake disaster related risks to the capital markets and reduce pressure on the public budget as well as ensure that adequate funds were in place for relief activities (Bank, 2013)

Julius Huho (2010) observes that the severity and frequency of droughts in Kenya has been increasing over time and in the last 100 years Kenya has experienced approximately 30 droughts, three of which have occurred in the last decade. Over the years, these droughts have caused the number of food insecure people to rise from 1.3million to 2.7 million.

In the event of such catastrophic droughts, the Kenyan government usually steps in to offer relief amenities to those badly affected as well as calling for international aid. With a drought linked catastrophe bond in place, perhaps the Kenyan government would be better prepared for such an occurrence in the future.

## **1.2 Problem Statement**

Mahul & Cummins (2008) note that in the event of widespread disasters, developing countries often divert from priority development projects to fund emergency and recovery needs resulting in high opportunity costs for these countries. To counter this, the Kenyan government in cooperation with the World Bank and a number of insurance companies launched the innovative Kenya National Agricultural Insurance Program and The Kenya Livestock Insurance program in 2012. Olivier Mahul, Program Manager of the Disaster Risk Financing and Insurance Program at the World Bank, describes the program as one that introduces a state-of-the-art method of collecting crop yield data, using statistical sampling methods, GPS-tracking devices, and mobile phones and triggers payments once pasture levels are noted to go below a certain level. This program helps the Government of Kenya reduce the financial burden of natural disasters as the government estimates that it spent on average more than Ksh 7 billion per year on disaster relief between 2005-2011(Keziah Muthembwa, 2016).

However, according to Dror (2015), the program has experienced growing pains due to challenges with reaching the targeted clientele who are unfamiliar with the program's benefits. This challenge is common with traditional methods of agricultural insurance which makes them inadequate in mitigating drought related risks.

Therefore, a great financial burden still falls on the government with regard to tackling climate change related disasters since it still has to offer relief to farmers and herders. With a catastrophe bond in place, the government would be in a better position to handle these catastrophes. This research therefore sought to construct a government issued drought linked catastrophe bond in Kenya and assess its benefits to investors.

### **1.3 Research Objectives**

The objectives of this research were:

1. To understand the structure of catastrophe bonds
2. To highlight the benefits of catastrophe bonds to investors
3. To price a drought linked catastrophe bond in Kenya

### **1.4 Research Questions**

This research sought to answer the following questions:

1. What is the structure of a catastrophe bond?
2. What benefits do catastrophe bonds offer investors?
3. How would a drought linked catastrophe bond be priced in Kenya?

### **1.5 Significance of the study**

This research will benefit:

1. The Kenyan government by providing an ex-ante approach to drought related disaster management.
2. Capital market players by providing an alternate tool of investment which offers diversification benefits.
3. Scholars who will understand what CAT bonds are and their use.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Theoretical Framework

##### 2.1.1 Multiple of Expected Loss Model

To best price CAT bond transactions, previous research usually follows either an econometric approach or an empirical approach. The expected loss of the CAT bond is found to be the most economically important factor for predicting the spread premium (Trottier, Lai, & Charest.). Several empirical studies have therefore attempted to identify the most suitable parametric relation between the spread and the expected loss.

The total coupon rate to investors is the LIBOR plus the spread. The LIBOR rate is intended to compensate investors primarily for the holding of their wealth but not for the catastrophe risk and thus the spread is the component of the coupon rate that relates to the event risk of a CAT bond loss. Therefore, the spread is used to generally measure the price of risk transfer of a catastrophe risk and while the spread represents the price of the bond, it does not measure the net cost to the sponsor of the bond (Trottier, Lai, & Charest.).

Bodoff & Gan (2009), observe that practitioners in the CAT bond market often measure, report, and benchmark CAT bond spreads as a “multiple of expected loss.” The model used is as follows:

$$\text{Spread (\%)} = \text{Expected Loss (\%)} * \text{multiple} \quad (1)$$

Where the multiple varies with respect to the expected loss in that when expected loss is large, the multiple is small and when expected loss is small, the multiple is large. An advantage of this model is that it is not too complex and is therefore easily understood by investors. However, Bodoff & Gan (2009) critique the model as a neither complete nor accurate description of spread and identify yet another common model that includes risk in measuring the spread:

$$\text{Spread(\%)} = \text{expectedloss(\%)} + \text{margin(\%)} \text{based on standalonerisk} \quad (2)$$

*Where the standalone risk is the standard deviation.*

However, this model is inefficient for highly skewed distributions which have long tails, such as the distribution of catastrophe losses, because in such cases the standard deviation would be an inaccurate description.

### **2.1.2 Closed form Solution of CAT Bond pricing**

Lin Sun, (2015) model catastrophe events using a closed form pricing model developed by Jarrow (2010) as follows:

$$\begin{aligned}
 B_t = & A(L_{t+k} - \Delta + c) \Delta p(t, t+k) \exp(-\int_t^{t+k} \mu u \, du) + A p(t, t+k) \exp(\int_t^{t+k} \mu u \, du) \\
 & + \int_t^T E_t(Y_s) \mu \exp(-\int_t^s \mu u \, du) p(t, s) \, ds - \int_t^T (A - E_t(Y_s)) p(t, s) \mu \exp(-\int_t^s \mu u \, du) \, ds \\
 & + A(\theta + c) \Delta E_t \left( \sum_{t+k}^T p(t, t+k) \exp(\int_t^u \mu u \, du) \right) \quad (3)
 \end{aligned}$$

The first term in this equation is the discounted value of the next coupon payment with both the floating forward Libor rate and the fixed spread, weighted by the probability of no catastrophe event. The second term is the discounted price of a Libor floating rate note with a face value A of the CAT bond at time (t+k), weighted by the probability of no event during time (t) to (t+k). The third term is the discounted recovery of principal, weighted by the probability of a catastrophe event between time (t) and (t+k). The fourth term is the expected loss after the next coupon, which is the difference between the principal and the recovered portion, weighted by the probability of catastrophe event between time (t+k) and the maturity time T. The last term is the fixed payment after the next coupon, which contains both the shift term and the spread term, weighted by the probability of no catastrophic event.

