WEATHER DERIVATIVES and PRICING APPROACHES
HAVA (İKLİM) TÜREVLERİ VE FİYATLAMA YAKLAŞIMLARI

"Everbody talks about the weather
but nobody does anything about it"
Mark Twain (1897)∴

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Özet: Bugün itibarı ile 50 Milyar USD'yi aşan bir işlem hacmine sahip olan hava türevlerinin kullanımına 1996'da başlanmış ve ilk kez 1997'de ticarete konu olmuşlardır. Söz konusu ürünler, mal ve kar kaybına yol açan iklimsel risklerden ve mevsimsel değişikliklerden bireylerin ve kurumların korunabilmesi amacıyla oluşturulmuşlardır. Sıcaklık, don, fırtına vb. hava değişkenlerini temel alan bu ürünler genel olarak Isıtma ve Soğutma Derece Günleri'ni göz önünde bulundurarak değerlenmişlerdir. Ancak, bu ürünlerin fiyatlanması konusunda günümüze kadar birçok yaklaşım öne sürülmekle birlikte bir uzlaşı sağlanamamış ve bu bir problem olarak süregelmiştir. Bu makalede ilk olarak önceki çalışmalarda ortaya konulan yaklaşımların bir bütün olarak ele alınarak sunulması hedeflenmiş, akabinde yaklaşımların değerlendirilmesi ile uygulanabilirlik bakımından en uygun iki yaklaşımın Monte Carlo Simülasyonu ve Burn Analizi olduğu sonucuna ulaşılmıştır.

Anahtar Kelimeler: Hava türevleri, Isıtma ve Soğutma derece günleri, Hava sigortaları, Monte Carlo simülasyonu, Burn analizi

Abstract: The usage of weather derivatives which have a volume exceeding 50 billion USD today, began in 1996 and they were subject to trade first time in 1997. The products that are in question are created in order to protect the individuals and the institutions from climatic risks and seasonal changes which cause commodity and profit loss. These products baselined from weather variables such as heat, frost, storm and hurricane are valued generally by considering the Heating Degree Days and Cooling Degree Days. On the other hand, there has not been any compromise on the pricing of these products until today, although there are lots of approaches that were put forward and so the pricing is still . On the other hand, there has not been any compromise on the pricing of these products until today, although there are lots of approaches that were put forward and so the pricing is still a problem today. In this paper, first of all it is aimed to present the approaches that were put forward in the previous studies as a whole, and then by evaluating these approaches it is concluded that in terms of applicability the most appropriate two approaches are Monte Carlo Simulation and Burn Analysis.

Key Words: Weather derivatives, Heating and Cooling degree days, Weather insurances, Monte Carlo Simulation, Burn Analysis

∴ Warner, Charles Dudley (1897), *Hartford* (Connecticut) *Courant,* August 27, 1897, p. 8.

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I. Introduction

This paper will discuss the fundamentals of pricing and analyzing the weather contracts and its' derivatives. Weather derivatives are financial instruments that are used by organizations as a risk management strategy to reduce risk associated with diverse weather conditions. The weather risk management market is growing rapidly as the methods used to hedge and trade the weather derivatives. It evolved into tools, which address new types of risk and attempt to mitigate the effects of a changing climate. It is distinct with other derivatives as the underlying asset has no direct value to price the weather derivatives.

The weather derivative started trading in 1996 when Aquila Energy (Considine, 1998) structured a dual-commodity hedge for Consolidated Edison Co. A year later, weather derivatives began trading over the counter as the market of the new product was launched into the market by the Chicago Mercantile Exchange (CME). The launch of the CME has seen tremendous increase in the use of its products as its product has began to secure a place in the financial market. The traders are using the products to help predict the future where prices of natural gas are unknown, and also aimed at assisting and steering the market direction and evolution.

The users of these products include the farmer who uses it to hedge against poor harvest due to drought; power companies who use Heating Degree Days[1] (HDDs) contracts to smooth earnings; and sporting event companies who may use it to hedge against the vagaries of weather. The CME is introducing the weather contracts electronically in order to increase the size of the market and reducing the effect of credit risk in the trading of weather contract. The CME weather products were the first standardized weather futures and options on the exchange and are traded publicly.The CME today offers a total of 47 cities which are listed on the exchange for trading (Table 1).

Despite the interest caused by the weather derivatives, their development is significantly rapid. This is caused by the departure of the main actor in the industry such as, Enron, Aquila and El Paso. Thus lowering the number of transactions, distrust of investors for the weather product that seems

[1] Heating Degree Day (HDD) and Cooling Degree Day (CDD): HDD is a measurement designed to reflect the demand for energy needed to heat a home or business. It is derived from measurements of outside air temperature. The heating requirements for a given structure at a specific location are considered to be directly proportional to the number of HDD at that location. A similar measurement, CDD, reflects the amount of energy used to cool a home or business. for historical reasons HDD are often made available with base temperatures of 18.3°C (65°F), or 15.5°C (60°F) - base temperatures.
To convert °F HDD to °C HDD: °C HDD = (5/9) x (°F HDD)
To convert °C HDD to °F HDD: °F HDD = (9/5) x (°C HDD)
HDD are relative to a base temperature (as opposed to being relative to zero), it is incorrect to add or subtract 32 when converting degree days from Celsius to Fahrenheit or vice versa.

risky, and limiting the participants to energy companies, which do not promote the liquidity of the market. Apparently, evaluation of the weather derivative tends to fix a high bonus to compensate for the difficult exercise of valuation thus hindering climate market expansion.

