# Effectiveness of weather derivatives as a hedge against the weather risk in agriculture

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**Abstract**: Weather affects the economies worldwide and all economic sectors are to some extent weather sensitive. Agriculture is traditionally highly weather sensitive. While the catastrophic impact of weather has been long recognized, studied and managed the non-catastrophic weather risk gains in importance as the climate change becomes more pronounced. Weather derivatives provide a flexible management solution for the non-catastrophic weather risk. The paper presents weather derivatives as a new weather risk management tool and reviews and discusses the effectiveness of their application in agriculture.

**Key words**: agriculture, hedging effectiveness, non-catastrophic weather risk, weather derivatives

Weather is a major factor that affects the economies worldwide, having a significant impact either on the companies' revenues or costs, or both. Auer (2003) states that four fifths of the world economy is, directly or indirectly, exposed to weather. The sensitivity or exposure to weather can be defined as the sensitivity of sale, production or costs to meteorological elements such as the temperature, sunshine, rainfall, snowfall, wind, etc. If the volatility of output of a certain sector is caused by the changes in weather, the sector is said to be weather sensitive. Studies show that weather sensitivity varies between the economic sectors and geographical areas and that all economic sectors are to some extent weather sensitive (Larsen 2006, Lazo et al. 2011).

Regarding the severity of its impact, weather can be characterized as catastrophic and non-catastrophic. Catastrophic weather includes events with a low probability of occurrence that cause massive financial damages such as floods, hurricanes, tornadoes and windstorms. Non-catastrophic weather relates to the minor deviations from the usual or normal weather, such as a wormer than usual winter and a rainier than usual summer. The main difference is that the non-catastrophic weather affects the companies' performance but do not threaten lives and property. Uncertainty in future cash flows as a result of seasonal deviations in average i.e. the normal weather is defined as the non-catastrophic weather risk (Brockett et al. 2005). Catastrophic impact of weather has long been recognised, acknowledged and managed. However, the non-catastrophic weather exposure has been given much needed attention only since the turn of the century as the effects of the climate change became more apparent and the economic crisis forced companies to strengthen their cost control. The climate change has shown that weather does not need to be extreme to have serious financial consequences on sales and profits (Berlage 2013). Adverse weather deviations can cause negative impacts on the company's cash flows and value. In order to face these risks and to attract financing, it is necessary to diminish the probability of appearance of such events and the consequential earnings volatility. Weather insurance is a common instrument of protection against extreme weather events, however, when it comes to the non-catastrophic weather, it shows certain disabilities. By contrast, weather derivatives present a new tool of the non-catastrophic weather risk management, offering many advantages over the alternative management tools.

The aim of the paper is to present weather derivatives as a new weather risk management tool and based on the review of the existing studies to discuss the effectiveness of their application in agriculture. The paper is organized as follows. The next section reviews the literature on the weather impact on agricultural production. The third section presents weather derivatives and illustrates their application in agriculture. The fourth section gives a literature review and discussion on the effectiveness of weather derivatives as a risk mitigating tool in agriculture. The final section gives concluding remarks.

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## WEATHER IMPACT ON AGRICULTURAL PRODUCTION

Agriculture is traditionally perceived as a highly weather sensitive sector of economy. Lazo et al. (2011) confirmed it to be the second most weather sensitive sector of the US economy, following mining, with 12.1% of output being exposed to weather. Within the EU project "Weather Impacts on Natural, Social and Economic Systems – WISE", the impact of weather on agriculture has been studied in the United Kingdom (Subak et al. 2000), Netherlands (Tol 2000), Germany (Flechsig et al. 2000) and Italy (Galeotti et al. 2004).

The impact of weather has often been cited as one of the major risks farmers face (Harwood et al. 1999, Njavro et al. 2006, Gugić et al. 2008). The relationship between weather and the crop yield is highly complex because weather affects both the quantity and quality of yield. An excessive rain during the harvest can significantly impair the quality of barley, cotton, tobacco, vegetables, etc. (Skees 2002). Growing crops is often affected by several meteorological elements that are mutually interrelated. For example, the grapes cultivation is exposed to temperature, sunshine, humidity and rain (Gladstone 1992). Respective meteorological elements affect different crops at different stages of their growth cycle. Weather that favours the germination phase can harm the ripening stage, and vice versa. Moreover, insufficient amounts of a certain meteorological elements adversely affect the quantity and quality of the yield of many crops, as well as the excessive amounts of the same meteorological element (Manfredo and Richards 2009, Zara 2010). In addition to affecting production in the open field, weather impacts the profitability of the indoor greenhouse production as well.

