

# WEATHER RISK MANAGEMENT IN AGRICULTURE

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## Abstract

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The paper focuses on valuation of a weather derivative with payoffs depending on temperature. We use historical data from the weather station in the Slovak town Košice to obtain unique prices of option contracts in an incomplete market. Numerical examples of prices of some contracts are presented, using the Burn analysis. We provide an example of how a weather contract can be designed to hedge the financial risk of a suboptimal temperature condition. The comparative comparison of the selected option hedging strategies has shown the best results for the producers in agricultural industries who hedges against an unfavourable weather conditions. The results of analysis proved that by buying put option or call option, the farmer establishes the highest payoff in the case of temperature decrease or increase. The Long Straddle Strategy is the most expensive but is available to the farmer who hedges against a high volatility in temperature movement. We conclude with the findings that weather derivatives could be useful tools to diminish the financial losses for agricultural industries highly dependent for temperature.

Keywords: weather derivative, option contract, temperature, Burn analysis, hedging

## INTRODUCTION

Weather often has a significant impact on agricultural production. Climate change has increased the frequency and intensity of catastrophic weather events that can caused serious financial damages to the farmers (see, e.g., Černý *et al.*, 2013; Fukalová *et al.*, 2014; Velecká *et al.*, 2014). Actually, it is to be expected that weather fluctuations will increase in the future due to climate change (Pérez González and Yun, 2012).

Weather and its changes have driven a demand for weather risk management. Traditional insurance can be used to avoid high losses coming from catastrophic events but it does not provide an adequate solution to mitigate financial losses which are caused by suboptimal weather conditions (Cyr *et al.*, 2010). Weather derivatives display advantages over traditional insurances. The management of weather risk with derivatives is regular theme of scientific papers. For example studies (Chen *et al.*, 2011; Musshoff *et al.*; 2011; Spicka and Hnilica, 2013;

Ender and Zhang, 2015) analyze weather derivatives as the potentially effective risk management tool for agricultural industries.

Like stated Alexandridis and Zapranis (2013) weather derivatives can be used by corporations or individuals as part of risk management strategy to reduce, i.e. hedge, risk associated with adverse or unexpected weather conditions. They are contracts with the payoff depending on the temperature, rainfall, snowfall, humidity, sunshine or wind. Since, the most common underlying variable is temperature, temperature derivatives will be considered in this paper. Weather market is incomplete in the sense that the underlying weather assets are not tradable. Therefore the price of a weather derivative is usually based on various underlying weather indices. In the majority of papers focused on weather derivatives, authors deal with temperature indices Heating Degree Days (HDD) index (for the fall and winter months) and Cooling Degree Days (CDD) index (the spring and

summer months). There are for example works (Considine, 2000; Taušer and Čajka, 2014). Jones (2011) examines the structure of HDD and CDD contracts along with agricultural hedging uses of weather derivatives.

Weather derivatives are usually structured as futures, swaps and option based on different underlying weather indices (see, e.g., Dischel, 2002). In this work we will only study call/put weather options. The buyer of a call option will receive a payoff if the underlying weather index value is greater than the predetermined strike level at the maturity day. The buyer of a put option will receive a payoff if the predetermined strike level is greater than the underlying weather index value at the maturity day. The buyer of a call/put option pays the seller a premium at the beginning of the contract. Alaton *et al.* (2002) stated that a weather option can be formulated by specifying the following parameters: contract type, contract period, weather station from which the temperature data are obtained, underlying weather index, strike level.

Weather options are either negotiated between two parties in the Over-The-Counter (OTC) market or traded on organized exchanges. The first exchange where standard weather derivatives could be traded was the Chicago Mercantile Exchange (CME). Although the use of weather derivatives is now widespread and increasing, the European market has not developed as quickly as the US market. The key fact is that their understanding by potential issuers and investors (primarily agricultural and energy industries) has been relatively poor.

The main aim of this paper is to price and design a weather derivative and to present the hedging strategies of a suboptimal weather. Based on the data set, we price the call/put options with the payoff depending on temperature index HDD, using the Burn analysis. Basic source of data for the option pricing were daily average minimum and maximum temperatures from the weather station in Košice.