The advantages of the closed form solution for pricing a catastrophe bond are that it is robust to different term structures. Second, this closed form valuation formula utilizes inputs inspired by historical data, including the likelihood of a catastrophe, the realized loss rate and the initial zero coupon LIBOR bond price curve. This approach makes the valuation formula immune to the calibration inaccuracy of complex models. This model also provides computational ease for both the issuer and the investor (Lin Sun, 2015).

### **2.1.3 Other Pricing Models of CAT Bonds**

Loubergé et al (1999) provide a numerical estimation of the pricing of CAT bonds under the assumptions that the catastrophe loss follows a pure Poisson process, the loss severity is an independently identical lognormal distribution, and the interest rate is driven by a binomial random process.

Lee & Yu (2002), develop a contingent claim model to price a default-risky, catastrophe-linked bond. However, their results are focused on CAT bonds being issued directly by insurers.

An arbitrage pricing approach has been used by Vaugirard (2003) whereby the model accounts for four sources of randomness across states of the world: non-catastrophic natural risk, the occurrence of insured catastrophes, the size of insured losses caused by insured catastrophes, and the uncertainty of interest rates. Assuming that interest rates follow a mean-reverting process, that the risk index follows a Poisson jump diffusion process, and that investors are neutral toward jump risk, Vaugirard (2003) proves that a well-defined arbitrage price exists for contingent claims on the catastrophe risk index.

## **2.2 Empirical Literature**

### **2.2.1 Catastrophe Bond Structure**

CAT bonds belong to a family of index based instruments because the occurrence of the catastrophic event is usually determined based on realizations of a specified stochastic variable. A CAT bond purchaser typically agrees to forfeit a portion of all the expected financial payments from the bond in the event that the index exceeds a pre-specified threshold (Cummins, 2008).

CAT bonds are usually issued for a short time for example a year to three years. A CAT bond transaction begins with an insurer/reinsurer (also known as a sponsor) establishing a Special Purpose Vehicle (SPV) that issues the bond on behalf of the sponsor to investors in order to separate the legal and financial liabilities of an insurance firm from the liabilities associated with the bonds. The SPV provides coverage for risks of specific assets and receives a premium from the sponsor (Lakdawalla & Zanjani, 2012).

The SPV then sets the terms of the bond by defining the trigger event, maturity period and the coupon rate. With these terms in place, the SPV then issues the bond to investors. The principal

received from investors in exchange for the bond is then deposited in a collateral account and along with the periodic premiums received from the sponsor; these funds are reinvested in low risk securities. Kish (2016) notes that the underlying firms invest these collateral funds in low risk investments such as highly rated money market funds in order to maximize returns to the underlying firm.

Until late 2008, it was common to protect the collateral against interest rate risk and impairment through a total return swap (TRS) whereby in exchange for (fixed) coupons and value gains of the trust account assets, the swap counterparty provided a floating rate payment minus the TRS spread and covered potential value losses. However, the default of the investment bank Lehman Brothers, which acted as swap counterparty in four transactions, led to a post crisis CAT bond structure that refrains from utilizing a TRS altogether (Braun, 2016).

The investors' coupons are made up of the interest that the SPV makes from the collateral and the premiums the sponsor pays, which make the CAT bond a safe investment. The investors receive the London Interbank Offered Rate (LIBOR) plus the risk premium in return for providing capital to the trust (Cummins, 2008).

On the occurrence of an event that meets the trigger conditions, the SPV liquidates the assets in the collateral account to reimburse the sponsor, who uses the money to pay for the claims arising from the event. An investor faces the risk of losing out their principal amount, depending on the size of the event, to the SPV. If the contingent event does not occur, however, the SPV will liquidate the assets in the collateral account to pay back the principal to the investor at the maturity date of the CAT bond (Vedenov et al., 2006)

Vedenov et al. (2006) notes that assuming a zero-coupon CAT Bond is issued at time zero,  $t = 0$ , with a face value  $F$  and time to maturity  $T$ , then the payoff  $V_T$  of the bond is conditional on realization of a certain index  $L$  relative to the predetermined trigger value  $D$  such that:

$$VT = \begin{cases} A * F & \text{if } L > D \\ F & \text{if } L \leq D \end{cases} \quad (4)$$

Where  $0 < A < 1$  is the proportion of the face value repaid to an investor.

### 2.2.2 Types of triggers for Catastrophe Bonds

According to Kish(2016), the Financial Industry Regulatory Authority (FINRA) outlines the five key catastrophe trigger descriptions as: parametric, modeled loss, industry loss index, indemnity and hybrid.

A parametric bond is the most transparent and easiest to verify of the triggers as it is triggered if specific, objective “parameters” are met for example, ground acceleration for an earthquake-linked bond. It usually pays a lower yield than bonds with other trigger types, as it may not cover all of the sponsor’s losses (Kish, 2016).

