USING METEOROLOGICAL DERIVATIVES FOR WEATHER RISK MANAGEMENT IN AGRICULTURE. THEORETICAL APPROACH

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Abstract
The aim of this paper is to explore weather risk management by application of weather derivatives in agriculture and rate the hedging performance. Meteorological elements highly affect the agriculture sector by influencing the yield of many crops. Weather indices depending on temperature, rainfall and wind speed. The price of hedging is determined by using the Burn analysis applied to the index modeling method. By appliying the weather derivatives in weather risk management we can reduced the yield volatility in agriculture. As the study of Štulec (2017) showed, weather has had a growing impact on the global economy evolution in the last decades, approximately 80% of the world economy is directly or indirectly influenced to the weather. Leggio (2007) states that companies use weather derivatives to stimulate sales and diversify investment portfolios. Contracts with meteorological derivatives make profit depending on the weather (Alexandridis and Zapranis, 2013a). The assets of these contracts are represented by weather indices because the weather is not a physical asset that can be traded.
Keywords: burn analysis, hedging efficiency, long call strategy, weather option, weather risk management.

Introduction

Weather impact can be either catastrophic or non-catastrophic. Depending on the geographical area, catastrophe-type events are unlikely to occur (Stulec 2017). However, if these events occur, we have huge financial damages, not to mention the loss of human lives. In the specialized literature, we find articles regarding the role of insurance to cover the possible financial losses of farmers in the conditions of climate change (Falco et al. 2014). The classic insurances that farmers can buy only cover losses resulting from catastrophic events, financial losses resulting from events that are not considered to be catastrophic are not covered by insurance. (Cyr et al., 2010). Non-catastrophic weather refers to small deviations from normal weather with a high probability of occurrence (Brockett et al., 2005; Bartkowiak, 2009). Hedging against the exposure of catastrophic events can be achieved due to the introduction of meteorological derivatives (Stulec et al., 2016). The weather market is incomplete in the sense that the underlying weather indices are not tradable. Most studies (Davis, 2001; Alaton et al., 2002; Cao, Wei, 2004; Richards et al., 2004; Benth and Benth, 2007; Zapranis, Alexandridis, 2009; Zapranis, Alexandridis, 2011) have analyzed meteorological derivatives and the method of determining insurance prices. Alternative methods for pricing options when the underlying security volatility is stochastic have been examined by Heston (1993), Alaton et al., (2002), Brody et al. (2002), Benth (2003), Benth and Benth (2005), Turvey et al. (2006), Benth et al. (2007), Benth (2011), Benth and Benth (2011), Swishchuk and Cui (2013).

Aims

The use of weather derivatives has proven to be effective in many industries (Yang, 2011). However, we can say that agriculture depends to the greatest extent on climate changes. In this sense, the public sector plays an important role in ensuring a legislative and methodological framework regarding the coverage of farmers' eventual losses, respecting the specific environmental conditions. At European Union level, the Common Agricultural Policy, known as the PAC, supports and regulates the measures applicable at the level of the EU countries regarding the agricultural sector, helping farmers to increase food security.

Food security is influenced by crop yields, which in turn are dependent on the weather. The relationship between the weather and the level of production by crop types is quite complex because the weather influences both the quantity and the quality of the crops. Meteorological elements such as temperature, sunlight, humidity, precipitation level, wind speed and duration are interdependent. In addition to these elements, the production and quality of the crops also depend on elements such as the quality of the soil, the quality of the seeds/seedlings, as well as the degree of technology of the farmer (Stulec et al., 2016). These aspects will be discussed later. As we could see, extreme weather can occur for short periods of time and in areas that initially do not present a risk of extreme weather conditions. Meteorological derivatives considered as a solution for managing non-catastrophic meteorological risks are investigated by various studies. (Chen et al., 2006; Deng et al., 2007; Taušer, Cajka, 2014). The values of meteorological derivatives become effective only if their application will lead to a lower volatility of the economic value of the production. There is no generally accepted criterion for measuring the effectiveness of weather derivatives. Most authors Ender and Zhang (2015), Zhou et al. (2018), and Raucci et al. (2019) analyze the variance and standard deviation to assess their effectiveness in reducing yield volatility.

Materials and Methods

The agricultural sector is susceptible to the risks determined by climate change. In this sense, farmers are the potential users of meteorological derivatives. The purpose of the work is to project the method of calculating the meteorological derivatives with the aim of using them in the calculation of the risk in agriculture regarding the weather, but also to self-evaluate the effectiveness of the measures taken against climate change.

Indices are the basic parameters of any meteorological derivatives. The most popular indices are those that refer to temperature, wind speed, wind power, precipitation and humidity. On the market, the most used meteorological derivatives are those related to temperatures. In this sense, three indices of temperature derivation are determined and used, namely: Heating Degree Days (HDD), Cooling Degree Days (CDD) and Cumulative Average Temperature (CAT).