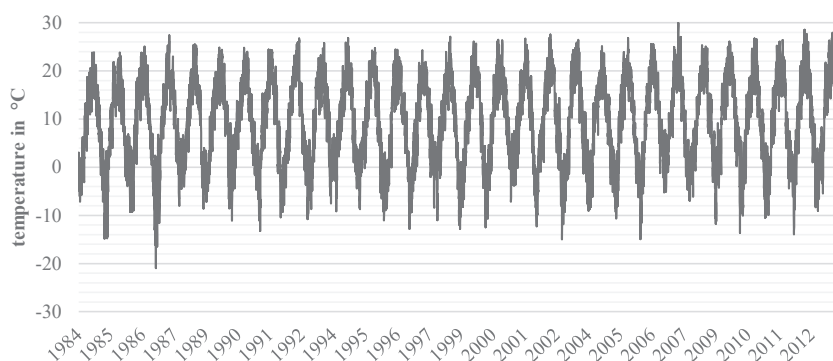
We also design hedging strategies, which can reduce economic impacts of temperature.

Pricing models for weather derivatives exist at many levels of sophistication (see, e.g., Benth and Benth, 2011; Benth and Benth, 2012; Schiller *et al.*, 2012; Zapranis and Alexandridis, 2009; Zapranis and Alexandridis, 2011). The model shown here is not necessarily what the market makers use. This said, a simple model can give a rough idea of what an option should cost. Our findings help to raise the ability of them to understand the application of weather derivatives in order to reduce the financial risk of suboptimal temperature events. Weather derivatives can be very useful to risk managers who understand options and the risk profile associated with buying and selling weather options relative to their business. When investors start to look at the weather derivatives market for hedging purposes, increased liquidity as well as new products will probably follow.

## MATERIALS AND METHODS

There is not a market for weather derivatives in Slovakia. This is attributed to the fact that it is unclear whether and to what extent weather derivatives are a useful instrument of risk management. Since the most common underlying variable is temperature, only the temperature based derivatives will be considered in this paper. A simple pricing formula for an option contract depending on temperature index HDD will be suggested. Agricultural application of weather derivatives to risk management will be indicated.

The data were collected for the studied area Košice. Our methodology can be applied to different cities. The time period consists of 30 years (from 1984 to 2013) with 10,958 observations. The data consists of daily minimum and maximum temperatures from the weather station in the mentioned area. Historical temperature observations were obtained from the National climatic data centre. In Fig. 1 is shown the daily average temperature in the studied area.



1: Graph of the daily average temperature development in Košice from 1984 to 2013.  
(Source: The author's processing based on historical temperatures from the National climatic data centre.)

We use the burn analysis based on historical data from the studied area to compute the price of the option with payoff depending on temperature. The price of the option depends on the temperature index and the strike price.

Based on commonly used temperature index HDD (heating degree-days index) presented by Zapranis and Alexandridis (2009), Benth and Benth (2011) and many others the options are priced. The daily value of the HDD index is:

$$\text{daily HDD (t)} = \max (18 - T(t), 0),$$

where  $T(t)$  is the daily average temperature. The daily average temperature is calculated by averaging each day's maximum and minimum temperature from midnight-to-midnight. To illustrate the concept of HDD, suppose that on a given winter day the high temperature was 11 degrees and the low temperature was 1 degree. This weather results in a daily average temperature of 6 degrees with 12 HDD for this day. The lower is the temperature, the higher is the daily HDD. Weather options are written on the cumulative HDD over a specified period. The annual payoff is calculated as:

$$\text{annual payoff} = \text{annual average HDD} \times \text{tick level}.$$

The owner of a call option obtains the payoff if the HDD index value is higher than the strike price. Assuming the put option owner the payoff is paid if the strike price is higher than the HDD index value.

Let us denote the annual average payoff  $\mu$ , the standard deviation calculated from the annual payoffs  $\sigma$ , the risk-free interest rate  $r$ , the maturity date  $T$ , the relation to the risk  $\alpha$ . The long and short option price is:

$$\text{long} = e^{-rT} (\mu + \alpha \cdot \sigma),$$

$$\text{short} = e^{-rT} (\mu - \alpha \cdot \sigma).$$

The strike prices  $X$  calculated according to the papers (Garcia and Sturzenegger, 2001; Platen and West, 2004; Roustant *et al.*, 2003) have the following forms:

$$A : X = \text{annual average HDD};$$

$$B : X = \text{annual average HDD} - \frac{\text{standard deviation of annual HDD}}{2};$$

$$C : X = \text{annual average HDD} + \frac{\text{standard deviation of annual HDD}}{2};$$

## RESULTS AND DISCUSSION

In pricing we consider following parameters:

- the risk-free interest rate is AAA-rated Slovakia government bond yield for 30 years maturity relating to the historical data,
- the time of HDD option contract conclusion is 31st of december 2013 and the contract is for annual temperature events,
- 20% relation to the risk.