For modeled loss, catastrophe models are used to calculate the total losses using input values from actual events. The bond is triggered if the sponsor’s exposure exceeds a specified dollar amount. It allows for faster verification and if the computer program is good, then the estimates are regarded as reliable (Braun, 2016)

Within the industry-loss index, a bond is triggered when the amount of the overall industry loss from an event, usually determined by an independent third party, exceeds a certain amount. There is minimal potential for a sponsor to influence the bond’s performance, as the index is based on industry-wide losses for each event(Smyth, 2016).

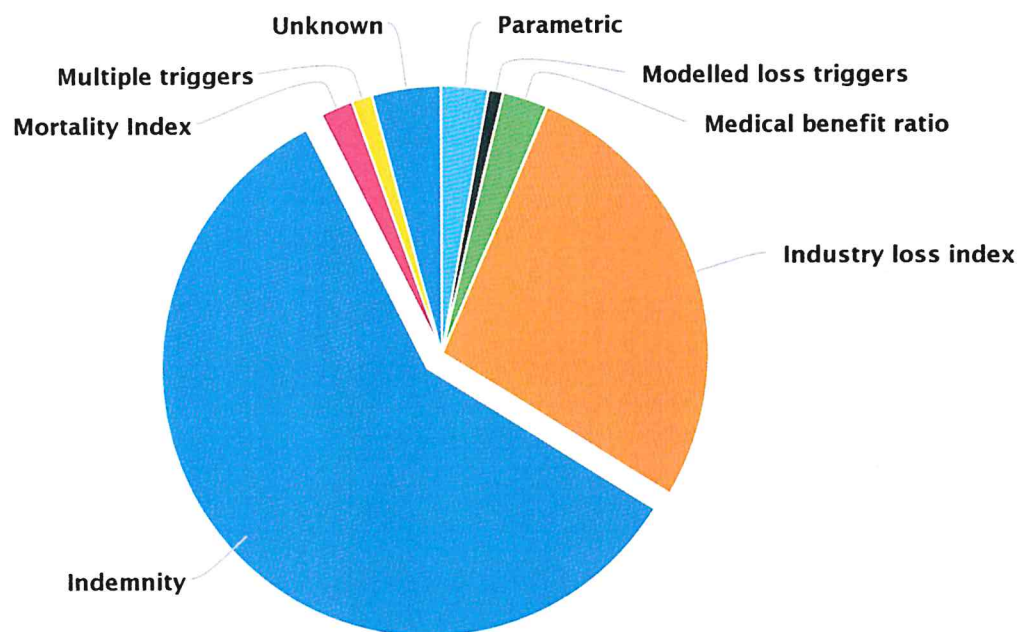
An indemnity trigger is effected when the sponsor’s actual underwritten loss on specific insurance policies exceeds a predetermined amount. It typically pays the highest yield of the different trigger types, as it provides the best protection to the sponsor, but presents the most potential for the sponsor to influence bond performance, as payouts are based on the individual policy claims against the sponsor and the way the sponsor settles those claims(Linnerooth-Bayer,

Mechler, & Hochrainer-Stigler, 2011).Cabrera (2006) points out that this type of catastrophe trigger bond increases the sponsor’s moral hazard risk.

A hybrid trigger bond combines one or more trigger to form a hybrid trigger bond. However, it can be complicated and difficult to quantify or verify to investors(Loubergé et al., 1999).

The figure below shows the contribution of each trigger to the total outstanding CAT bonds as at June 2017:

Catastrophe bond & ILS risk capital outstanding by trigger type



Source: [www.Artemis.bm](http://www.Artemis.bm) Deal Directory

**Figure 1: Outstanding CAT bonds by trigger**

Source: [www.Artemis.bm](http://www.Artemis.bm)

**2.2.3 Catastrophe Bonds and the investor**

Large investors such as hedge funds, money managers, insurers, reinsurers and banks often have large amounts of funds at their disposal. Their investment patterns are often targeted at achieving high returns as well as meeting and at times matching their liquidity requirements. They build investment portfolios rather than investing in a single financial instrument. An investment portfolio is a collection of different financial instruments.

There are many types of financial instruments to invest in ranging from money market instruments, fixed income instruments, to derivative instruments. The purpose of building an investment portfolio is to diversify specific risks. The total risk of a portfolio is measured using the variance or standard deviation of the return on the portfolio (Markowitz, 1952).

According to Litzenberger et al., (1996) catastrophe bonds are often said to be zero beta investments. Beta is the measure of the volatility of a security in relation to the market as a whole. The structure of CAT bonds attempts to isolate investors from market related risks and expose them only to event risk. This means that with a catastrophe bond in their portfolio, an investor diversifies market risk. As a result, these securities are considered to be a valuable new source of diversification for investors.

Bantwal&Kunreuther (2000) illustrate the benefits of CAT bonds to potential investors using simulations. They support the claim that CAT bonds offer a unique opportunity to enhance portfolios since they provide a high-yielding return that is uncorrelated with the market.

Perez & Carayannopoulos (2013), observe that the spreads on investment linked securities (ILS), of which CAT bonds are a subset, are considerably higher than the spreads for corporate bonds of the same grade.

Barrieu & Louberge (2009) support earlier findings that the CAT bond market offers benefits through diversification and high returns, but the main focus of their research is on explaining why the CAT bond market remains small. They argue for the introduction of a hybrid CAT bond tied to protection against a stock market crash to add appeal and hopefully expand the CAT bond market sector.