The non-negotiability on the market of the meteorological index compromises with the use of the traditional methods of valuing weather derivatives such as the Black and Scholes (1973: 637-654) making it difficult to price weather derivatives.

Table 1: *Current Cities Available for Trading*

24 US Cities		6 Canadian Cities	11 European Cities	3 Australian Cities	3 Japanese Cities
Atlanta	Las Vegas	Calgary	Amsterdam	Bankstown,	Hiroshima
Baltimore	Little Rock	Edmonton	Barcelona	Sydney	Osaka
Boston	Los Angeles	Montreal	Berlin	Brisbane	Tokyo
Chicago	Minneapolis	Toronto	Essen	Aero	
Cincinnati	New York	Vancouver	London	Melbourne	
Colorado Springs	Philadelphia	Winnipeg	Madrid	Regional	
Dallas	Portland		Oslo-Blindern		
Des Moines	Raleigh Durham		Paris		
Detroit	Sacramento		Prague		
Houston	Salt Lake City		Rome		
Jacksonville	Tucson		Stockholm		
Kansas City	Washington,DC				

Source: *The Weather Derivatives Markets at CME Group: A Brief History, p.2.*

II. The Birth and Today of Weather Derivatives

Weather derivative was first started in US in 1997 during the El-Nino[*], a catastrophe that attracted huge public outcry. These necessitated companies to hedge their seasonal risk caused by a risk in a drop in their earnings and funds have become a sophisticated partner in providing this protection. After that, weather derivatives markets have expanded quickly and it started trading on the counter as individuals' negotiated contracts. These growths in the use of derivatives has over the past few years moving from primarily fund of funds investment in weather risk, to more direct investment for investors looking for non-correlated items for their portfolio. The birth of weather derivative is also attributed to the convergence of capital market with the insurance markets and is growing due to catastrophic bond and options in the market. People have stopped blaming weather on their low earnings and realize the need to hedge

[*] El-Nino is a periodic warming of the tropical Pacific ocean which affects weather around the world. Typical consequences of El Nino include increased rainfall in the southern US and drought in the western Pacific. Winter temperatures in the north-central US states are typically higher than normal in El Nino years, and lower than normal in the south-east and south-west of the country (Alaton, Djehiche and Stellberger, 2002: 2).

their business against catastrophes' and growth of weather derivative is a logic extension of this.

The weather derivative has grown tremendously although it is not very liquid; it seems that many companies have not yet firmly established a hedging policy or their exposure to risk. Insurance was the only tool used by companies for protection against the adverse effect of weather on their operations. The problem with insurance is that it does not protect against the reduced demand that business experience as a result of weather that is unexpected; this has enhanced the growth of weather derivatives.

Currently, the European market is not established as the US market and signs of future growth are big. This is attributed to existence of standardized contracts aimed at increasing the size of weather derivative market. The European's energy industry is not fully deregulated and as this deregulation spreads out, the volume in the weather deals traded s expected to increase thereby, increasing the liquidity of the market and encouraging new actors in the industry.

However, barriers to growth should be removed for instance; ensuring that the quality of the weather is good so that the companies can rely to when pricing derivatives. The cost and quality of weather data varies considerably across Europe and companies needs to analyze their performance against historical weather data from the meteorological department; this should be reduced as it is very expensive.

III. Market Participants

The advantages of the weather derivative products are increasingly known to many and the momentum is expected to continue to increase. The effect of weather affects almost every individual and business world-wide. The main users of the weather derivatives products includes; farmers who require the products to protect themselves against poor harvest; utilities and energy related business, which has to hedge their business against lower sales during warm winter or cool summer; the ski resort who depend on cold weather to stay in business require the products to protect their business against the possibility drop in earnings during warm winter. They can sell the contract during warm winter at their level of their choice and buy back the contracts at lower price and use the profit to offset the losses; a home improvement company who depend on spring and summer to run their business, knows that during cool weather there will be no customers.

Therefore, it is necessary to protect their business against potential risk of cool weather; retail and tourist industries that need the derivative to hedge against low consumption of wine and other beverages during cold seasons. This is common in England which as used by wine bars to hedge against low wine consumption during cold temperatures.

The derivative is also used in the viticulture industry as it is weather sensitive. Lack of exposure to sunshine and cool temperature during pre-bloom and maturation affects the quality of the grapes and subsequently the resulting wine. A lot of rain can also lead to rotting on the vines and delayed harvesting hence causing drop in earnings. The growth of the weather market has attracted insurers and reinsurers, investment banks, insurance broker, and hedge funds.

Insurance was not providing coverage for catastrophic risk; it realized that there is close similarity between weather derivatives with the traditional insurance products covering the property damage and business interruption. The hedge funds and commodity trader saw the opportunity to trade on either on speculative basis or taking the arbitrage advantage relative to energy and agricultural commodities (Alaton, Djehiche and Stillberger, 2002: 1-20). Finally, the investment banks realize that financial risk management product could sell alongside other financial products for hedging interest rates risks and currency rates risk.

Other users of the weather derivatives are; construction companies, offshore rig operators, beverage and food companies, municipalities, transportation industry, entertainment event organizers, and local natural gas distribution companies.

