IJBFMR 5 (2017) 52-60 ISSN 2053-1842

International Journal of Business and Finance Management Research
www.bluepenjournals.org/ijbfmr

Weather risk management and Black-Scholes option pricing model

Turgut ÖZKAN

Beykent University, Faculty of Economics and Administrative Sciences, Ayazaga 34396 Maslak-Istanbul, Turkey.
E-mail: turgutozkan@beykent.edu.tr.

Article History
Received 19 September, 2017
Received in revised form 16 October, 2017
Accepted 19 October, 2017

Keywords:
Quanto option,
Weather Risk Management,
Black-Scholes,
Cooling degree days.

Article Type:
Full Length Research Article

ABSTRACT

Weather risk management can be described as all financial activities that are geared towards keeping the income flow deviations, which the weather conditions will create, in stability band by using preventive financial tools. Like other financial derivatives, weather derivatives have special quality types that consist of weather related securities such as floor, cap, collar, swap, Quanto option besides conventional types like forward, option, futures. In this study, implementation of Black-Scholes option pricing model, which is used in pricing of options, on weather risk management and especially weather risk options is specified. It is concluded that, the model can be used for effective weather risk management as well.

INTRODUCTION

Among the notions that are becoming increasingly important, affecting personal and economical life deeply, ‘risk’ is the leading one. With its broadest description, risk can be explained as a conclusion which exists in an event or a fact because of its nature and damages when it materializes.

Within this description, weather risk, which is known as the oldest risk notion, is of capital importance. When the changes in weather conditions are unforeseen and above seasonal normals, they constitute unavoidable or systematic risk type since they are natural events which can occur in every season. Global warming has made the management of risks that were created by weather risk by accelerating the dissentient from seasonal normals . Despite the meteorological forecast methods that are developing fast with the help of technological aid, there are still ten-day of short terms which include gradually decreasing forecast success.

The possibility of a short-term prediction enhances the importance of the weather risk. Deviations from seasonal normals that are defined by long-term local meteorological data often cause 'getting caught unprepared' by the risk and the extent of the damage to rise unexpectedly.

The tendency of expectation of global warming to continue increasingly also means that the risks which depend on weather conditions will intensify. Thus, it should be expected that the interest and necessity of financial tools for avoiding weather risks will increase in parallel to this change in the future.

The effect of weather and climate change risk on numerous segments and firms are much more than the changes in economic factors and price fluctuations of financial assets. Indeed, the changes in weather conditions and the volume of this change affect personal life, and changing one’s habits accordingly, can affect the economic life directly and deeply.

Besides, according to the deviation level of abnormal weather conditions such as hurricane, extreme cold, rain, snow, there can be catastrophic economic damages and loss of lives. These losses cause fluctuation of fund flow on the basis of individual, firm, segment, national economy and even global level. While an abnormally cold winter period can put a fuel supplier or a firm that sells winter clothes on their budget targets, it can cause delays in projects of construction and contracting firms, thereby income losses and indemnities. Off-season anomalies such as heavy rain and snow or storm, hurricane urge municipalities to spend more than expected on operating expenditures to eliminate the effects of these hitches. These conditions which are resourced from the nature can cause the rise in lack of repayment to credit institutions, to push the limits of loss ratio for indemnity payment of insurance companies, enforcement of re-insurance agreements against insurance companies and loss of profit. The risk of ski facilities is inadequate snow depth, whereas the risk is not having hot weather that year for an air conditioner manufacturer. Moreover, it is known that rain and air temperature have a certain effect on crop yield in agriculture segment.

One third of the Gross National Product (GNP) of developed countries are directly affected by climate change. More than 80% of the world economy is dependent on weather conditions and the climate either directly or indirectly. Every year, weather risk-related loss of the companies is about 420 billion dollars in total (www.wrma.org, d.a.25.08.2016).

Global warming stimulates this uncontrollable fluctuation more and increases the changes of weather conditions and their effects. According to the USA National Weather Service reports (www.weather.gov, d.a.25.08.2016), the average Earth temperature was 13.6°C in March 2015, which was the hottest March since 1880 and 0.85°C above the 20^{th} century average. In the last ten years, there has been an up-going trend of getting warmer in the Earth and the average Earth temperature has accelerated from 15 to 17°C. A lot of segments have been affected by this global warming trend such as water resources, dry farming and generation of hydro-electric power. The expectation that global warming trend will accelerate means weather condition-related risks to intensify as well. Thus, it should be expected that the interest and necessity of financial tools for avoiding weather risks will increase in parallel to this change in the future.