Hagendorff et al. (2014) finds that the issuers of CAT bonds are usually less likely to exhibit risky underwriting and this trait allows them easier access into the financial markets as they have a better reputation with investors. They however warn investors that this easy access could lead to risky behavior in the future especially for an indemnity triggered catastrophe bond.

### 2.2.4 Pricing a Zero Coupon CAT Bond

Vedenov et al. (2006) notes that a catastrophe bond is valued by taking the discounted expectation of its possible payoffs under the derived distribution of the realized losses of the triggering variable and the required rate of return on investments. The formula for pricing a CAT bond with maturity T is then given as:

$$V = E(\theta, \rho) [V_T * e^{-\int r(t) dt}] \quad (5)$$

Where  $V_T$  is the payoff of a CAT bond,  $r(t)$  is the appropriate interest used to discount future cash flows, and  $E(\theta, \rho)$  indicates expectations with respect to two state variables. It is reasonable to assume that the state variable  $\theta$ , which for the valuing of catastrophe bonds essentially encompasses the term structure of interest is independent of the state variable  $\rho$ , which pertains to catastrophe risk. Under this assumption, the CAT bond price becomes:

$$V = E(\rho) V_T * E(\theta) e^{-\int r(t) dt} \quad (6)$$

Where the first term is the expected payoff of the CAT bond and the second is the expected value of a conventional zero coupon bonds.

To obtain an analytical pricing formula for a conventional coupon bond, a constant interest rate  $r(t) = r$  is assumed and then the solution  $B(0, T)$  is found by discounting the face value of the bond at the discount rate for the time period (T) as follows:

$$E(\theta) e^{-\int r dt} = B(0, T) = \exp(-RT) \quad (7)$$

Using equation (4), the expected payoff of the CAT bond can be written as:

$$E(\rho) V_T = F * \Pr(L \leq D) + A * F * \Pr(L > D)$$

Thus, the general pricing formula for zero coupon CAT bonds can be given by

$$V = B(0, T) * (F * \Pr(L \leq D) + A * F * \Pr(L > D)) \quad (8)$$

Thus the price of the zero coupons CAT bond can be represented as the product of a conventional zero-coupon bond and the expected payoff from the CAT modeled bond.

This pricing model assumes that the financial market is liquid and that there are no arbitrage opportunities.

### 2.3 Conceptual Framework

The independent variable in this study will be the government issuing a drought-linked CAT Bond while the dependent variable will be the availability of assets to liquidate in the event a drought occurs.

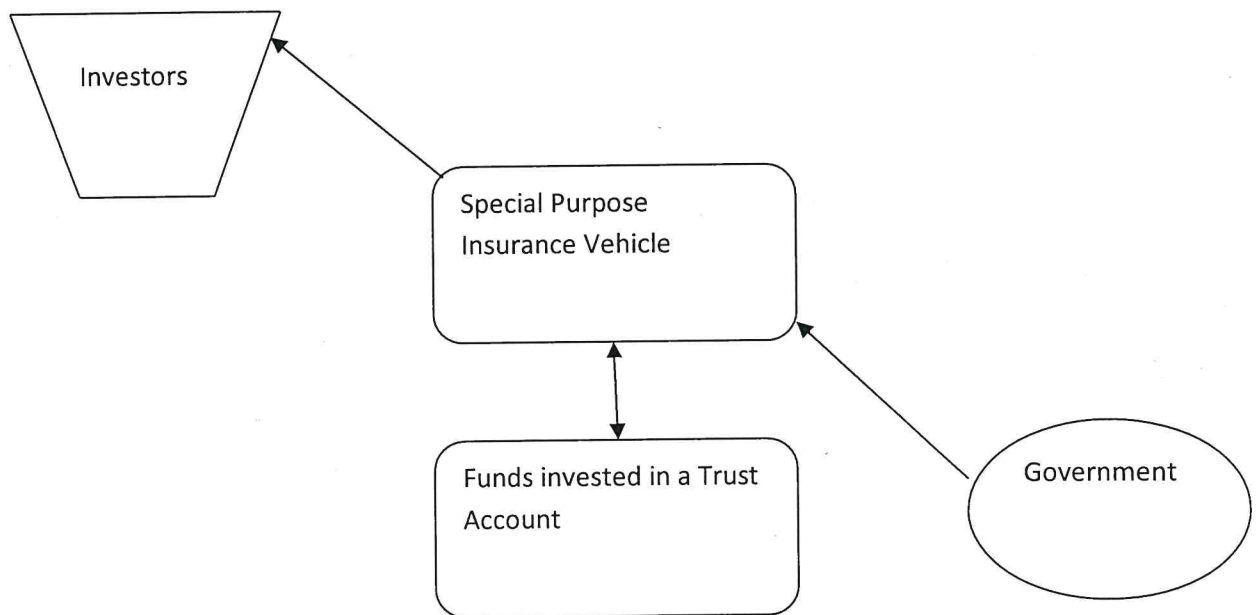


Figure 2: Conceptual framework

## **CHAPTER THREE**

### **RESEARCH METHODOLOGY**

#### **3.1 Research Design**

This study was exploratory in nature as it aimed at investigating the efficiency of CAT bonds in managing catastrophic risks in agriculture.

This study was also quantitative as it incorporated numerical inputs in calculating the price of a drought-linked catastrophe bond.

The study was also cross-sectional since it took place over a short period of time and data was only collected once.

#### **3.2 Population**

The target population was all the historical rainfall amount data available in all the 47 counties in Kenya.