Weather derivatives are continually being researched and discussed with market participants (Table 2).

Table2: *Examples of Potential Weather Risks and Participants*

Economic Sector	Hedgeable Weather Risks
Agriculture	Crop yield, Handling, Storage, Pests
Construction	Delays, Incentive / Disincentive Clauses
Energy	Redeuced and/or exceesive demand
Entertainment	Postponements, Reduced Attendance
Governments	Budget overruns
Hedge Funds	Making profits on volatile markets
Insurance	Increase claims, Premium diversification
Manufacturing	Reduced demand, Increased raw material costs
Offshore	Storm frequency/severity
Retailing	Reduced demand of weather-sensitive products
Transportation	Budget overruns, Delays

Source: *The Weather Derivatives Markets at CME Group: A Brief History, p.3.*

IV. Weather Derivatives vs. Weather Insurance

In the weather derivatives it is possible for two parties to enter into agreement so that they can hedge each other’s risk. This is when one will be able to make profit during cold while the other will benefit from warm winter. This cannot work with insurance. The insurance contracts are usually designed to protect the holder from extreme weather events or catastrophe such as;

hurricane, earthquake, typhoon, and tornado. On the other hand the insurance contracts do not work with uncertainties with normal weather. The weather derivative can be constructed to have payouts in any weather conditions unlike the insurance contracts, which only deal with extreme weather condition cases.

In the insurance contract the holder of the insurance contract has to prove that he or she has suffered a financial loss as a result of weather for him to be indemnified. In the circumstance that he or she is not able to prove that, there will be no compensation. This is in contrast to weather derivatives as the pay-out is based in the outcome of the weather regardless of the intensity and magnitude of the effect to the holder. In the weather insurance speculations about the weather are made since one does not need to have weather sensitive production for him to benefit from the derivative.

The weather products are based on the fact that temperature variations can be financially damaging and not life threatening. For instance, a utility company may use weather derivative to hedge against a winter that it is predicted to be seven degree warmer and they predict financial loss as a result to that weather condition. At the same time they can purchase an insurance policy to hedge against damages caused by a flood, hurricane, earthquake or tornadoes.

Weather derivative is quite different from the insurance as the underlying asset is not tradable and it hedge against volumetric risk instead of price risk. The indemnity is calculated on the weather index rather than asset price. The weather derivatives are less liquid since weather is location specific (Alaton, Djehiche and Stillberger, 2002: 1-20). This is much advantageous because weather conditions are symmetrical and adverse selection is removed. The use of weather derivatives is accompanied by a basis risk caused by the fact that an end user location is not fixed at the same reference location o the weather derivative he holds.

V. Weather Derivatives Instruments / Structures

Weather contracts are based on the actual observation at one or more times on the weather station. The indexing of weather derivative is defined basing on the underlying index and the measure of weather which governs how pay-out on the contract will occur. The most common indexes in the market are the HDDs and the CDDs and they are used to measure the cumulative variation of the average daily, as well as, being the standard indexes in the energy industry that correlate well with energy consumption. The structure of the derivatives are based on a standard derivative structure, which includes; swaps, puts, collars, straddles, strangles, and the calls.

A. Weather Options

Many businesses are exposed to the weather risks in their earnings and it therefore, demands that an appropriate tool to reduce the effects be developed. The weather derivatives serve as the measure to hedge the risks in an investment portfolio. In the weather options, there are two types of options; calls and puts. The buyer in the HDDs call buys a premium at the beginning of the contract and if the number of HDDs is greater than predetermined strike level then, he will receive a pay-out in return. The size of the payout is determined by the strike and the tick size, which is the amount of money that the holder of the call receives for each Degree Days above the strike level for the period.

In formulating the weather options, one need to confine himself in the following parameters; the contract type, is it a call or a put? ; the underlying index to be used, if it is HDDs or CDDs; an official weather station from which the temperature data are obtained; if there is a maximum payout; the strike level, and the tick size. Normally the option premium is stated in the option agreement, and the contract relieves the option holder any obligation to pay the liquidated damages to the writer for refusing to perform. In order to have a bona fide option, the amount of the option should be less than the holder's potential liability for non-performance in the bilateral contract. Options can be categorized as;

Catastrophe option is one of the oldest and known product of the genre: It gives the holder a specified amount of cash payment in exchange for an upfront option premium if the index insured exceed catastrophe losses. This method as used by the insurance companies to hedge a catastrophe risk.

Storage option is meant for gas storage contracts and is weekly released on the Energy Information Administration (EIA). The auction gives the trader an opportunity to buy and sell option payoff depending on where the storage number comes: it takes place a day preceding the weekly release of the gas storage number. The weekly changes in the inventories determine which options are in the money and which are out of the money.

In conventional options types, the participants are able to go a long or short the statistic using the call and put options whereas, the investors choose from a range of strike prices conforming to the standard option convention in the payout profiles. The payoff is determined basing on the difference between the relevant strike and the actual data release. However, the call or put options expires if the settlement is below or above the option strike.

Over-the–counter option is traded between two parties, not listed in the exchange. The terms and conditions are unrestricted as they are individual tailored to meet their own needs; it requires that one party to be a well established institution.