All this example and such from real life strongly emphasizes the importance of Weather Risk Management notion in economic and financial literature. Weather risk management is described as all financial activities that are to keep the income flow deviations, which the weather conditions will create, in stability band by using preventive financial tools.

In weather risk management, beside using conventional financial tools such as insurance, weather risk financial derivatives that have developed and diversified in financial market rapidly, or ‘weather derivatives’ in short, have the potential to be a more effective and common financial tool. The aims of this study are to mention weather risk options which are one of the weather risk by-products gaining a place in literature very recently; however becoming more important; and to carry out a mathematical analysis of the usage of Black-Scholes option pricing model on weather risk options. For this purpose, firstly, weather risk options and a type of these option contracts, Cooling Degree Days (CDD), have been illustrated. Afterwards, Black-Scholes weather risk option pricing model has been discoursed; then the process of the model in Quanto options has been especially emphasized, and in the last part of the study, evaluation and the conclusion have been included.

WEATHER RISK OPTIONS

Weather derivatives aim to avoid the damages which can be created by weather anomalies ongoing above seasonal normals. Unforeseen hot and cold weather, rain, snow, frost, hurricane cause physical damage and this may cause national and even global economic loss. Weather conditions that are above seasonal normals affect the firms’ sales, and cause exorbitant expense and/or income loss. When the weather conditions spoil the financial structures, and cause unforeseen deviations in fund flow and profits, it affects almost every sector and especially becomes one of the main reasons of crop yield decline in agriculture sector.

Weather risk options in financial market are processed as standardized weather option contracts depending on; Heating degree days (HDD), CDD, rainfall, snowfall, growing degree days (GDD), frost (freezing) degree days (FDD), melting degree days (MDD) and hurricane indices.

Among these options, the process of CDD call option has been illustrated. Figure 1 shows how the option dealer can avoid the weather risk (Özkan, 2008: 107). According to Figure 1, the right side shows the cold, and the left side shows the hot temperatures. In return for the risk they are undertaking, the option dealer who pays for the option risk premium in the amount of DE to the other option dealer, acquires the right to receive a certain amount from the option dealer for each strike that is above the threshold in case the cumulative cold weather temperature is above the strike that was stated in the contract during the contract period. At the end of the contract, the option dealer will multiply the temperature strike that is above threshold–above the temperature that was stated in the option contract-and the amount that was set per temperature strike and make the payment to the dealer on the expiry date of the contract.

For a natural gas vendor, when the winter is warmer than expected, it causes a sharp decrease in sales revenue. If the firm wants to provide a hedge against such a risk, it purchases CDD call option in return for a contract premium (as much as DE) and receive the loss until the next level that was stated in the contract from the

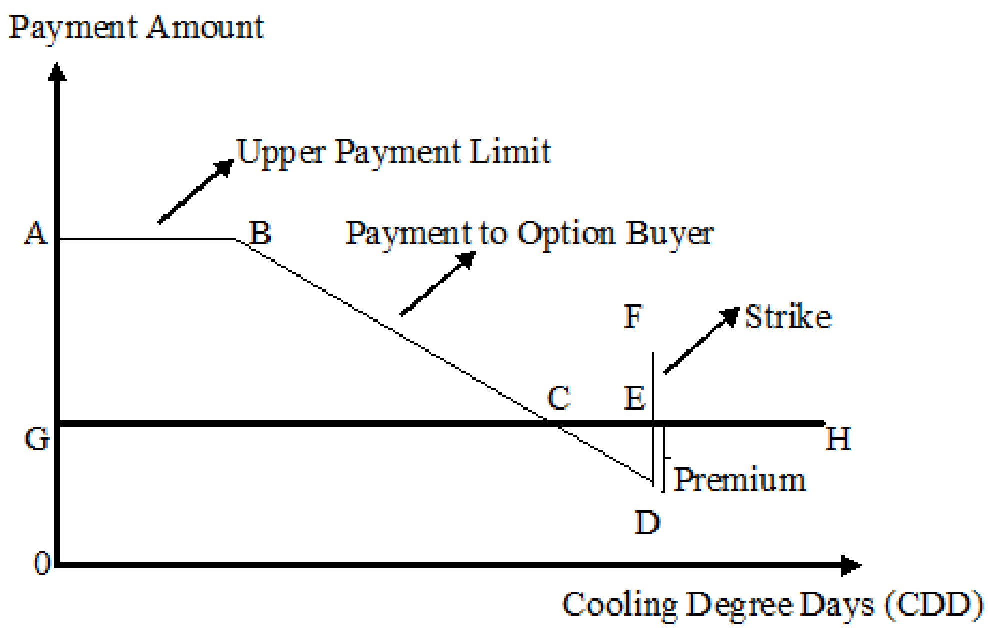

Figure 1. Cooling degree days (CDD) call option.
Source: Özkan (2008).