#### **3.3 Sample**

The sample considered was monthly rainfall data from Narok County for a period of 16 years from 2000-2015. A random sampling method was used to select Narok County from the 47 counties in Kenya. Narok is one of the most agricultural dependent counties in Kenya with its wheat production being the highest in East Africa.

#### **3.4 Data Collection**

Secondary data collected from the Kenya Meteorological Department was used in this study. The Kenya Meteorological Department aims at facilitating accessible climatic information so as to foster socio-economic growth and development.

#### **3.5 Data Validity**

The data that was used for this study was be reliable because it was collected from the Kenya Meteorological Department, which is an accredited government data collection body with historical records of climate data.

### 3.6 Methodological Approach

A zero coupon drought linked catastrophe bond was analyzed. This type of bond is in the category of parametric trigger bonds.

Vedenov et al. (2006) and Lin Sun (2015) show that pricing of a drought linked catastrophe bond involves the following steps:

- a) Determining the probability distribution that the historical monthly rainfall data follows and thus the probabilities of triggering the bond. To estimate the underlying probability distribution, non-parametric techniques such as the Kernel density estimation were used. The probability distribution used to fit the rainfall data is commonly accepted in hydrological literature.
- b) Incorporating the estimated probabilities and the required rate of return into the bond contract price.

Prices of CAT bonds were calculated using the pricing formula:

$$V = B(0, T) * (F * \Pr(L \leq D) + A * F * \Pr(L > D)) \quad (8)$$

## CHAPTER FOUR

### FINDINGS AND DISCUSSIONS

#### 4.1 Data

The historical precipitation data for Narok County was obtained from the Kenya Meteorological Department. Interest rate data was retrieved from the Central Bank of Kenya. The data was analyzed using Microsoft Excel as well as R programming.

Following the approach of Vedenov et al. (2006), the distribution of the underlying index was first obtained and then fit into the pricing formula:

$$V = B(0, T) * (F * \Pr(L \leq D) + A * F * \Pr(L > D)) \quad (8)$$

##### 4.1.1 Rainfall Data

The monthly precipitation data for Narok County for the years 2000-2015 was analyzed in order to obtain statistics that would aid in identifying the underlying distribution of the data. The total number of observations was 191.

As shown in Figure 2 below, the months that receive the highest amounts of rainfall are March, April and May. This is the long-rain season in Kenya. The short rain season falls in October, November and December. These months are also observed to have a high amount of rainfall within the data set. The driest months in Narok County fall between June and October.