The call option represent the right to purchase a set number of stock at a predetermined strike price before the option reaches its expiry date and it is purchased in the hopes that the underlying stock price will rise. The put option represent the right to sell a set number of shares in the stock at a predetermined strike price before expiry date and it is purchased with the hope that the underlying stock price will drop below the strike price. The investor benefit from put option when, the market falls without having to sell short stock and has limited risk if market goes up against them.

The strangle option is build on the put and call option thereby, reducing the net debit of the trade and the risk of the loss in the trade although, their strike is different. Closely related to strangle is the straddle, which gives the trader a greater profit than a butterfly if the final stock price nears the exercise price (Alaton, Djehiche and Stillberger, 2002: 1-20). Finally, the collar option is a strategy that limits the range of loss of earnings on an underlying asset to a specific range.

Employment stock options - it is particularly used in the United States and is rewarded by a company to their employee as a form of incentive compensation with the aim of motivating them; the real estate's options, which a financial contract used to assemble large parcel of land; and the prepayment options, which are usually included in the mortgage loans.

B. Weather Swaps

Swaps are contract in which two or more parties exchange risks during a predetermined period and the payment are made by both parties: one side paying a fixed amount and the other paying a variable amount. They are over the counter instrument that can be modified or customized to suit the needs of the parties involved by protecting their business against weather uncertainties.

In this type of derivative there is only one date when the cash flow is swapped, as opposed to interest rate swaps which usually have the swap dates. The swap with only one period is thought to be a forward contract although; the contract period is often a single calendar month. In the case of the standard HDDs, the parties agree on a given strike of the HDDs for the period and the swapped amount

Most swaps are costless: there is no premium, and the loss from a swap is equated with a payoff, it only has a standard industry contracts. The parties write a contract to pay each other at some point according to the weather in future, the swap acting like a spread bet on the future weather. In cases of long swap, the buyer has to pay the seller for low values of the index, thereby hedging against high value index.

If the swap is traded without premium, then the strike should be set at a level where the expected payoff is close to zero thus shifting to compensate for the risk they are taking (Geman and Cummins, 1996: 219-246). Once the swap has been traded, valuation consisting of the calculation of distribution of the possible of financial outcome is done. If the hedger is using linear swap contract to protect his business, then the optimization size of the hedge is given by the regression coefficient obtained by regressing the profit of the business onto the weather contract.

The detail of the swap can vary depending on the need and the objective for instance; energy distributors can use the weather swap to hedge against warmer than normal winter. Similar to swaps, there is weather floor, which allow parties the right to enter into a long and short position at a specific weather condition. It is similar to swaps because they provide protection at a predetermined level and time.

Credit default swap is one of the latest generation of financial products on tax purposes, and is option type derivative product that allows market participants to put a price on, and thereby transfer to a counterparty, third party credit risk. These products are not termed as option in form though they have payout terms suggestive of options. In the simplest form, the CDS makes either a single lump sum payment that is based on the notional principal amount, in the exchange for a contingent payment from the other party.

C. Weather Futures and Forwards

Weather futures are a type of weather derivative that obligates the buyer to purchase the value of the underlying weather index, and it enables the businesses to protect themselves against losses caused by unexpected shifts in weather conditions (Geman and Cummins, 1996: 219-246). It is a growing method in the energy companies used in hedging against change in demand due to change in temperature. The future derivatives are used only to hedge risk associated with adverse weather. The underlying variables include: HDDs, CDDs, Average Temperature, Frost, Snowfall, and Hurricanes

On the other hand, forwards contract is type contract between two parties to buy or sell asset at a specified time at a predetermined price today, contrary to spot contract where assets are bought or sold today. Forwards are used to hedge risk as a mean of speculation on the increase on interest rates in future dates.

D. Collar, Strangle and Straddle

Collar is a strategy that limits the range of loss of earnings on an underlying asset to a specific range. It is a combination of a call and a put option enabling one to use a long or a put option with a particular strike by financing it with short of either a put or a call option with a different strike (Geman and Cummins, 1996: 219-246). This strategy provides the user with the price protection against adverse weather events in the underlying asset thereby, forcing price to move within a defined range. Notably, this is provided at the expense of giving up some of the returns. Importantly the collars contain the premium for one of the parties.

Strangle is an investment strategy involving the purchase or sell of particular option derivative that allows the holder to profit based on how much the price of the underlying security moves, with relative exposure to the direction of the price movement: the purchase is known as a long strangle while the sale of the derivative is a short strangle. The strangle option is build on the put and call option thereby, reducing the net debit of the trade and the risk of the loss in the trade although, their strike is different.

Straddle gives the trader a greater profit than a butterfly if the final stock price nears the exercise price. Straddle is closely related to strangle since it, too involves buying a call and put option with the same strike price at the expiry date resulting to a significant profit in the market direction (Geman and Cummins, 1996: 219-246). The owner of a long strangle makes a profit if the underlying price moves far enough away from the current price; and it is important that the investor should take a long strangle if the security is volatile.