These three indices are also used by energy companies (Bemš and Aydin, 2021), the presumption of a relationship between the level of energy consumed and the temperature variation is a real one. Without committing an obvious logical deviation, we can assume that there is a deterministic relationship between the yield of agricultural productions and the temperature variation.

Previous studies (Turvey, 2001; Hess et al., 2002; Musshof et al., 2011; Alexandridis and Zapranis, 2013b; Ender and Zhang, 2015; Bobriková, 2016; Raucci et al., 2019), have focussed on weather risk management using weather derivatives in agriculture. Considering their findings, we adopt the following meteorological indices:

a) temperature indices: CAT and CDD

CAT (Alexandridis, 2012) is defined as:

$$\text{CAT (t)} = \sum_{i=1}^{t} T_i \tag{1}$$

where:

- $CAT(t)$– is the cumulative average temperature for the period t,
- t – is number of days

and T_i is the avarage temperature of day i

$$T_i = \frac{Tmax_i + Tmin_i}{2} \tag{2}$$

where

Tmax(i) and Tmin(i) are the maximum and minimum temperatures on day „i" respectively

According to Alaton (2002), the degree day index CDD is:

$$C_t = \sum_{i=1}^{t} CDD_i \tag{3}$$

where:

- Ct– is the cumulative $CDDi$ for the period t,

$$CDDi = max\{Ti - 18 \,;\, 0\} \tag{4}$$

where:

- $CDDi$– is the Cooling Degree Days for the day i.
- Ti – is the avarage temperature of day i.

b) rainfall index: RFI

$$RFI_t = \sum_{i=1}^{t} r_i \tag{5}$$

where:

- r_i – is the amount of precipitation for the day i,
- t – is number of days.

c) wind speed index: CAWS and it is the sum of daily average wind speeds over a period of time and is given by Alexandridis (2012) as:

$$CAWS_t = \sum_{i=1}^{t} DAWS_i \tag{6}$$

where:

- $CAWS_t$– is the wind speed index for the period t,
- $DAWS_i$ – average wind speed for the day i.

Once these indices are determined, any farmer can ensure his yields by covering with options, paying an option premium for them. The price of these options must be calculated considering the fact that meteorological options are not traded on the market (Musshof et al., 2011). In order to be able to calculate the price of the option, three parameters must be determined: the strike value, the spot value of the index and the tick size. The spot value of the index is calculated for each year on the basis of historical data. We set the tick size at 1 Euro. We can determine the strike values on the basis of the average and standard deviation of the annual indexes:

$$K_1 = \frac{1}{N}\sum_{i=1}^{N} CI_i - \frac{\sigma}{2} \tag{7}$$

$$K_2 = \frac{1}{N}\sum_{i=1}^{N} CI_i \tag{8}$$

$$K_3 = \frac{1}{N}\sum_{i=1}^{N} CI_i + \frac{\sigma}{2} \tag{9}$$

where:

- K_1, K_2, K_3 – are strike prices
- σ – is standard deviation of the underlying index during the period
- CI_i– is value of the chosen index in year i
- N – is number of years

The next stage is the application of the Burn analysis on the strike prices calculated in the previous stages. This method calculates the expected payoff of weather option as the average of the payoff's in the past during the period (Jewson, Brix, 2005; Benth and Benth, 2007). The expected payoff is defined by the equation:

$$Expected\ payoff = \frac{1}{n}\sum_{i=1}^{n} p_i \tag{10}$$

with payoff pi in the year i and the call and put option premiums
where:

$$p_{ic} = max\{CI_i - K; 0\} * \text{tick size for call option} \quad (11)$$
$$p_{ip} = max\{K - CI_i\ ; 0\} * \text{tick size for put option} \quad (12)$$

and the CI_i refers to the chosen index value in the year i and the symbol K is the strike index.

Using the Burn analysis, the price of options can be calculated as a so-called fair premium. The term fair premium means a price at which the expected profit from an option for both parties is exactly zero. The option price can simply be calculated as the expected payoff of the option if risk premiums for the seller or buyer or transaction costs are not taken into account. The amounts expressed by (11) and (12) is discounted at the annual risk-free interest rate r, since the option premium is paid at the time of the contract conlusion. Based on the above, the price of options can be expressed as:

$$\text{Option Premium} = e^{-rT} * \frac{1}{n}\sum_{i=1}^{n} p_i \quad (13)$$

where:

- r – is risk-free interest rate;
- T – is maturity period of an option.

The values of the indices obtained for a certain zone/area using the specific formulas can be the object of the determination of strategies to cover meteorological options with the aim of guaranteeing farmers' yields in adverse weather conditions during the year. In practice, an option strategy involves combining two or more options positions in the same time period. We can have a combination between the following options: Long Call, Short Call, Long Put, and Short Put. A put option gives the buyer/seller the right to buy/sell the obligation to buy an underlying weather index at a fixed strike price. The buyer of an option has to pay an initial sum of money called the premium to the seller of the contract. Options may be combined, by means of which new forms and attractive investment opportunities are created. The farmer is the one who selects the appropriate strategy to cover the crop based on his attitude towards risk.