The impact of weather on agricultural production has been abundantly studied. Studies have been made on the cultivation of corn (Turvey 1999, Woodard and Garcia 2007, Cafiero et al. 2007), wheat (Flechsig et al. 2000, Spaulding et al. 2003, Kusunose 2010), soybean (Turvey 1999), barley (Marković and Jovanović 2011), rice (Vedenov and Sanchez 2011), sugar beet (Flechsig et al. 2000), potatoes and strawberries (Flechsig et al. 2000, Galeotti et al. 2004), nectarines (Manfredo and Richards 2009), citrus fruits (Roll 1984, Galeotti et al. 2004, Lou et al. 2009) and vines (Happ 1999, Chiang 2004, Galeotti et al. 2004, Zara 2010).

In addition to the plant cultivation, weather affects the animals farming as well. Skees (2002) founded that a high temperature over an extended period of time can reduce the amount of milk produced by cows and the quality and quantity of eggs laid by poultry. Weather also affects fishing as the increase in the water temperature of only several degrees Celsius can partially or completely displace certain fish species from their natural habitats (Scott 2003). Thus, jobs and revenues created by fisheries are threatened, as well as the accompanying tourist activities based on sport fishing.

## WEATHER DERIVATIVES AND THEIR APPLICATION IN AGRICULTURE

The recent literature proposes weather derivatives as a flexible risk management solution. Weather derivatives are financial contracts traded on the derivatives markets, designed to provide the indemnity in the case of adverse weather and as such serve as a hedge against the non-catastrophic weather risk. The underlying asset of weather derivatives is the weather index and, since weather is not a physical good, there is no spot market for weather indices. The weather derivatives market allows for the exchange of the financial exposure to weather. The weather derivatives market traces its roots to the deregulation of the US energy sector in mid-1990s and the extremely warm El Nino winter in 1997/1998 in the USA. With the deregulation, the monopolies began to be replaced by the competitive market structures and many energy and utility companies learned that, while they can hedge away the price risk with futures and options on energy itself, they had no instrument to hedge away the weather risk that can dramatically alter the demand for their products and services. In these circumstances, the weather derivatives made public debut in 1997 with an over-the-counter (OTC) transaction between the Koch Industries Inc. and the Enron Corp., based on the heating degree days index for Milwaukee (Brockett et al. 2005).

A weather derivative contract is defined by the following attributes: (1) a start and an end date of the contract period, (2) a measurement station, (3) a weather variable such as temperature, rainfall, snowfall, wind speed and sunshine hours, measured at the meteorological station over the contract period, (4) a weather index, which aggregates the weather variable over the contract period, (5) a pay-off function, according to which derivative contract is being settled shortly after the end of the contract period and (6) for some types of weather derivative contracts, a premium

paid from the buyer to the seller at the start of the contract (Jewson and Brix 2005). Weather derivatives are financially settled at the maturity according to the deviation of the underlying weather index from the predetermined strike index. Strike level reflects the expected value of the weather index and is commonly calculated as a 10-year historical average (Pres 2009). Some authors believe that it is more accurate to include longer weather observations, heading back 20 to 40 years, as to include more variation (Dischel 2002). Given the pronounced climate change, a more recent weather may be a better presentation of the expected future weather, implying that a shorter weather observation would provide a more credible strike level. It is not necessary to hold the contract until its maturity as the investors can offset their positions by inverse operations on the market prior to the maturity (Taušer and Čajka 2014).

The main advantage of weather derivatives over the weather insurance is that the indemnities are determined solely on the value of the weather index at maturity thus eliminating possibilities for the moral hazard and adverse selection which are the major weather insurance shortcomings.

Weather derivatives can be traded on the regulated exchange or OTC market both for the insurance and reinsurance purposes. The Chicago Mercantile Exchange (CME) is currently the only exchange that offers the weather derivatives trading. Attempts have been made to establish regulated weather derivatives market in Europe. The London International Financial Futures Exchange (LIFFE) introduced in 2001 the temperature weather derivatives on London, Berlin and Paris, but it has suspended the weather derivatives trading in 2004 because of the lack of demand and major structural problems (Tindall 2006). The
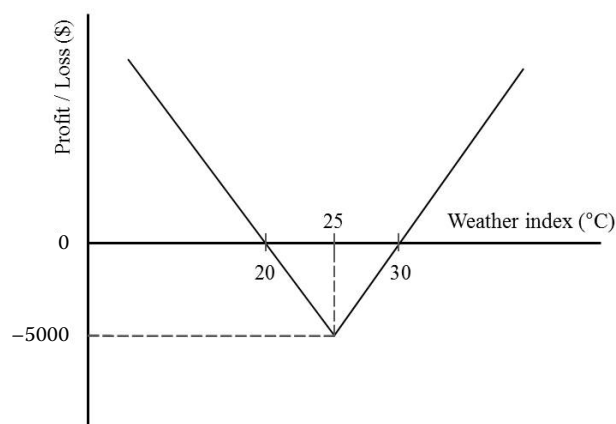
insurance companies and brokerage firms act as important counterparties on the OTC market thanks to their ability to effectively pool the weather risk.