option writer. During the contract period, if the weather (in the winter) is above threshold (warmer that foreseen) and tends to the left side, per each temperature that has exceeded threshold, it gives the right to receive the loss until the next level that was stated in the contract from the option writer. The difference between the maximum payment level of the indemnity and the contract premium will constitute the net indemnity sum of the party that has the option. Moreover, a construction and contracting firm can purchase a CDD (put) option against the risk of much colder weather than foreseen in the winter. Therefore, it can hedge the loss which is the result of the slow work due to too cold weather or the damage that can be created by too cold weather on the construction.

Accordingly, it is possible to describe CDD as below:

Call option (CDD) = max(0, Tm – 65°F) × d (colder than expected)
Put option (CDD) = max(0, 65°F – Tm) × d (hotter than expected)

(Benth and Benth, 2013: 2, 118; Ritter et al., 2010):

$$CDD(\tau_1,\tau_2) \overset{cont}{=} \int_{\tau=\tau_1}^{\tau_2} \max[T(\tau)-c,0]d\tau \overset{disc}{=} \sum_{\tau=\tau_1}^{\tau_2} \max(18-T(t),0)$$

WEATHER RISK OPTIONS AND BLACK-SCHOLES OPTION PRICING MODEL

There are various methods to calculate the pricing of by-products and to determine the market price or forward prices. Among these methods that complicated formulas form, -despite all the criticisms- the most frequently used one is Black-Scholes option pricing model.

Black-Scholes option pricing model

Black-Scholes formulas are used to calculate the valid cash option values. Therefore, it provides valid price and the market price comparison but it is not effective in guessing the prices in the future. Hence, it cannot test the implementation price (of the future). Despite similar inadequacies, it is still a useful method in calculating daily transactions.

Black-Scholes option pricing model is used as below in order to calculate the market price or current value of a Europe call (C) option:

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

$$d_1 = \frac{\ln(\frac{S}{K}) + (r + \frac{\sigma^2}{2})(T-t)}{\sigma\sqrt{T-t}}$$

$$d_2 = \frac{\ln(\frac{S}{K}) + (r - \frac{\sigma^2}{2})(T-t)}{\sigma\sqrt{T-t}} = d_1 - \sigma\sqrt{T-t}$$

As for Put (P) option, the formula below is used to calculate its value:

$P(S, t) = Ke^{-r(T-t)} - S + C(S,t)$ or;
$P(S, t) = Ke^{-r(T-t)} N(-d_2) - S\,N(-d_1)$

The relation between the call and put option prices of a European type which has the same forward and implementation price is called put-call parity. In case the lack of the parity or the relation showed below, there can be arbitrage between the call and put options. An investor can obtain a risk-free arbitrage by purchasing call and put options, which are based on the same financial asset and with equal terms and implementation prices, simultaneously.

$P = C - S + Ke^{-rt}$
$P + S_0 = C + PV(K)$

Informula:
Q: Spot price of theunderlyingshares,
K: Strike price of option,
σ: Yield variability of the underlying asset (standart deviation),
r: Yearly continuous compounding value of the risk-free ınterest rate
T - t: Maturity period / year's days,
e-r (T-t): continuousdiscountingfactor (e = 2.71828).
n (d): cumulative distribution function of thethe standard normal distribution or cumulative normal distribution function.

Black-Scholes option pricing model in evaluating weather risk options

According to Davis (2001) and Geyser (2004), Black-Scholes option pricing model will be able to be implemented on the weather risk by-products under certain conjectures. These conjectures are; all data showing Brownian motion, maximization of the expected profit, natural growing ratio of degree days, natural enhancement of cash prices such as petrol, which are related to weather risk and natural expansion of firm profits.

The payment amount of a CDD weather risk by-product is a function of the strike, the probability distribution of CDD and the payment amount per CDD contract. It can be showed with the parity below (Considine, 2009):

$$E = M \int_{CDD=0}^{\infty} P(CDD)Q(CDD)d(CDD)$$

Inequality:
E: Expected payment amount of CDD option,
M: Amount of dollars per CDD in contract,
P (CDD): Probability distribution of CDD (standard deviation),
Q (CDD): Option payment amount of per CDD unit,
d (CDD): Differential of CDD are stated.

The price of a weather risk option is effected by three elements that are stated below (Considine, 2009):

1) Standard deviation of time series (σ),
2) Distancefrom strike threshold to mean (μ) of series,
3) Money amount of conrtactper degree days.