VI. Pricing of Weather Derivatives

Pricing weather derivatives require an historical temperature database and the application of the statistic for fitting the distribution function to the data. This can be found from the National Oceanic and Atmospheric Administration among other inexpensive statistical packages; Chi-Square and Kolmogorov-Smirnoff tests is the most common tool of evaluating this type of a problem. The probability distribution of the HDDs and CDDs can be fitted using the Gaussian (normal) distribution. It is worth noting that, market for weather derivative is an example of an incomplete market since the underlying variable in this case, temperature is not tradable. However, there are complications in the pricing method such as, simple distribution not being able to be fitted directly into the historical data (Geman and Cummins, 1996: 219-246). These data show a lot of invariability and long term trend, which should be accounted for calling for a clear analysis of the data. The Gaussian distribution of HDDs and CDDs can help to derive a sufficient formula for pricing individual options with the assumption that one knows the mean and the standard deviations of the HDDs and CDDs. However, it is difficult to determine the mean and standard deviation to use in the model because the climate is not stationary meaning that the mean and the standard variation will evolve over time.

A. Issues

Weather Data

The actuarial method of pricing depend much on statistical modeling of stationary time series of historical meteorological data, which must be processed in a number of ways to remove the absurd values and fill the gaps. It is required that one identifies jumps in the data that occurs as a result of station changes and the gradual trends from the data. These meteorological data are usually made national meteorological services, universities, private firms, and military organization. We shall however, restrict our study with the data provided by the national meteorological service since this is the weather data used in the market. Notably, availability of weather data varies from one country to another.

In U.S. these data are cheaply availed to individual thus enhancing the growth of the meteorology department contrary to European countries where data is not available on digital electronic format. This makes the dissemination of the data disorganized and fragmented. To remove these confusion one, needs to clean the data by identifying the gaps. To do this, analysis of available historical metadata is necessary to identify dates when the changes occurred that might have caused the jumps.

The analysis of the linear dependences between the target station and the surrounding station is done to test and estimate the procedure used to estimate the size of the jumps. Data from the surrounding station can be used to replicate the target stations using the regression and any disparity caused by time series and the actual one (Geman, 2005). Once the jump has been identified, one can; ignore, use the data after the jump, or attempt to adjust the data prior to the jump using the estimated size of the jump.

Historical meteorological data is not used in the weather derivative pricing because we care on the future effect of the weather. The only usefulness is that it can be use to show the present patterns with the assumption that the past climate will behave the same as today. Importantly, climate is not stationary and this is believed to be cause by: urbanization, which has caused increased warming as a result of increased surface coverage with ground, concrete and tarmac; predictable internal climate variability, which arises from sampling long timescales; anthropogenic climate change, which is the idea that man's activity has effect on the climate. Activities such as, release of carbon gases and burning of fossil fuels can cause global warming; and variability in solar forcing.

Computer mechanistic models of the climate have been used to test this idea. It is necessary to understand the origin of the trends in order to decide whether the trends should be removed or not for the purposes of pricing the weather derivatives. Studying the spatial variations of trends can be instrumental in giving the partial information about the cause of changes in weather data. The anthropogenic effects will help to create large pattern, while urbanization will be expected to be localized on scales of the urban area.

Weather Forecasting

Financial contract, that are derived from weather-specific measures for instance, the expected future value of a local temperature, require the ability to foretell the regional weather conditions for months (Geman, 2005). This will enable one to effectively model the variations of the weather specific measures over the course of many months as it I necessary for the pricing of the weather derivative. Weather traders heavily rely on the meteorological forecast in inputting the expected temperature.

The forecasting firms use a variety of sophisticated models to make both long and short range predictions about evolving weather conditions. However, regardless of the assumption employed to model the weather specific model, it is difficult to predict the future weather behavior since weather dynamics are governed by the law of physics albeit with a measure of uncertainty. This uncertainty prevails when forecasting the weather. Importantly, one need to understand past weather patterns in predicting the future, and this weather data are provided by weather forecasting firms.

It is important for one to decide which data to use to price a weather derivative, in most cases it is the look back period (Geman, 2005). This is the period of time in which one can estimate the average temperatures and volatilities and a common wisdom holds that the period required is 10-20 years. In order to find the price of the contract at the date sufficiently close to the start of the contract period, one must adjust his model of the temperature.

Modeling Temperature

Temperature is never deterministic and it therefore, demands that one should use a model that adds to some sort of noise to the deterministic model. One of such model is the Wiener process, which is reasonable with the regard to mathematical tractability of the model. A closer scrutiny of data series reveals that temperature varies across different months of the year though, constant within each month. Temperature cannot change daily over a long period of time, and this means that the model should not allow the temperature to deviate from its mean value for more than short period.

B. Evaluation of Weather derivatives and Pricing Approaches

Evaluation of a derivative is determining its value at the present moment or at any time before the maturity date of the contract, knowing that it will provide a variable pay-off to the buyer at some point in the future. The main reasons for evaluating the weather derivatives is pricing: to determine a suitable strike for a costless swap for an option prior to trading. It is also important to know the current values of all the holdings based on the latest weather forecast and how to develop these values.

Evaluation of the weather derivative is contract is useful for internal and external regulators for monitoring the risk faced by a weather trading organization as a result in the contrast they are trading with. The amount of pay-off depends on the underlying asset. However, there is no standard model for valuing weather derivatives as those given by Black-Scholes formula for pricing the European style option and derivatives. The weather derivatives are priced in a number of ways and they include;

i. Black-Scholes

This model was developed by Fisher Black and Myron Scholes (1973: 637-654) to a price put and call options that are currently into use. However, the model is based on assumption that do not realistically apply to the weather derivatives; one of the assumption being that the model is that the underlying of the contract follows a random walk without mean reversion. The model predicts that the variability of temperature increases with time, so temperature could wander off to any level what so ever.