Most common types of weather derivatives are the weather swaps and the call and put options, while some more complex structures involve the collars, straddles, strangles, binary options and baskets (Jewson and Brix 2005). The purpose of weather derivatives application is to smooth the revenues, to cover excess costs, to reimburse the lost opportunity costs, to stimulate sales and to diversify investment portfolios (Leggio 2007).

The application of weather derivatives in agriculture can be illustrated on the example of the grapevine producer who is seeking protection against adverse temperatures. The optimal atmospheric conditions for wine growing are temperatures between 20 and 30°C (Van Lennep et al. 2004), implying that the winegrower should enter into a derivative transaction that simultaneously protects him/her from both a too low and a too high temperatures. Such protection can be provided with the straddle which is a combination of a call and a put option with the same underlying weather index, strike and maturity. Farmers often need a weather derivative design to offset a complex weather exposure. Let us assume that the winegrower enters a long straddle, meaning he/she buys a put option with the strike level at 25°C for the premium of $2500 and a call option with the same strike level of 25°C for the premium of $2500. The underlying weather index is defined as the average daily temperature. The Pay-off function is determined in accordance with the sensitivity of the grapevine production to the temperature and amounts to $1000 for every °C of deviation from the strike level. The call option provides the farmer with the indemnity in the case of a temperature increase above 25°C, whereas put option provides indemnity in the case of temperature decrease below 25°C. If the temperature moves in the opposite direction, the farmer's loss is bound to the amount of the premium. The graphical presentation of straddle strategy is given by Figure 1.

The Pay-off function of given straddle can be presented by the following equation:

$$p(W) = max[0, T \times (S - W)] + max[0, T \times (W - S)] - premium_{put} - premium_{call}$$

where $T$ stands for the tick, i.e. monetary value of the weather sensitivity, $S$ for the strike and $W$ for the underlying weather index. It can be seen that the



Figure 1. Long straddle

indemnity paid increases as the deviation from the strike increases, however, to cover the transaction costs, the difference between the observed index value and the predetermined strike must be higher than the cost of two premiums. The value of the strike is determined as to assure that the break-even point form the derivative transaction coincides with the true temperature thresholds of 20 and 30°C.

Let us assume that in the observed day, a temperature of 18°C was recorded. The winegrower would receive the payment from the put option in the amount of $7000 [(25°C – 18°C) × $1000], whereas the call option would remain unexercised. After subtracting the cost of two premiums, the net payment would amount to $2000. Weather derivatives typically cover a longer period of time such as a week, a month or a season, so in these cases, the protection strategy would be created on the basis of the cumulative value of the weather index recorded during the covered time period.

## EFFECTIVENESS OF WEATHER DERIVATIVES AS RISK MITIGATING TOOL IN AGRICULTURE

The purpose of the weather derivatives application, as well as any other risk management instrument, is to reduce the volatility of revenues and/or costs caused by volatility of the non-catastrophic weather. The purpose of indemnities paid by weather derivatives is to provide a cover for the lost revenues and excess costs caused by an adverse weather. Accordingly, weather derivatives can be considered effective if their application results in a lower volatility of the realized profits, thus decreasing the uncertainty i.e. the riskiness of future cash flows. A lower volatility of profits can increase the company's credit rating and assure lower rates of the borrowing capital.

The application and effectiveness of weather derivatives have been studied and proven in the production of grapes, corn, wheat, barley, soybean and cotton. The most commonly used measure of volatility i.e. risk is the variance and the standard deviation. However, some authors argue that the investors are not concerned about the total deviation, meaning both positive and negative, but solely the negative deviation from the average and use the semi-variance as risk measure. Semi-variance is similar to variance with the difference that solely the negative and not both the positive and negative deviation from the average is taken into calculation.