It is a well-known fact that, seasonal datum are not stable. This means the normals (expected) values of time series that are formed of seasonal indicators and standard deviations are also derivative. Taking the seasonal datum for 10, 20 and even 50 does not change this feature of climate datum. Unusual and infrequent climate events such as hurricane, storm, and hail increase the derivatives of the series of a specific meteorological area and deflect from the normal distribution. Not only long-term series are produced in meteorological data source field, but also the results are partly accurate and they provide low-quality analyses.

However, when the seasonal periods are taken into consideration, calculating mean and standard deviations of degree days with Gaussian models turn the specified statistical concepts into very well estimators. Therefore, the terms of weather risk by-products are dominantly limited by seasons.

At times, purchasing a series of contract that carries the season to shorter terms is more effective than purchasing seasonal contract in weather risk by-products. This situation, which seems against the common belief of the feature of classic option contracts, happens because there is lack of inter-period correlation and the seasonal datum occur randomly.

Instead of buying a whole single period's parts separately, when a single contract is bought in balk including a few sub-periods; there is standard deviation (risk) lower than total of sub-periods. However, since the standard deviation of the contract series increase in total; when compared to short-term ones, long-term contracts are treated with more expensive option premium.

It is possible to exemplify the subject as below with the help of datum in Table 1 (Considine, 2009). If we assume that implementation or threshold strike for an option

Table 1. Exercise threshold of option contract.

	Mean (μ)	Standard deviation (ϭ)
January HDD	386	78
February HDD	322	64

contract in stock or Over-the-Counter (OTC) markets is found by adding the 50% of the standard deviation to the average value; the implementation threshold of a whole single contract including January, February and both will be calculated as below:

$K_{JANUARY}$ = 386 + [78 (0.50)] = 386 + 39 = 425
$K_{FEBRUARY}$ = 322 + [64 + (0.50)] = 322 + 32 = 354
K_{J+F} = 386 + 322 + [(78 + 64) 0.50] = 708 + 71 = 779

This means that, if the temperature goes above the calculated implementation threshold, call option will be practiced. The standard deviation of both months;

$$\sigma_P = \sqrt{{v_1}^2{\sigma_1}^2 + {v_2}^2{\sigma_2}^2 + 2v_1v_2\sigma_{1,2}}$$

will be calculated as below by using this formula.

$$\sigma_{JANUARY+FEBRUARY} = \sqrt{\begin{matrix}\sigma^2_{JANUARY} + \sigma^2_{FEBRUARY} \\ +2\sigma_{JANUARY}\sigma_{FEBRUARY}\sigma_{O;Ş}\end{matrix}}$$

$$\sigma_{JANUARY+FEBRUARY} = \sqrt{78^2 + 64^2 + 0} = \sqrt{6.084 + 4.096}$$
$$= \sqrt{10.180} = 100{,}9$$

As it is seen, the standard deviation of a whole single contract including both months is to be more than the deviations of the months it includes. For this reason, the possibility of long term contracts to be more profitable than short-term ones provides them to be treated with more expensive option premium.

This study “The pricing of options and corporate liabilities” by Black and Scholes (1973), who applied Brownian motion method, which is used to guess random movements that will occur from the collusion of liquid molecules (for example, dust, pollen) with smaller particles (for example, gas, liquid) with stochastic methods, to guessing option prices successfully, is called Black-Scholes option pricing model.

With the help of Black-Scholes option pricing model, it is possible to describe the calculation method of call (C) and put (P) option values or prices of weather Risk management options (for HDD, CDD and CAT) as below (Benth and Benth, 2013: 168; Cao and Wei, 2004):

Call option value:

$$C_{Ind}(t,\tau,K,\tau_1,\tau_2) = e^{-r(\tau-t)}E_Q[\max(S_{Int}(\tau,\tau_1,\tau_2)-K,0)|S_t]$$

Put option value:

$$P_{Ind}(t,\tau,K,\tau_1,\tau_2) = e^{-r(\tau-t)}E_Q[\max(K-S_{Ind}(\tau,\tau_1,\tau_2),0)|S_t]$$

$$d(t,\tau_1,\tau_2,K) = \frac{S_{CAT}(t,\tau_1,\tau_2)-K}{\sum_{CAT}(t,\tau,\tau_1,\tau_2)}$$