The partial results used in our analysis are in Tabs. I, II. All results can be provided upon request.

### I: Call option pricing

| Strike price in EUR | Annual average payoff | Standard deviation | Price of Long Call option in EUR | Price of Short Call option in EUR |
|---------------------|-----------------------|--------------------|----------------------------------|-----------------------------------|
| 3225.53             | 6.29                  | 4.54               | 7.03                             | 5.26                              |
| 3331.70             | 5.10                  | 4.86               | 5.93                             | 4.03                              |
| 3437.88             | 2.94                  | 4.57               | 3.76                             | 1.98                              |

Source: The author's own calculations

### II: Put option pricing

| Strike price in EUR | Annual average payoff | Standard deviation | Price of Long Put option in EUR | Price of Short Put option in EUR |
|---------------------|-----------------------|--------------------|---------------------------------|----------------------------------|
| 3225.53             | 2.83                  | 4.07               | 3.56                            | 1.97                             |
| 3331.70             | 4.02                  | 4.38               | 4.78                            | 3.07                             |
| 3437.88             | 6.18                  | 4.13               | 6.84                            | 5.23                             |

Source: The author's own calculations

Weather risk for producers in agricultural business refers to the uncertainty about the expected weather conditions. If a farmer wanted to have protection from an extremely cold winter he could buy HDD call options or HDD put options, for an extremely hot winter. For example, if a wheat farmer wanted to use options to hedge his cold weather risk, he could buy HDD call options for a some city at a some strike. The buyer of a weather option has theoretically unlimited profit potential on the upside, while only risking the premium paid for the option on the downside. This limited downside risk is transferred to the writer of the option, who accepts potentially unlimited downside risk in return for receiving the option premium at the time of the sale. The HDD options are European style, which means that they cannot be exercised before their respective maturity dates. The following hedging strategies based on HDD index are examples of how to manage weather risk using option contracts.

Let construct a call option on HDD index with various strike prices. We assume that the call option on the HDD index will buy a farmer whose profits are affected by low temperatures.

The future payoff for every scenario is given in the Tab. III. Two variants of the scenario can occur at the maturity of an option. If the HDD index value at the maturity date  $T$  is below the strike price  $X$ , then the farmer will lose the option premium  $c_B$  which is the cost of risk management benefit. If the HDD index value at the maturity is above the strike price, then the farmer will obtain the payoff of  $(HDD - X - c_B)$ .

| III: Payoff from the buying call option |                 |
|---|-----------------|
| HDD index value scenario                | Payoff          |
| $HDD < X$                               | $-c_B$          |
| $HDD \geq X$                            | $HDD - X - c_B$ |

Source: The author's processing

On 31 December 2013 we will buy the call option on HDD index with the strike price  $X = 3225.53$ . The income function for weather option 1 (WO1) is:

$$P_1(HDD) = \begin{cases} -7.03 & \text{if } HDD < 3225.53, \\ HDD - 3232.56 & \text{if } HDD \geq 3225.53. \end{cases}$$

The income function for weather option 2 (WO2) with the strike price  $X = 3331.70$  has the following form:

$$P_2(HDD) = \begin{cases} -5.93 & \text{if } HDD < 3331.70, \\ HDD - 3337.63 & \text{if } HDD \geq 3331.70. \end{cases}$$

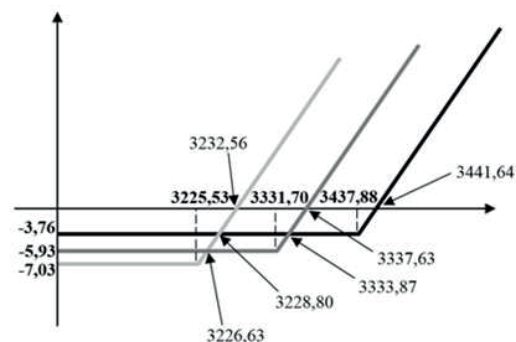
and for weather option 3 (WO3) with the strike price  $X = 3437.88$  is:

$$P_3(HDD) = \begin{cases} -3.76 & \text{if } HDD < 3437.88, \\ HDD - 3441.64 & \text{if } HDD \geq 3437.88. \end{cases}$$