The Black-Scholes formula used in calculating the put and call option is given as

$$C(S,t) = N(d_1)S - N(d_2)Ke^{-r(T-t)} \tag{1}$$

$$d_1 = \frac{\ln\left(\frac{s}{k}\right) + \left(r + \frac{\sigma^2}{2}\right)(T-t)}{\sigma\sqrt{T-t}}$$

$$d_2 = \frac{\ln\left(\frac{s}{k}\right) + \left(r - \frac{\sigma^2}{/2}\right)(T-t)}{\sigma\sqrt{T-t}} = d_1 - \sigma\sqrt{T-t}$$

The price of the corresponding put option based on put-call parity is given as:

$$P(S,t) = Ke^{-r(T-t)} - S + C(S,t) \tag{2}$$

$$= N(d_2)Ke^{-r(T-t)} - N(-d_1)S$$

Where *N*: the cumulative distribution function of the sStandard normal distribution

(T-t) : Time of maturity
S : Spot price
K : Strike price
r : Risk free rate
σ : Volatility of returns

This formula was developed with the following assumption: dividends, volatility, and continuous compounded returns on stock price are constant, as well as, no transaction costs and any amount of stock may be sold short and borrowed at risk-free rate.

The Black-Scholes model in appropriate for weather derivatives because of the following reasons; weather does not walk like an asset price which can in principle move from zero to infinity, instead tend to remain within relatively narrow bands due to their mean reverting tendency; the option payoff is determined by the value of the underlying exactly at the maturity of the contract but the weather derivatives usually provide for averaging over a period of time (Geman, 2005). This is similar to the Asian or the averaging options and is unsuitable for Black-Scholes Model; weather is approximately predictable in the short run and random around historical average in the long run unlike the short dated derivative which behaves differently; many weather derivatives are capped in a pay-off , unlike the Black-Scholes model; finally, the underlying variables are not tradable, and so the pricing cannot be free of the economy risk aversion factors, unlike the Black- Scholes model.

ii. Burn Analysis

This analysis refers to a simplified approach to valuing contingent claims often employed in the insurance industry (Geman and Leondardi, 2005: 46-72). The method basically consist of pricing option as the discounted average of the payoff that would have otherwise, been observed in the past basing on the historical values of the underlying variable. The burn analysis tend to undervalue option due to the fact that it will assign a value of zero to the option that are out of the money and not necessarily incorporate the true volatility of the underlying asset in the pricing.

The model is based on the idea of evaluating how a contract would have performed in preceding years: it is calculated easily and simply on a spreadsheet. The burn analysis includes the data prior to evaluating how the contract is performed and excludes fitting distribution. Notably, burn analysis may be a more accurate in pricing any contract as it gives an indication of mean and range of possible payout of a weather derivative contract simply on a spreadsheet. However, the only shortcoming of burn analysis cannot capture the possible extremes that may unduly influence in the historical record and it can't be extended easily to analyze a portfolio of contracts.

The steps in describing burn analysis include; estimating fair strike swap, which is strike that gives an expected pay-off of zero. Notably, burn analysis represents a simple calculation that provides some sense of order.

iii. Monte Carlo Simulation

The Monte Carlo simulation approach is a computer-based generating random numbers, which can be used to statistically construct weather scenarios and providing a flexible way to price different weather derivatives structure. Many types of averaging periods are easily specified using this model, as well as, placing the contractual cap on the price of the derivative. This approach involves generating a large number of simulated scenarios of HDDs or CDDs to determine possible payoffs for the instrument.

Therefore, the fair price of the instrument is the average of the entire simulated payoff. However, it is important to choose the right random process for temperature as it is clear that, temperature is mean reverting and any model that assumes the Black Scholes approach will be inadequate to model temperature. Notably, Monte Carlo based simulation approach offers maximum flexibility to price different instrument, and provides a necessary degree of accuracy and transparency to become a standard for pricing and trading the instruments.

When simulating the weather derivatives using this approach, the temperature should be simulated from today, and use today's observed temperature as the initial value. However, if the contract period is far enough ahead in time, it will be pointless to start simulation today because the temperature in the nearby future will not affect the temperature very much in the future (Sahalia, 2004: 487-528). In the long run, the temperature process will not dependent on the initial value and the variance will have reached its equilibrium value. Alternatively, if we are close to the start of a contract, simulation can start at a current date.

iv. Valuation Based on Dynamic Stochastic Model

Stochastic model is based on using a process to simulate the future behavior of the underlying weather, in this case temperature (Sahalia, 2004: 487-528). This process was developed when the actuarial method and the Black-Scholes failed to account for the market price associated with the temperature variable. The traditional weather derivative models were only useful from the perspective of a single dealer and this called for a model that will establish a unique market price, which will incorporate a risk premium. The valuation based on the dynamic model of temperature behavior is made of complex structures and the selection of the process is subjective. Notably, the set up comes with additional shortcomings, for instance, it does not incorporate the market price at risk but imposing a risk neutral value without any theoretical justification. The model is also developed for temperature and are not really mean reverting since they cannot reflect the persistence serial correlation typically present in daily temperature.

v. The Equilibrium Framework

The equilibrium framework is an extension of the work of Lucas's Model (1978: 1429-1445) to include weather as a fundamental variable in the economy. In this model, a discrete process is adopted where the underlying variable are the aggregate dividend and the temperature thereby, allowing the two to correlate with one another both contemporaneously and in a lagged fashion (Sahalia, 2004: 487-528). The market price of the risk is determined by the dividend process and temperature process and since the specification for the dividend and the temperature process renders it difficult: calling for the use of Monte-Carlo simulation.