If we define the call and put options as N for CDD, HDD (Heating Degree Days) or CAT (Catastrophe Risk), in order to calculate the call and put option values, ‘‘d’’ defines cumulative normal distribution function, and we can write:

$$C_N(t,\tau,K,\tau_1,\tau_2) = e^{-r(\tau-t)}S_N(t,\tau,\tau_1,\tau_2)\Phi(d_1) - e^{-r(\tau-t)}K\Phi(d_2)$$

$$P_N(t,\tau,K,\tau_1,\tau_2) = e^{-r(\tau-t)}K\Phi(-d_2) - e^{-r(\tau-t)}S_N(t,\tau,\tau_1,\tau_2)\Phi(-d_1)$$

$$d_1 = \frac{\ln S_N(t,\tau_{1,}\tau_2) - \ln K + \frac{1}{2}\int_t^\tau \sum_N^2(s,\tau_1,\tau_2)ds}{\sqrt{\int_t^\tau \sum_N^2(s,\tau_1,\tau_2)ds}}$$

$$d_2 = \frac{\ln S_N(t,\tau_{1,}\tau_2) - \ln K - \frac{1}{2}\int_t^\tau \sum_N^2(s,\tau_1,\tau_2)ds}{\sqrt{\int_t^\tau \sum_N^2(s,\tau_1,\tau_2)ds}}$$

Call and put values substantiate the positions lack of arbitrage.

In the formulas, Ind defines the index value of weather changes that were calculated in (τ_1, τ_2) periods, showing CAT, CDD or HDD values. As for $C_{Ind}(t,\tau,K,\tau_1,\tau_2)$, it is the call or put option price at the time of t ≥ 0, which is in option exercise term from “K” exercise price τ ≥ t. Moreover, it is $\tau \leq \tau_1$ during the calculation of the option and S: is the Spot Price of the Base Stock.

In this case, we can define the put-call parity as below:

$$C_{Ind}(t,\tau,K,\tau_1,\tau_2) - P_{Ind}(t,\tau,K,\tau_1,\tau_2) = e^{-r(\tau-t)}S_{Int}(t,\tau_1,\tau_2) - e^{-r(\tau-t)}K$$

Put-call parity is defined as the parity that shows the relation between the European type of call and put option price based on the same term and implementation price.

This parity means, the value of a portfolio consisting of a long position and a short position option will be equal to the value of a forward contract with the same implementation price and forward contract. If there is not equality or relation showed with formulas, there is arbitrage possibility between the call and put options.

The by-products to hedge the weather risk can be forward, futures or option contracts. If the weather risk is forward contract, the parties contract an engagement to swap the product and the cash based or anchored upon HDD, CDD or another weather index value no matter what the weather index value is in a specified term in OTC market. Therefore, by guaranteeing a specific weather index, with a weather risk forward contract;

$$HDD(\tau_1,\tau_2)=\sum_{t=\tau_1}^{\tau_2}\max(18-T(t),0)$$

in ''T'' in term, index or conclusion, for instance HDD value is fixed. If we also take forward premium into consideration, it is possible to turn the parity into the form below (Cao and Wei, 2004):

$$HDD(\tau_1,\tau_2)=\sum_{t=\tau_1}^{\tau_2}\max(18-T(t),0)+\frac{\operatorname{cov}[\delta_{\tau_2}^{\gamma}\sum_{t=\tau_1}^{\tau_2}\max(18-T(t),0]}{E_t(\delta_{\tau_2}^{\gamma})}$$

The first term in the parity shows the expected cash value of HDD in the future, and the second term shows the forward premium. It is clear that the same formula can be used for CDD forward contract too. In this parity, if the market is in normal backwardation position for forward contract, negative risk premium provides the balance, if it is in contango position, positive risk premium provides it.

We can examine the pricing of weather by-products according to Black-Scholes option pricing model with an example: Let's assume that strike price (K), which is based upon the meteorological weather datum of Chicago O'Hare Airport, of a call option based on February cumulative HDD index of a specific year is 700 and the payment step per degree day is \$10.000. If the datum with lognormal distribution feature dates and the foreseen average or expected (mean: μ) value is 710, and the standard deviation of HDD index value that is calculated by taking its natural logarithm is equal to (σ) 0.07 (Hull, 2012: 760; Company et al., 2007); we can write:

C = 10.000 [710 N (d_1) – 700 N (d_2)]

If d_1 and d_2 show the cumulative normal distribution values:

$$d_1=\frac{\ln(\frac{710}{700})+\frac{(0,07)^2}{2}}{0,07}=0,2376$$

$$d_2=\frac{\ln(\frac{710}{700})-\frac{(0,07)^2}{2}}{0,07}=0,1676$$

is calculated. Accordingly, from Cumulative Normal Distribution Table, it is N(0.2376) = 0.5939 and N(0.1676) = 0.5665. When we replace these values in the first parity, the payment amount that the call option is to provide at the end of expiry date is;