We can consider that weather derivatives are effective if their application leads to a reduction in yield volatility, or in other words, to a decrease in the uncertainty of future cash flows. In this sense, the most common method of measuring volatility will be used, i.e. the coefficient of variation and the standard deviation.

Results

In order to be able to formulate strategies, we must consider the choice of a region for which we must know data series for at least 10 years for each of the following indices: CAT, CDD, RAINFALL, CAWS and Yields. For each index, the basic statistical characteristics must be calculated, such as: average, median, standard deviation, dispersion, margin, minimum, maximum and variation coefficient.

Table 1: Basis statistical characteristics of indices

	CAT	CDD	RAINFALL	CAWS
Avarage	a_{11}	a_{12}	a_{13}	a_{14}
Median	a_{21}	a_{22}	a_{23}	a_{24}
Standard deviation	a_{31}	a_{32}	a_{33}	a_{34}
Dispersion	a_{41}	a_{42}	a_{43}	a_{44}
Margin	a_{51}	a_{52}	a_{53}	a_{54}
Minimum	a_{61}	a_{62}	a_{63}	a_{64}
Maximum	a_{71}	a_{72}	a_{73}	a_{74}
Variation coefficient	a_{81}	a_{82}	a_{83}	a_{84}

Source: Bobriková, M. (2022), where a_{ij} are the values calculated for each index for a specific time and zone

The next step is to calculate the correlation between the meteorological indices and the yields of agricultural products specific to the analyzed area. The result will form the basis of a correlation matrix.

Table 2: Correlation matrix of weather indices and yields in agriculture

	CAT	CDD	RAINFALL	CAWS	Yields
CAT	1				
CDD	b_{21}	1			
RAINFALL	b_{31}	b_{32}	1		
CAWS	b_{41}	b_{42}	b_{43}	1	
Yields	b_{51}	b_{52}	b_{53}	b_{54}	1

Source: Bobriková, M. (2022), where b_{ij} are the correlation values

The element whose correlation has the highest value in the sense of the negative influence of the yields will be chosen as representing the meteorological index that will be used to determine the hedging strategies. We will call it representative index (RI) of the analyzed area. For the analyzed period, we can calculate the prices of insurance premiums based on RI using the Burn method for the time to maturity 1 year (Jewson S., Brix A., 2005).

At the beginning, we can use the Long Call strategy to calculate the price risk against the RI. We can assume that the real value of RI is RI_0. The call option on the RI will attract the farmer whose profits are affected by the high RI values in the future RI_T. Long Call option on RI is the right to buy the RI value for a fixed strike price K at maturity time T. Following the calculations, applying this strategy, we can have two scenarios. One variant is the one in which the value of RI at the maturity date T is lower than the strike price K, in this case the farmer will lose the insurance premium (cL) of the management risk. In the case in which the value of RI is higher than that of K, then the farmer will achieve the payoff of the equation RT-K-CL.

Table 3: Hedged scenarios using the Long Call strategy

RI range	Unhedged index value	Payoff from strategy	Hedged index value
RI_T<K	-RI_T	-cL	-RI_T -cL
RI_T≥K	-RI_T	RI_T-K- cL	-K-cL

Source: Bobriková, M. (2022)

The Long Straddle approach is another method for weather risk management. It is formed by combining Long put option position with a strike price K and option premium pL and Long call option with the same strike price K and option premium cL.

Table 4: Hedged scenarios using the Long Straddle strategy

RI range	Unhedged index value	Payoff from strategy	Hedged index value
RI_T<K	-RI_T	-RI_T +K-cL-pL	-2RI_T -K-cL-pL
RI_T≥K	-RI_T	RI_T -K-cL-pL	-K-cL-pL

Source: Bobriková, M. (2022)

A long straddle is set up for a net debit (or net cost) and profits if the underlying stock rises above or falls below the upper break-even point. Profitability is unlimited on the upside and significant on the downside. The maximum loss is the total cost of the straddle plus commissions.

Conclusion

Using options whose strike index values are different, in the idea of examining a possible hedge through profit, for an insurance premium comparator they represent the maximum cost that can be lost. If the value of the strike index is high, then to buy a hedging option the pay price will be low, and in this case the profit of this strategy is also low.

The premium estimations provided by the burn analysis and index modeling methodologies are quite uncertain. On the other hand, the premium calculated are vulnerable to Monte Carlo mistake. Further research can provide the hedging efficiency of mixed-based weather derivatives that are based on several weather variables, e.g., temperature and rainfall. Moreover, an important issue is to investigate the potential benefits and limitations of weather derivatives for particular crops and areas. Finally, other climate models can suggest a double seasonal analysis for meteorological variables.

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