According to Cao and Wei (2003), reasonable pricing model must incorporate accurate modeling of the underlying and the assessment of the market price of risk. Temperature will also carry a market price for its risk just like the stochastic interest rate and stochastic volatility, which commands risk premium in equilibrium as a non traded underlying (Brockwell and Davis, 1998). However, the equilibrium framework accounts for the market price of risk, as well as, allowing easy estimation of the temperature system and bring in features of daily temperature, for instance uneven variations and seasonal cycles. The framework can handle weather contracts and requires only a one-off estimation

It should also be observed that, the market price of the risk associated with the temperature variable is significant. The risk premium can present a significant portion of the derivative of the price of the derivative and lastly, one should be careful when to use the model when the derivatives are with non-linear payoff structure.

vi. Incomplete Market Approach

Incomplete market model is the appropriate method for the evaluation of the weather derivative since it recognizes the derivatives that can be hedge and those that cannot be hedge (Davis, 1998: 216-226). It is also important that a good pricing approach be used to increase the transparency, market confidence and further develop weather derivatives into a robust thriving market.

Incomplete market is the market in which the securities is less than the number of states of nature and this shortage will likely restrict individuals from transferring the desired level of wealth among states. Weather derivatives as earlier noted is an incomplete because the underlying variable for this case, weather is non-tradable and cannot be replicated in any means of self-financing trading activities. Many approaches have been developed for the incomplete market, for instance, the marginal utility developed by Davis (2001: 305-308). This method explores weather derivative pricing using the marginal utility approach, meaning that the agents will buy or sell derivatives only if it increases its utility.

vii. Other Pricing Approaches

Indifference Pricing Approach finds its roots from the basic principle of equivalent utility and is based on the utility argument and produces the reservation price. It is build up on the investors' preference toward risks that cannot be eliminated because of market incompetency; commonly applied in pricing the traditional financial derivative market. The indifference pricing approach offers a vital benchmark to the market players in the customized weather derivatives market, as well as, in the exchange market (Sahalia, 2004: 487-528). For market to be viable, the market price of the market derivative must be between the buyer and the seller indifference price. It is important for hedgers to know their indifference prices in order to determine if participating in the weather derivative market will hedge their hedging objective. The indifference method incorporate price risk, and weather risk in the financial market, the actuarial price and the indifference price of the weather derivative is analyzed. The utility indifference price is based on the comparison between optimal behavior under the alternatives of buying the claim now and the receiving the payoff later and not buying claims. This method is advantageous as it help in risk reduction and economic justification, it also lead to a price which is linear in the number of claims. The price indifference also reduces to the complete market price which is necessary feature of any good pricing mechanisms; it can also incorporate wealth dependence (Brockwell and Davis, 1998). This may be desirable since the price an investor is willing to pay could well depend on the current position of his derivative book. Utility difference gives an explicit identification of the hedge position. However it should be noted that the indifference pricing methodology includes the fact that explicit calculation may be done in only a few concrete model, mainly for exponential utility. The exponential utility has a feature that wealth or initial endowment of the investor factor out of the problem, thereby making the mathematic tractable and a strong assumption.

Arbitrage Pricing Model (APM) is an asset pricing model based on the idea that an asset's returns can be predicted using the relationship between that same asset and many common risk factors and was created by Stephen Ross (1976: 341-360). The APM predicts a relationship between the returns of a portfolio and the returns of a single asset through a linear combination of many independent macro-economic variables. The APM describes the price where a mispriced asset is expected to be and it is often viewed as an alternative to the capital asset pricing model (CAPM). The main reason being that since the APM has more flexible assumption requirements. The difference between the CAPM and the APM is that, The CAPM formula requires the market's expected returns while APM uses the risky asset's expected return and the risk premium of a number of macro-economic factors (Brockwell and Davis, 1998). Arbitrageurs use the APM to profit by taking advantage of mispriced securities this is because the mispriced security will have a price that differs from the theoretical price predicted by the model. Arbitrage free pricing method is used to prohibit arbitrate opportunity and to implement this, the price of the option at present moment must be equal to the initial cost of the portfolio as they both provide the same income at the expiry date. It is difficult to evaluate the weather options using this method since it is not easy to create the portfolio of duplication with meteorologist index. To solve the problem, Geman (1999) has suggested to substitute a contract on energy for the meteorological index in the portfolio by emphasizing the dependence of the energy price with the climate. However, Brix, Jewson and Ziehmann (2002) proposed to use the weather futures contracts as the viewed it as highly correlated with the underlying of the weather option of which we intent to value. Henderson (2002: 351-373) also suggested a general equation for the pricing of the derivative that included discounting, risk loading, the cost of hedging and current portfolio position. Cao and Wei (2000: 67-70) used an equilibrium argument to conclude that the weather option is the expected pay-off and due to its transparency, lower overhead cost and the possibility of hedging one's position in the secondary market it is widely preferred.