C = 10.000 [710 N (d_1) – 700 N (d_2)] = 10.000 [710 (0.5939) – 700 (0.5665)]
C = 10.000 [25,119] = \$ 251.190,00

If the risk-free interest rate is 3%, the value of the option in the beginning of the term (the previous year) (present value: PV) (e = 2.71828) is calculated as shown;

PV_C = 251.190,00 e $^{-0.03(1)}$ = 251.190,00 (0.970445) = \$ 243.766,22

If the expiry date HDD index value recedes from 710 to 705 (warmer winter than foreseen on 0.704% level) because of global warming or warmer winter than foreseen, it is;

$$d_1=\frac{\ln(\frac{705}{700})+\frac{(0,07)^2}{2}}{0,07}=0,1367$$

$$d_2=\frac{\ln(\frac{705}{700})-\frac{(0,07)^2}{2}}{0,07}=0,0,067$$

N(0.1367) = 0.5546 ve N(0.0667) = 0.5266

And the expected value of the call option for expiry date is calculated as below;

C = 10.000 [705 (0.5546) – 700 (0.5266)] = 10.000 [22.36515] = \$ 223.651,50

The value of the option in the beginning of the term (the previous year) based on the 3% risk-free interest rate is;

PV_C = 223.651,50 e $^{-0,03(1)}$ = 223.651,50 (0.970445) = \$ 217.041,60

Therefore, in this case, when HDD index is warm in 0.704% (= % Δ HDD) ratio, it causes a decline in expiry date of the weather option in 10.96% [% Δ C = (223.651,50 – 251.190,00) / 251.190,00] ratio and in the same ratio as [10.96% = (217.041,60 – 243.766,22)/ 243.766,22 = % ΔPV_C] at the beginning of the term.

As it is seen, the changes in index value and in option value are not in a linear, but convex relation. It means it is;

$\Delta HDD < \Delta C$ and $\Delta HDD < \Delta PV_C$

Such a convex relation creates arbitrage possibility between weather by-products with different terms and an active portfolio management policy.

The change in interest rate is an important element affecting (Δr) option. If the interest rate increases from 3 to 4% (Δ r = + 1%), it recedes to the value below:

PV_C = 251.190,00 $e^{-0.04(1)}$ = 251.190,00 (0.960789) = $ 241.340,71

This means, in given circumstances, an increase by 1% leads to a decrease by $2.425,51 ($\Delta$ C = 243.766,22 – 241.340,71) or in 0.995% ratio per term value of the weather option.

In case of a drop (for example, from 3 to 2% ratio and Δr = –1%) % ΔPV_C increases (PV_C = $246.216,11, ΔPV_C = $2.449,89 and % ΔPV_C = +1.00502%). There is also a convex relation instead of linear relation here, and the correlation between % Δ HDD, % ΔPV_C and Δr can be more or less than 1. In short; the negative relation principle between the interest and the financial asset is also valid for weather by-products.

Quanto options

The abbreviation of Quantity-Adjusting option; Quanto, Quanto options or Cross-Currency derivatives are by-products, arranging the option depending on an underlying asset from a fixed rate with another currency while underlying asset is defined by a specified currency. As is, Quanto options are somehow a currency forward with derivative amount.

This option type, enabling two different currencies to invest directly or indirectly and minimizing the exchange risk; is a suitable by-product for the investors who want to invest in financial assets that are processed by foreign bill and speculators. Thus, an effective protection is provided against currency fluctuations. For instance, a Turkish investor buys German Commerzbank or American General Electric Co. on Swiss Stock Exchange (SIX) with Swedish Franc (CHF), they also buy risk against the changes in CHF / TRY currencies. By purchasing Quanto option with derivative amount forward, the investor can exchange to domestic currency from a fixed currency in term and can protect themselves against the currency fluctuations. From this aspect, compared to the protection with swap contract against a risky position with the same qualification, amount options include a broader risk and a lower cost advantage.

Quanto options are used in weather risk management or energy market. However, ‘Quanto option’ and ‘energy Quanto option’ are different by-products in terms of process dynamics they have. In response to heavily-used amount options in currency markets, energy-amount options are thinner markets. Furthermore, since the underlying asset cannot be called or put, the liquidity degree of energy Quanto options is more limited.

In organized or OTC markets, especially in energy Quanto options that are weather-conditioned and energy by-product featured, the payment depends on the market price of a commodity (for example, electricity) being processed in the market. In case the temperature, rain or other weather conditions exceed a fixed exercise price (strike price) below or above, taking the right of option payment has a financial value.