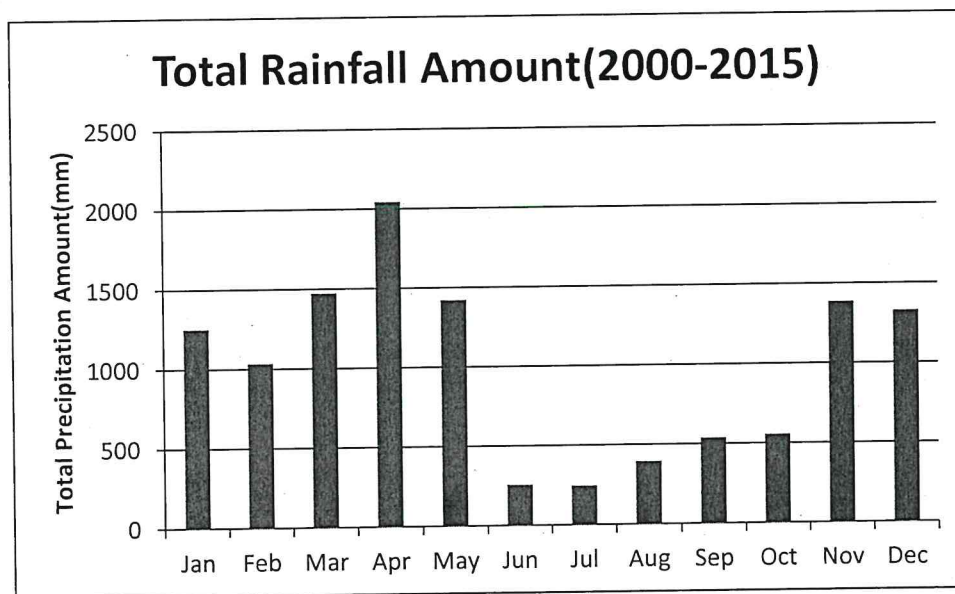


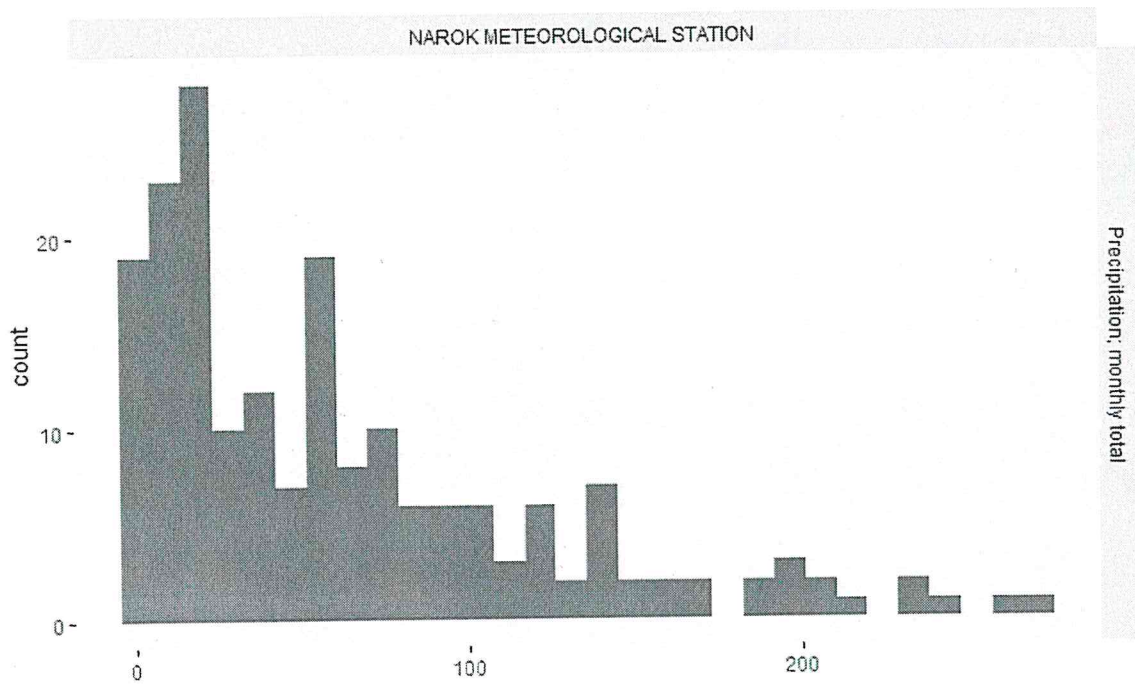
Figure 3: Frequency distribution of rainfall amounts

**Table 1: Descriptive Statistics for each month**

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Monthly average	78.24	64.7	92.1	127.8	88.87	15.99	15.4	24.7	33.7	34.8	86.69	88.62
Standard Deviation	63.48	35.28	48.38	74.39	65.64	16.66	13.2	21.1	27.6	35.5	76.78	65.37
Minimum	0	0	17.1	11.8	7.8	0	0	0	3.6	0	12.7	1.6
Maximum	232.9	143.2	201.3	246	261.4	49.2	51.5	79.3	89.3	144	271	198.5
Skewness	1.02	0.215	0.426	0.149	1.155	0.764	1.26	1.32	0.76	2.02	1.156	0.359
Kurtosis	0.9	0.632	0.209	-1.07	1.889	-1.01	2.5	1.7	-0.8	5.43	0.535	-1.1

The descriptive statistics in the above table show that rainfall amounts are highest within the long rain season with the highest averages, standard deviation and maximum amounts falling within this period.

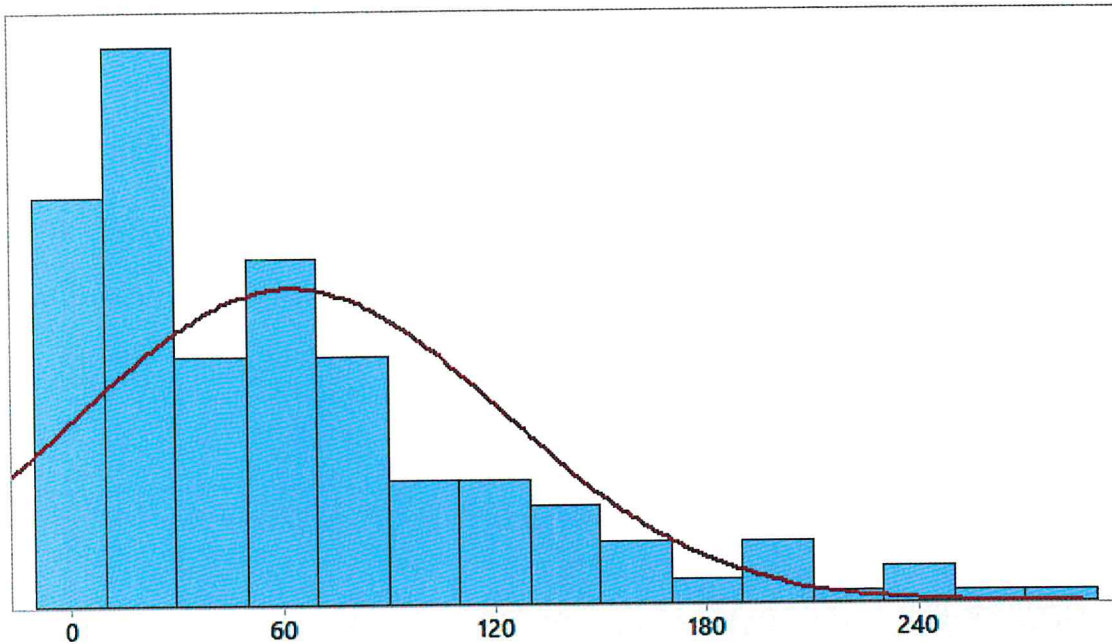
To give a visual representation of the data, a histogram was used. According Cabrera (2006), a histogram is a Kernel density estimation used to smooth frequencies within the data hence accurately reflecting the distribution of the underlying variable.



**Figure 4: Histogram of the data**

The monthly rainfall data was found to follow a normal distribution under the following statistics:

N	N*	Mean	Standard Deviation	Median	Minimum	Maximum	Skewness	Kurtosis
191	0	62.4991	60.2362	47.9	0	271	1.31856	1.32020



**Figure 5: Figure showing data follows a normal distribution**

The Maximum Likelihood Estimates for the distribution were:

Distribution	Location	Shape	Scale
Normal*	62.49911		60.23615

\* Scale: Adjusted ML estimate

In order to price the drought linked catastrophe bond for Narok County, the underlying trigger was drought. Drought was defined as the probability of the rainfall amounts falling below the long term average. Most rainfall amounts were observed to fall between 0 and the median, hence the 1st quartile was used as the long-term average. To trigger the bond, the rainfall amount would have to fall below this long-term average. Using the data, the probability of rainfall amounts falling below the 1st quartile was calculated as 0.1070112(10.7%).