For an option buyer, the premium represents the maximum cost or amount that can be lost, since the option buyer is limited only to the initial investment. The comparison of incomes of WO1, WO2 and WO3 at various development of HDD index value at the maturity time of options is shown in Fig. 2. It can be seen, but also be calculated exactly using income function presented above, that:

- the weather option 3 (with a strike price 3437.88 calculated using formula C), if the HDD index value at the maturity date of options is lower than 3228.80;
- the weather option 1 (with a strike price 3225.53 calculated using formula (B)), if the HDD index value at the maturity date of options is higher than 3232.56.

The lower the strike price, the higher the income from the call option. The income is unlimited, the loss is limited by the option premium. The weather option 1 ensures the highest profit. The cost of this benefit is the highest option premium. This hedging variant is available to the farmer with a higher degree of risk aversion. Low-risk-aversion farmer will prefer the weather option 3. The weather option 2 is the most suitable hedging strategy for the farmer with a neutral risk aversion. It should be noted that, only the weather option with the strike price 3331.70 is used for further analysis.



2: Graph illustrated payoff from the weather options 1, 2 and 3 proposed for Košice. Source: The author's processing

The Long Put strategy is a simple bearish strategy. By buying put option the buyer hedge against a temperature increase. The following table lists the payoff from buying put option.

| IV: Payoff from the buying put option |                  |
|---------------------------------------|------------------|
| HDD index value scenario              | Payoff           |
| $HDD < X$                             | $-HDD + X - p_B$ |
| $HDD \geq X$                          | $-p_B$           |

Source: The author's processing

Assume the put option on HDD index with the strike price  $X = 3331.70$ . The income function of weather option 4 (WO4) is expressed by the formula:

$$P_4(\text{HDD}) = \begin{cases} -\text{HDD} + 3326.92 & \text{if } \text{HDD} < 3331.70, \\ -4.78 & \text{if } \text{HDD} \geq 3331.70. \end{cases}$$

Results of the analysis of weather options 4:

- if the HDD index value at the maturity date of options is lower than 3326.92, then the hedger is profitable;
- otherwise, he suffers a financial loss 4.78.

Options may be combined, by means of which new forms and attractive investment opportunities are created. Option strategies can offer opportunities and advantages to protection or investment from changes in values of various underlying assets and can be also used in the creation of modern structured products. More detailed information about structured products' creation can be found, e.g., in works (Šoltés, 2010; Šoltés, 2011; Harčariková, 2015; Harčariková and Bánociová, 2015; Šoltés and Harčariková, 2015; Šoltés and Pinka, 2015). Much of the trading is concentrated in several popular strategies such as covered call and put, bull and bear spread, strangle and straddle. We want to demonstrate that option strategies can also be a weather risk management tool.

Long Straddle strategy is a neutral strategy that is formed by buying a put option with a strike price  $X$  and option premium  $p_B$  and at the same by buying a call option with a same strike price  $X$  and option premium  $c_B$ . The payoff for every scenario is indicated in the Tab. V.

| HDD index value scenario |  | Payoff                        |
|--------------------------|--|-------------------------------|
| HDD < X                  |  | $-\text{HDD} + X - p_B - c_B$ |
| HDD ≥ X                  |  | $-X + \text{HDD} - p_B - c_B$ |

Source: The author's processing

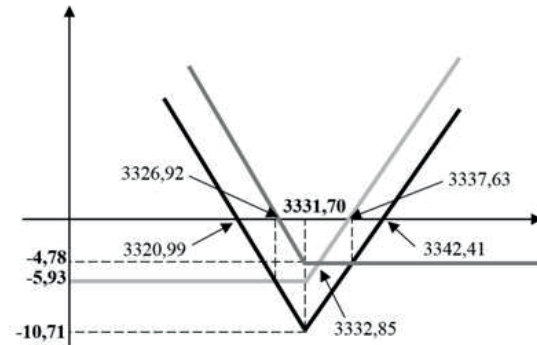
Assume the Long Straddle strategy formed by buying a put option on HDD index with the strike price  $X = 3331.70$  and at the same time by buying a call option with the same strike price. The income function of weather option 5 (WO5) is:

$$P_5(\text{HDD}) = \begin{cases} -\text{HDD} + 3320.99 & \text{if } \text{HDD} < 3331.70, \\ \text{HDD} - 3342.41 & \text{if } \text{HDD} \geq 3331.70. \end{cases}$$

Results of the analysis of weather options 5:

- if the HDD index value at the maturity date of options is lower than 3320.99 or higher than 3342.41, then the farmer is profitable;
- if the HDD index value at the maturity date of options is between 3320.99 and 3342.41, then the farmer makes a loss;
- the maximum lost is 10.71.