For instance, in case the weather is warmer (colder) than expected, electric consumers turn on their air conditioners (heaters), and the increase of demand against fixed electricity offer causes a dramatic increase in prices. In this case, the expenses of retailer electricity consumers increase as well. When an amount option is purchased against the risk of this increasing expenses, the option is exercised in case the temperature exceeds or stays below a fixed threshold. Depending on the threshold value, per each negative deviation or tick in temperature, the right of collecting indemnity is used. Thus, unexpected electricity expenses resourcing from temperature deviations can be hedged.

As another example we can give a natural gas or heating fuel retailer. After the winter passes warmer than expected, the energy distributor firm will face a decline in price in both demand and price; contrary to other economic price-demand feature. Complicated strategies that are implemented by means of standard by-products such as futures, option or common ones, will not be able to protect against the risks in which cash flow volatility is affected by a number of factors (price and demand) and will urge to take expensive and risky positions.

As in the examples, Quanto options are related to a third price standard which is called Quanto factor as well as the temperature (weather conditions) and electricity (commodity) volume relation. So it can hedge energy Quanto option against three risks that can occur because of price and temperature and volumetric risks.

In relation to this, in Quanto options in energy markets, there are three factors enabling to exercise the option:

1) Temperature (or HDD as a technicalprovisions of temperature)
2) Volume and
3) Theprice of energy.

If we show the HDD index and index values of implementation values in the amount option contract of average gas price (P) in cash market with K_{HDD} and K_P, and if the degrees are above the implementation values stated in the contract because of a colder winter than expected; which means benefited from (Benth et al., 2013) if it is;

HDD > K_{HDD} ve P > K_P

The investor who has the option will exercise the call option,

$$C = \sum_{t=\tau_1}^{\tau_2} [[\max(HDD - K_{HDD}, 0)][\max(P - K_P, 0)] Miktar]$$

will receive indemnity as much from the option. We can calculate HDD and P index values as below:

$$HDD = \sum_{u=\tau_1}^{\tau_2} g(T_t) \text{ and } P = \frac{1}{\tau_2 - \tau_1} \sum_{u=\tau_1}^{\tau_2} S_u$$

Informulas;
S_u: Spot market energy prices,
T_t: Temperatures on "t" Time as a function of "g" [g(t) = max(0, 18°C – g(t)] (g: Daily average temperature). If the degrees are below the implementation values stated in the contract because of a warmer winter than expected, which means;

HDD<K_{HDD} and P < K_P

the investor who has the option will exercise the call option,

$$C = \sum_{t=\tau_1}^{\tau_2} [[\max(K_{HDD} - HDD, 0)][\max(K_P - P, 0)] Miktar]$$

will receive cash flow as much from the option.
As it is seen, in Quanto options, if both the temperature and the price is below (or above) the contract implementation values, the option is exercised. This structure explains why Quanto options are a better alternatives compared to other standard by-products.

This feature of Quanto options enabled Quanto options to use a great amount in energy market. Because Quanto options are suitable and effective by-products in terms of management of risks both resourced from price and volume in energy market. For this reason, other than Quanto options; options such as Quanto futures, Quanto swap, Quanto barrier, Quanto forward, Quanto corridor are also being used effectively in the markets as of now.

It is possible to calculate the value of a Quanto forward putting contract based on Black-Scholes option pricing model with the help of formulas below (Wystup, 2008; Haugh, 2010; Benth et al., 2013; González-Gaxiola and Chávez, 2016):

Application condition of a Quanto option = Q [Ø(S_T – K)]$^+$

$$C(X,t) = Qe^{-r_{dQ}T} \phi \left[S_0 e^{\mu T} N(\phi d_+) - KN(\phi d_-) \right] \quad \text{and}$$

$$d_{\pm} = \frac{\ln \frac{S_0}{K} + \mu \pm \frac{1}{2} \sigma_d{}^2 T}{\sigma_d \sqrt{T}}$$

Correction value: $\overset{\Delta}{\mu} = r_d - r_f - \rho_{d,f} \rho_d \rho_f$

Informula:
Q: Quanto factor,
Ø: Short-long position indicator,
S_0: Market price of the underlying asset (present value)
T: Option maturity
K: Exercise price (strike price),
t: Option time-to-maturity,
$e^{-r_Q T}$: Continuous discount factor for Quanto factor (e Coefficient = 2.71828),
$e^{\mu T}$: Continuous discount factor for underlying asset,
N(d): Cumulative normal distribution function,
ln: Logarithm,
σ_d: Yield variability of the underlying asset,
σ_d^2: Variance of the underlying asset,
μ: Correction coefficient,
$\rho_{d,f}$: Correlation coefficient between domesticand foreign currencies,
r_d: Yearly continuous compounding value of the domestic risk-free interest rate,
r_f: Yearly continuous compounding value of the foreign risk-free interest rate.