Correlation between the data was observed to be low and hence the monthly data was assumed to be independent.

#### 4.1.2 Interest Rate Data

Interest rate data for 91 day, 182 day and 364 day Treasury bills and bonds was retrieved from the Central Bank of Kenya. The data contained monthly interest rates from the year 2005 to August 2017. Since the commencement date of the catastrophe bond was set as August 2017, the given interest rate of 10.9%, 10.32% and 8.17% for the 91 day, 182 day and 364 day respectively was used to discount the bond's payoff.

#### 4.2 Pricing the bond

For the baseline model, the zero coupons CAT bond was assumed to have been issued on August 1, 2017 with varying maturity periods of 91 days, 182 days and one year. The face value of the CAT bond was assumed to be Ksh. 50,000 while the probability of drought was calculated as 0.1070112(10.7%). The proportion of the face value to be paid back on maturity, A, was set as 0, 0.3 and 0.5.

After modeling the monthly rainfall data and estimating the probability of falling below the long-term mean, the expected payoff of the CAT bond was calculated as follows:

$$V_T = \begin{aligned} & \text{(The face value of the CAT bond} \times \text{Probability that there is no drought)} \\ & + \text{(Proportion of the face value} \times \text{The probability that there is drought)} \end{aligned}$$

The price of the catastrophe bond was then found by discounting expected payoff using the 91 day, 182 day and 364 day risk free rate of interest, as follows:

$$V_0 = E_Q[\text{Payoff}]e^{-rT}$$

The price of the CAT bond, in the different scenarios was observed to be:

Proportion of Face Value	Maturity(years)	Payoff of bond	Price of bond	Realized Return (%)
0	0.25	44,649.44	43,747.34	14
0.3		46,254.61	45,320.08	10
0.5		47,324.72	46,368.57	8

**Figure 6: Price of 91 day CAT bond**

Proportion of Face Value	Maturity(years)	Payoff of bond	Price of bond	Realized Return (%)
0	0.5	44,649.44	42,405.46	18
0.3		46,254.61	43,929.96	14
0.5		47,324.72	44,946.29	11

**Figure 7: Price of 182 day CAT bond**

Proportion of Face Value	Maturity(years)	Payoff of bond	Price of bond	Realized Return (%)
0	1	44,649.44	40,038.51	25
0.3		46,254.61	41,477.91	21
0.5		47,324.72	42,437.52	18

**Figure 8: Price of one year CAT bond**

### 4.3 Discussions

In the three different scenarios, the price of the bond is observed to be lowest when the proportion of the face value, A, to be repaid is zero. This follows from finance theory since the price should be lowest when the risk of no repayment is higher.

The price of the bond increases as the proportion to be repaid increases. This means that when the contract terms offer a higher proportion of the face value on maturity in case drought is triggered, then the risk of losing out on a large amount is reduced thereby the bond is offered for a higher price.

The price of the bond decreases as the term to maturity increases. This is because with a longer term to maturity, the investor would be exposed to the risk of the risk of the bond being triggered for a longer period.

## **CHAPTER 5**

### **CONCLUSIONS AND RECOMMENDATIONS**

#### **5.1 Summary and Conclusions**

The study found that, given the structure of a CAT bond, the price seemed to be higher with a higher recovery rate. For a recovery rate of 0.5 of the face value and a term to maturity of one year, the price was calculated as Ksh. 42,437.52. Under the same contract terms, but with a recovery rate of 0.3, the price of the CAT bond was Ksh. 46,254.61. Where the contract terms dictate that the proportion of the face value repaid will be 0, then the price was lowest at Ksh. 40,038.51.

A zero coupon catastrophe bond is issued at a discounted price, offers no interest within the term of the bond and is recouped at the face value. If an investor purchases the bond at the lowest price at Ksh. 40,038.51, and rainfall amounts do not fall below the trigger amount of 47.9mm, then the investor receives the full face value amount of Ksh. 50,000. This scenario gives an investor the highest realized return of 25%. This is the highest realized return of the three scenarios considered in this study. The underlying risk, however, is that the investor stands to lose out on his entire investment if the bond is triggered within the term of the contract.

The choice of investment would depend on the risk appetite of the investor. A risk-averse investor would choose the bond with the shortest term and a high recovery rate despite it giving the lowest realized return of 8%. A risk-seeking investor would choose the contract terms that offer the highest realized return of 25%, the high risk within the bond notwithstanding. A risk neutral investor would be indifferent towards the choices.

#### **5.2 Recommendations**

A government issued catastrophe bond would go a long way in helping mitigate drought related disasters. The study recommends that a drought linked catastrophe bond be considered as a mode of transferring the financial risks brought about by drought to the capital markets. This would help the government be better equipped to offer emergency relief in case drought occurs.

Traditional methods of agricultural insurance should also be improved so as to offer adequate compensation in the case of drought. Additionally, the government could increase efforts to

ensure that people living in agricultural dependent areas take up agricultural insurance in order to lessen the burden of drought related relief efforts.

### **5.3 Limitations to the study**

The study considered historical rainfall amounts for a period of 16 years. This was a limited amount of data and perhaps with a longer period, more accurate prices could be derived.