Zara (2010) studied the effectiveness of weather derivatives in the wine grapes production in France. The application of strangle was assessed and the Ribereau-Gayon Peynaud (RGP) hydrothermal index was defined as the underlying weather index. The results show that application of strangle results in lower volatility of the economic value of the grapes production by 22.06% compared to the economic value of the grapes production without the weather derivatives application. Video and Barnett (2004) studied the effectiveness of weather derivatives in the production of corn, soybean and cotton in two regions in the USA. The authors stress out that because of the specificities of weather risk, the weather derivatives design should be customized for each crop and each geographical area. The results show that the weather derivatives application results in a lower output semi-variance ranging from 16.6 to 77.1%. Put options were based on the rain index and the call options were based on the temperature index. The results show that the weather derivatives application results in a lower semi-variance regardless of the underlying index. However, the temperature options prove to be more effective than the rain options in mitigating the weather risk in the corn production. Spaulding et al. (2003) studied the effectiveness of the rain put options in the corn and wheat production in Romania. The results show that the weather derivatives application can decrease the output variation by 39%. Torriani et al. (2008) studied the effectiveness of the rain put options in the corn production in Switzerland. The authors use the value-at-risk (VaR) as a risk measure and results show that the weather derivatives application reduces the maximum possible loss due to the adverse weather. Moreover, based on the long-run model the authors show that the weather derivatives application is to be even more effective in the future due to the pronounced climate change. Marković and Jovanović (2011) studied the effectiveness of the rain put option in the winter barley production in Germany. Measured by the standard deviation, the results show that the weather derivative application reduces the output variability by 40.42%. Summarized insights from literature review on hedging effectiveness of weather derivatives in agriculture are given in Table 1. Apart from the crop production, the weather derivatives effectiveness has been studied and proven in the dairy production as well (Chen and Roberts 2004; Chen et al. 2006; Deng et al. 2007).

Based on the reviewed literature, it can be concluded that there is no universally accepted measure of the

Table 1. Summary of studies on effectiveness of the weather derivatives application in agriculture

| Author/s | Crop | Field location | Derivative type | Weather index | Effectiveness measure | Risk reducing performance |
|---|---|---|---|---|---|---|
| Zara (2010) | Wine grapes | France | Strangle | Hydrothermal index | Decrease of standard deviation and variation coefficient, increase of mean yield | 22.06% |
| Vedenov and Barnett (2004) | Corn, soybean, cotton | USA | Put option | Temperature index, rainfall index | Decrease of mean root square loss (MRSL) and value-at-risk (VaR), increase of certainty-equivalent revenue (CER) | 16.6% to 77.10% |
| Woodard and Garcia (2007) | Corn | USA | Call option, put option | Temperature index, rainfall index | Decrease of mean root square loss (MRSL) | 10.80% to 46.45% |
| Spaulding et al. (2003) | Corn, wheat | Romania | Put option | Rainfall index | Decrease of variation coefficient, increase of mean yield | 39% |
| Marković and Jovanović (2011) | Winter barley | Germany | Put option | Rainfall index | Decrease of standard deviation | 40.42% |

weather derivatives effectiveness. Majority of the authors analyse the variance and semi-variance when assessing effectiveness, whereas the mean-variance criterion, the value-at-risk, the certainty equivalent revenue and the utility function enhancement are used less often. Effectiveness of weather derivatives varies between crops, geographical locations and time periods. Specificities of the weather risk call for a customized weather-sensitivity analysis and a customized design of weather derivatives.

**CONCLUSION**

Studies show that weather affects the economies worldwide having a direct or indirect impact on almost every economic activity. Primary sector of economic activities traditionally shows high weather sensitivity. Weather insurance proved to be an effective instrument of protection against the catastrophic weather risk, however, when it comes to seasonal deviations from the usual or normal weather, the weather insurance shows some deficiencies. On the contrary, weather derivatives provide a flexible non-catastrophic weather risk management solution with completely objective pay-offs, thus minimizing the moral hazard and adverse selection problems. Prior to the advent of weather derivatives, the companies had limited solutions for the non-catastrophic weather risk management. Many companies simply ignored the weather risk or were trying to cope with the consequences of the adverse weather to the best of their

abilities. Nowadays, the weather risk management principles are more necessary due to the omnipresent economic crisis and the increased weather volatility caused by the climate change.

Weather sensitivity of agricultural production is highly complex as weather affects both the quantity and quality of the yield and because the crop cultivation is exposed to more than one meteorological element the impact of which varies in different growth stages. A complex weather exposure calls for a complex design of weather derivative. The paper gives an illustration of the straddle application in viticulture as a hedge against both a too low and too high temperatures.

The application and effectiveness of weather derivatives have been studied and proven in the production of grapes, corn, wheat, barley, soybean and cotton. The most commonly used measure of the yield volatility i.e. risk is the variance and standard deviation, whereas some authors use the semi-variance arguing that hedgers are solely concerned about the negative and not both the positive and negative deviation from the average economic value of the yield. Weather derivatives are considered effective if their application results in a lower volatility of the economic value of the yield. The existing studies show that the weather derivatives effectiveness varies between the crops, geographical areas and the covered time periods and are measured relatively by the volatility reduction ranges from 10.8 to 77.1%.

The value of the paper is reflected in the outline of weather derivatives and the illustration of possible

application in agriculture. Reviewing the literature, we identified the crops for which weather derivatives proved as the effective non-catastrophic weather risk management strategy. A further research should focus on the comparison of effectiveness of different designs of weather derivatives and on the weather derivative pricing.

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