Conclusion

A systematic risk type and having stochastic features, a weather risk is very important in terms of following elements, 1) predetermining the damages, 2) measuring the risk, 3) specifying the measures and taking hedge positions, 4) turning of fund flow fluctuations into a stable trend, 5) price stabilization. Accordingly, weather risk management can be described as all financial activities that are to keep the income flow deviations, which the weather conditions will create, in stability band by using preventive financial tools.

Weather risk is possible to hedge with classic methods such as insurance, in 1996, a financial production which is a much more effective, accurate and with dispute preventive conclusions between the parties is traded in Chicago Mercantile Exchange (CME). This financial production, processed in organized and OTC markets and in all global stock is called weather derivatives and due to the serious advantages it creates, its process diversity and volume are increasing in a fast pace in the world.

Black-Scholes option pricing model is still an effective model in pricing options that are based on commodity and other financial products and taking suitable positions to hedge probable risks. It is understood that, especially in pricing the options to hedge weather risks, under specific circumstances, Black-Scholes model can be used effectively in weather risk management.

However; regarding the use of Black-Scholes option pricing model in weather risk option contracts, there are some limitations compared to other financial derivatives. While the model gives effective results in contracts about agricultural products, the idea of being an effective prediction tool in catastrophic risks like hurricane without transaction volume which the number of contracts create meaningful, statistical results, is suspicious.

Besides, the model is a good predictor especially in seasonal contracts in price predictions regarding weather options about agricultural products. While the model gives more accurate results in shorter periods than season, causes to an increase in the total premium cost of the contract portfolio which consists of short periods.

The assumptions which Davis (2001) and Geyser (2004) stated about applicability of the model are also valid for other option types. Whereas as Considine (2009) stated, unlike other options, long-term average meteorological thresholds about weather conditions for price predictions of the weather options have critical importance. In addition, global warming causes increasingly negative impacts on the stability of the climatic time series, raise the standard deviation variability problem and causes a convex trend in climate index values in accordance with Cao and Wei (2004) approaches. Therefore, the model also provides effective results in determining the arbitrage opportunity between weather options, mainly Quanto options.

REFERENCES

Benth F. E. & Benth J. S. (2013). Modeling and pricing in financial markets for weather derivatives. World Scientific Publishing Co., Advanced series on statistical science and applied probability. 17: 242.

Benth F. E., Lange N. & Myklebust T. A. (2013). Pricing and Hedging Quanto options in energy markets. www.nasdaqomx.com (e.t.08.04.2015).

Black F. & Scholes M. (1973). The pricing of options and corporate liabilities. The Journal of Political Economy. 81(3):637-654.

Cao M. & Wei J. (2004). Weather derivatives valuation and market price of weather risk. The Journal of Futures Markets. 24(11):1065-1089.

Company R., Jódar L., Rubio G. & Villanueva R. J. (2007). Explicit solution of Black–Scholes option pricing mathematical models with an impulsive payoff function. Math. Comput. Model. 45:80-92.

Considine G. (2009). Introduction to weather derivatives, weather derivatives group, Aquila Energy.

Davis M. (2001). Pricing weather derivatives by marginal value. Quant. Financ. 1:305-308.

Geyser J. M. (2004). Weather Derivatives: Concept and application fort their use in South Africa, Agrekon. 43:4.

González-Gaxiola O. & Chávez J. R. (2016). A nonlinear option pricing model through the Adomian decomposition method. Int. J. Appl. Comput. Math. 2:453-467.

Haugh M. (2010). Foreign exchange and “Quantos”. www.columbia.edu (e.t.08.04.2015).

Hull J. C. (2012). Options, futures and other derivatives, Eigth Edition, Pearson Prentice Hall, New Jersey.

Özkan T. (2008). Financial risk management by derivatives caused from weather conditions: Its applicability for Türkiye, risk management and value: Valuation and asset pricing, world scientific printers. World Scientific in International Economics. 3: 644.

Ritter M., Muβhoff O. & Odening M. (2010). Meteorological Forecasts and the Pricing of Weather Derivatives, Weather Derivatives and Risk CRC 646 Conference, Berlin.

www.weather.gov (National Weather Service).

www.wrma.org.

Wystup U. (2008). Foreign exchange Quanto options. http://www.frankfurt-school.de (e.t.08.04.2015).