The study also only considered one county, Narok County, and therefore the price cannot be extended to other agriculture dependent counties. The weather patterns of the other counties would have to be considered before pricing a drought linked catastrophe bond in these locations.

### **5.4 Suggestions for further research**

This study considered a single trigger catastrophe bond. The trigger was the probability of the rainfall amounts falling below the long-term average before the maturity of the bond. Another study could be carried out to determine what the price would be for a multi-trigger catastrophe bond with different trigger amounts considered.

Another study could also be carried out to determine if, given the underlying risks of the bond, investors would consider the bond an attractive investment and therefore be willing to buy the bond.

## REFERENCES

- Bank, t. W. (2013). *Mexico MultiCat Bond*. Retrieved from The World Bank: <https://www.gfdrr.org>
- Bantwal, V, & Kunreuther, H. (2000). A CAT bond premium puzzle. *Journal of Psychology and Financial Market, 1*, 76-91.
- Barrieu, P., & Louberge, H. (2009). Hybrid CAT bonds. *Journal of Risk and Insurance, 76*, 547-578.
- Bodoff, N. M., & Gan, Y. (2009). An analysis of the market price of cat bonds. In *CAS E-Forum*.
- Braun, A. (2016). Pricing in the Primary Market for Cat Bonds: New Empirical Evidence: Pricing in the Primary Market for Cat Bonds. *Journal of Risk and Insurance, 83*(4), 811–847.
- Cabrera, B. L. (2006). Pricing catastrophic bonds for earthquakes in Mexico. *Journal of Risk and Insurance, 350-402*.
- Carayannopoulos, P., Kovacs, P., & Leadbetter, D. (2003). Catastrophic event exposure and the role of insurance linked securities in addressing risk. *Institute of Catastrophic Loss Reduction, 603-712*.
- Cummins, J. D. (2008). CAT Bonds and Other Risk-Linked Securities: State of the Market and Recent Developments. *Risk Management and Insurance Review, 11*(1), 23–47.
- Dror, I. (2015). Capacity Development in the index-based Livestock Insurance Project. *ILRI Capacity Development*.
- Edesedd, M. (2014). Catastrophe Bonds: An Important New Financial Instrument. *Journal of Risk and Insurance, 300-347*.
- Hagendorff, B., Hagendorff, J., Keasey, K., & Gonzalez, A. (2014). The risk implications of insurance securitization: The case of catastrophe bonds. *Journal of Corporate Finance, 387-402*.
- Haslip, G., & Kaishev, V. (2010). Pricing of Reinsurance Contracts in the presence of CAT bonds. *Journal of International Actuarial Association*.
- Jarrow, R.A. (2010). A simple robust model for cat bond valuation. *Finance Research Letters, Vol. 7*, pp. 72-79.
- Julius Huho, E. M. (2010). The Effects of Droughts on Food Security in Kenya. *The International Journal of climate change, 62-64*.
- Keziah Muthembwa, R. P. (2016, March 12). *Kenya Farmers to Benefit from Innovative Insurance Program*. Retrieved from The World Bank: [www.worldbank.org/en/news/press-release](http://www.worldbank.org/en/news/press-release)
- Kish, R. J. (2016). Catastrophe (CAT) bonds: Risk offsets with diversification and high returns. *Financial Services Review, 25*(3).

- Lin Sun, C. G. (2015). Designing catastrophic bonds for catastrophic risks in agriculture. *Cornell University*, 48-50.
- Mahul, O., & Cummins, J. D. (2008). *Catastrophe Risk Financing in Developing Countries*. World Bank.
- Lakdawalla, D., & Zanjani, G. (2012). Catastrophe Bonds, Reinsurance, and the Optimal Collateralization of Risk Transfer. *Journal of Risk and Insurance*, 79(2), 449–476.
- Lee, J. and YU, M. (2002) Pricing Default-Risky CAT Bonds with Moral Hazard and Basis Risk. *The Journal of Risk and Insurance* 69(1), 25-44.
- Linnerooth-Bayer, J., Mechler, R., & Hochrainer-Stigler, S. (2011). Insurance against losses from natural disasters in developing countries: evidence, gaps and the way forward. *Journal of Integrated Disaster Risk Management*, 1(1).
- Litzenberger, R. H., D. R. Beaglehole, and C. E. Reynolds (1996). Assessing Catastrophe Reinsurance-Linked Securities as a New Asset Class. *Journal of Portfolio Management* 23, 76-86.
- Loubergé, H., Kellezi, E., & Gilli, M. (1999). Using catastrophe-linked securities to diversify insurance risk: A financial analysis of CAT bonds. *Journal of Insurance Issues*, 125–146.
- Markowitz, H. (1952). Portfolio selection. *The Journal of Finance*, 7(1), 77–91.
- Perez, M. F., & Carayannopoulos, P. (2013). Diversification Through Catastrophe Bonds: Lessons from the Subprime Financial Crisis
- Smyth, S. E. (2016). How Capital Markets Can Help Developing Countries Manage Climate Risk.
- Trottier, D.-A., Lai, V. S., & Charest, A.-S. (n.d.). Cat Bond Spreads: A New Model with an Empirical Validation Using Nonparametric Tests.
- Vaugirard, Victor E. 2003. Pricing catastrophe bonds by an arbitrage approach. *The Quarterly Review of Economics and Finance*, 43(1), 119-132.
- Vedenov, D. V., Epperson, J. E., & Barnett, B. J. (2006). Designing catastrophe bonds to securitize systemic risks in agriculture: the case of Georgia cotton. *Journal of Agricultural and Resource Economics*, 318–338.