Financial Pricing models have been developed basing on the CAPM, arbitrate pricing theory, and option pricing theory (Dybvig and Ross, 1982: 1525-1546) representing an advanced traditional actuarial model as it demonstrate asset pricing model and avoiding creation of an arbitrage opportunity. The drive to develop the model was due to the limitation of the existing financial pricing, which has an assumption that insurer produces only one type of insurance. This paper gives the theoretical analysis of the insurance pricing with the aim of inverting the weaknesses in the weather pricing models. The model relies entirely on risk-evaluation relationships and arbitrates argument in order to price the weather contracts (Doherty and Garver, 1986: 1031-1050).

Benchmark Pricing Approach was developed by Platen (2002: 540-558) with the aim of uniting the two methods through the use of a growth optimal portfolio (GOP), which act as a numeral portfolio from which the fair price of a particular instrument may be derived. The emergence of innovative products was aimed to securitize the core risk, which has led the researcher to question the validity of existing pricing method (Davis, 1998). The traditional methods of pricing weather derivative such as, actuarial, and arbitrage free were challenged by the catastrophe bonds, insurance and weather derivatives. However, the difficulty in pricing derivative under the incomplete market assumptions has called for a form of pricing rule to yield a rational result under the correct assumptions in finance and insurance.

Fair Pricing Approach is one of the new pricing system and is also referred to as Fee for Service Real Estate. This new system rewards the client's agent for providing the highest quality of service and saving the client time and money and is accomplished by the agent only being paid for the services they provide on an hourly rate for services rendered.

Actuarial Pricing evaluates the weather derivatives as being the conditional expectation of the future payment of the products, defined under the real probability of the future payment. The method is based on the law of large numbers, which clarify that by repeating a large number of time we obtained a more and more reliable estimate of the true value of the expectation of the observed phenomenon.

Consumer Based Pricing Method is based on the general equilibrium model of Lucas (1978: 1429-1445), which considers an economy in which a representative agent chooses the quantities of consumption, risky and riskless securities so as to maximize the expectation of the inter-temporal utility while respecting a budget constraint. This method is considered as a appropriate for evaluating the weather derivatives, however it requires the quotation to estimate the risk aversion coefficient and the discount factor.

Business Pricing requires that the company utilizing weather derivative instrument to understand how its financial performance is affected by the adverse weather condition and then determine how much to pay to hedge the risk of vagaries of weather. The business will then obtain a secured weather for the stated period thereby, largely reducing the expenses variation of the weather. The investors and the business persons have to determine the level of risk and what price they are willing to pay to protect their interest.

Index Modeling entails building a model of the underlying index and the simplest way to model the index is to model the distribution of historical index outcome. The predictive power of such model is rather limited and a better result can be obtained by modeling the index generating process on a finer scale. Alternatively, the approach to the model is to incorporate physical intuition into statistical models based on spatial and temporal correlation between occurring in various parts of the ocean- atmosphere system around the world.

Many of the pricing approaches concentrate on pricing individual transactions and this called for a method portfolio analysis. This was because many dealers of weather derivatives will write a large portfolio of transaction to take advantage of geographical diversification and hedging effects. Notably, it is appropriate for hedgers to use a combination of standardized weather contracts and basis weather derivatives in design to hedge risk of the standardized risks.

VII. Conclusion

There is need for weather derivative market to have a standard pricing model to remove the discrepancies between the different models, which are hindering the market to grow at an even faster rate. It is important to develop the weather derivatives since it is useful in hedging against losses and it is not correlated with the stock market. Individual stocks of the companies who don't take a hedge against weather fluctuation will be expected to be correlated with the weather that affects them.

The study also reveals that trading on the CME weather product is beneficial as there is price transparency due to the equal access to the bid and offers. This is because CME contracts are traded electronically. There is liquidity since the CME weather market are supported with automated trading system supplying continual price feeds from the global weather market system. CME market derivatives are easily available to those seeking protection against unanticipated weather situation around the globe. This paper sought for ways to contribute to the existing knowledge and the experience in weather derivatives market for developing countries, as they suffer most due to weather vagaries. More research need to be done on the pricing approaches since the future of weather derivative seems to be shining.

The weather derivative will help in hedging against revenue losses affected by weather risk. However, implementation of weather derivatives will be difficult due to unavailability of reliable and verified data and insurance regulation, which envisage weather derivatives as insurance instrument.

Weather derivatives are used to manage the impact of non-catastrophic-which refers to weather events that have a high probability of occurrence with a less payoff- weather risks unlike the weather insurance. Notably, the traditional financial derivatives are useful for price hedging, unlike the weather derivatives, which are focusing on the volume hedging.

The valuation of weather derivatives has been the disturbing thing to many researchers, they realized that traditional arbitrage free and actuarial pricing approaches are not appropriate for weather derivatives. They exerted a lot of effort to come with new models for pricing the instruments discussed, for instance, the historical burn analysis, which assumes that the past weather patterns are reflected in the future. This approach is easy to implement and relatives comprehensible, but it is not appropriate for pricing weather derivatives due to its unrealistic assumptions because weather is not stationary.

As a result of these, the mean reverting simulation by Monte Carlo and the Burn Analysis offers the maximum flexibility to price different instrument and provide the needed accuracy and transparency standard to price and trade this instrument

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