Producers in agricultural industries should learn how to evaluate and compare option and option strategies. The Fig. 3 compares weather options 2, 4 and 5 and illustrates the payoff at the maturity date under potential HDD index values. Each of the strategies has their own strengths and weaknesses.



3: Graph illustrated the payoff from the weather options 2, 4 and 5 proposed for Košice. Source: The author's processing

It can be seen, but also be calculated exactly using functions of WO2, WO4 and WO 5 that:

- the buying put option ensures the highest payoff if the HDD index value at the maturity date is lower than 3326.92, but it does not enable to participate in the HDD index value increase;
- the buying call option ensures the highest payoff if the HDD index value at the maturity date is higher than 3337.63, but it does not enable to participate on the HDD index value decrease;
- the farmer is unprofitable if the HDD index value at the maturity date is between 3326.93 and 3337.63.
- the Long Straddle strategy enable to participate on the HDD index value increase or decrease, but does not ensure the highest profit.

We can deduce following conclusions. By buying put option or call option, the farmer establishes the highest payoff in the case of temperature decrease or increase. The cost of this benefit is that the buying put option does not allow the farmer to participate on the price increase and viceversa the buying call option does not allow the farmer to participate on the price decrease. The Long Straddle Strategy is the most expensive but is available to the farmer who hedges against a high volatility in temperature movement.



## CONCLUSION

It is a common knowledge that weather represents the major source of uncertainty in agriculture businesses. This work contributes to the literature by dealing with weather risk management using weather derivatives with the aim to enhance their understanding.

Weather derivatives are increasing in popularity. Yet, there is much more historical data available for the agriculture markets than for other markets. As a result, the use of weather derivatives to hedge agricultural commodities and livestock is increasing. Weather option contracts could be easily used to hedge much of the risk in agricultural commodity volume and in turn lead to increased revenues for farmers and others in agricultural related businesses.

This paper focused on risk of unfavourable temperature movements and its negative effects on agricultural production from the economical point of view. We present options with the payoff depending on temperature index HDD. Companies in the agriculture industry, with revenues adversely affected by extremely cold or hot winters, can buy weather contracts and hedge lower revenues during extreme weather conditions. For example, let us suppose the farmer expects the temperature is going to rise in the future. This would be a good time to hedge against a temperature increase in the future using relevant option hedging strategy. With the options, a farmer is protected against an unfavourable temperature change.

The data for our analyses has been collected from the 30 years long observations of daily minimum and maximum temperatures from the weather station in Košice, Slovakia. Based on the analysis of these historical data, we price the call/put options using the Burn analysis.

Strategy using call option, strategy using put option and Long Straddle strategy for hedging of risks connected with temperature are created. Its economic analysis is performed as well. These hedging strategies are studied in the future scenarios. To conclude, these strategies are effective for the hedging of unfavourable temperature change. In case of extremely cold winter farmer could buy HDD call options, viceversa, for extremely hot winter he could buy HDD put options. Long Straddle strategy is suitable for cold winter and at the same time hot winter. These hedging strategies illustrate the diversity of ways in which agricultural options can be used. The key to using options successfully is the ability of producer to match an appropriate strategy to a particular objective at a given time. The flexibility of strike price selection allows producers to adjust their market risk exposure to any level with which they are comfortable. The strategies we looked at in this paper are fairly common ones, but by no means, there are many other strategies which have to be considered in the agricultural risk management.

This article examines the weather derivatives market and some of its benefits for agricultural risk management. Performed analysis should help to understand the pricing and design of the weather derivatives. In particular, this article is meant to serve as an overview of weather derivatives for those who may not be otherwise exposed to this type of market. Further studies are needed to find an option pricing model for weather derivatives with payouts depending on temperature in an incomplete market.

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