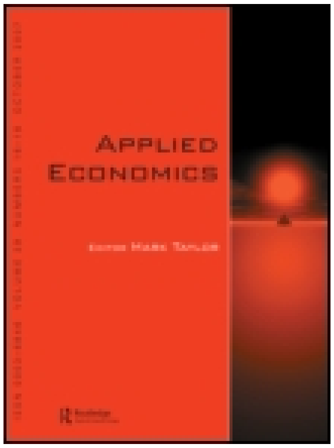

Applied Economics
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/raec20

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Published online: 05 Aug 2009.

To cite this article: Oliver Musshoff, Martin Odening & Wei Xu (2011) Management of climate risks in agriculture-will weather derivatives permeate?, Applied Economics, 43:9, 1067-1077, DOI: 10.1080/00036840802600210

To link to this article: http://dx.doi.org/10.1080/00036840802600210

Applied Economics, 2011, **43**, 1067–1077

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Management of climate risks in agriculture – will weather derivatives permeate?

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It is a matter of common knowledge that weather represents the major source of uncertainty in crop production. It is to be expected that weather fluctuations will increase in the future due to climate change. Traditionally, farmers tried to protect themselves against weather-related yield variations by buying insurances. More recently, there has been a discussion regarding the use of weather derivatives to safeguard against volumetric risks. Although weather derivatives display advantages over traditional insurances, there is only a relatively small market for these products in agriculture. This is partly attributed to the fact that it is unclear whether and to what extent weather derivatives are a useful instrument of risk management in agriculture. This study applies real yield and weather data from Northeast Germany in order to quantify the risk-reducing effect that can be achieved in wheat production by using precipitation options. To do so stochastic simulation is used. The hedging effectiveness is controlled by the contract design (index, strike level, tick size). However, the local basis risk and the geographical basis risk remain with the farmer. We separate both causes of basis risk and reveal the extent of each. This enables conclusions regarding the design of weather derivatives; thus the question dealt with here is relevant both for farmers and for potential sellers of weather derivatives.

I. Introduction

Weather is an important production factor and at the same time one of the greatest sources of risk in agriculture. Perhaps, the most obvious impact of weather is on crop production (cf e.g. Isik and Devadoss, 2006). There is scarcely a year in which there are no drought periods or extreme precipitation in the most diverse regions of the world leading to crop failures. The impact of the weather risk is not limited to crop production. The performance of livestock farms, the turnover of processors, the use of pesticides and fertilizers as well as the demand for many food products also depends on weather. Hence, large parts of the agribusiness are affected by weather risks.

It is expected that fluctuations in temperature and rainfall will increase in the wake of global climate change and thereby the volumetric risk will rise further. At the same time, the susceptibility of farms

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Applied Economics ISSN 0003–6846 print/ISSN 1466–4283 online © 2011 Taylor & Francis
http://www.informaworld.com
DOI: 10.1080/00036840802600210

to risk will rise as a result of the increasing capital intensity of agriculture and the associated increasing debt ratio. Therefore, it will become increasingly necessary for farmers to insure themselves against weather risks.

Farmers have always been confronted with risks. In the past, farmers tried to protect themselves against the negative economic consequences of bad weather events by using on-farm risk management instruments like choosing less weather-dependent production activities, choosing a widely diversified production program, procuring overcapacities or investing in technologies to control the environment (e.g. irrigation technologies). Additionally, farmers have tried to share risks through buying damage-based insurances (cf e.g. Mishra and Goodwin, 2006). Agricultural policy support (e.g. direct government aids in response to natural calamities and disasters) can also yield an insurance effect (cf e.g. Thompson *et al*., 2004).

From the end of the 1990s onwards, there has been a discussion about the use of index-based instruments, also called weather derivatives, as a new instrument to safeguard against volumetric risks (cf Tigler and Butte, 2001; Cao *et al*., 2003; Berg *et al*., 2004; Jewson *et al*., 2005). Weather derivatives are financial market products, such as futures, options or swaps, which allow exchanging weather risks. They are related to objectively measurable weather variables (temperature, rainfall, wind, etc.). Until now, weather derivatives have been used mainly by energy companies. Trading of weather derivatives also occurs predominantly in the Over-The-Counter (OTC) market. This means that the contracting parties have to establish their contract specification bilaterally. As a contractual partner for a farmer wishing to be insured against insufficient rainfall during the growth phase of crops, for instance, the tourist industry (e.g. theme parks) can be considered, which exhibits a contrary risk exposure with regard to rainfall. However, weather derivatives also offer attractive opportunities for institutional investors such as insurers or banks to diversify a portfolio, since the weather-related risks are only correlated relatively weakly with the systematic risk of a national economy.

Whereas traditional damage-based insurances predominantly protect against damages from catastrophic events (e.g. hail), weather derivatives can be designed to release payments even for less drastic events (e.g. insufficient rainfall). A holder of a traditional insurance must also prove the damage in order to obtain indemnity payments. Unlike conventional damage-based instruments, the hedge from weather derivatives results from payments which are tied to weather variables that are measured objectively at a specified location; that is, weather derivates are not impact-oriented, but cause-oriented. Weather derivatives thus offer administrative advantages over traditional insurances. Furthermore, weather derivatives, unlike insurances (cf e.g. Jin *et al*., 2005), are not affected by moral hazard problems and adverse selection. Therefore, weather derivatives have the advantage of relatively low transaction costs.

Although (i) agriculture is directly dependent on the weather, (ii) experts point out numerous potential applications of weather derivatives especially because of the advantages named above (cf Turvey, 2001; Skees, 2002) and (iii) there have already been some promising practical experiences in the USA and Canada, the market for weather derivatives in agriculture is currently still relatively small. This may partly be accounted for by the fact that farmers are not yet familiar with using weather derivatives. Another problem is that different valuation methods for weather derivatives can provide different prices. A possible consequence is that no unique price is found which market participants consider to be fair. The market then lacks liquidity and there is consequently a lack of orientation for other potential market participants. Another possible obstacle to their application can be seen in the basis risk which remains with the farmer when he uses weather derivatives and which means that yield variations are not compensated exactly by corresponding payoffs from the weather derivative. One cause of the basis risk is that yield variations are generally not perfectly correlated with the relevant weather variable (local basis risk). For example, the weather derivative could refer to the rainfall sum at the place of production in May, although e.g. the rainfall at other time periods, the timing of the rainfall and the temperature also influence the yield in the crop production. On the other hand, there is a geographical basis risk. In this context, this means the noninsurable risk which results from the difference between the weather event at the reference point of the derivative and the site of agricultural production. Although this aspect is not so important for temperature-related instruments, it cannot be neglected in the analysis of the hedging effectiveness of rainfall derivatives, as there is a high spatial variability of rainfall.

An increasing number of publications investigate the usefulness of weather derivatives as a risk management instrument in agribusiness. Previous studies have focussed on the one hand on theoretical questions of pricing weather derivatives and on the other hand on analysing temperature-related instruments (cf van Asseldonk, 2003; Richards *et al*., 2004;

Manfredo and Richards, 2005; Turvey, 2005). For agricultural applications, rainfall-related instruments ought to play a greater role. Hitherto, however, there have been very few publications especially on the analysis of the hedging effectiveness of precipitation-based instruments (cf Turvey, 2001; Stoppa and Hess, 2003). As yet, therefore, it is unclear whether weather derivatives will permeate in agriculture (Edwards and Simmons, 2004).

The aim of this study is to clarify the risk-reducing effect of using rainfall options, specifically by considering wheat production in Northeast Germany by means of a with/without derivative comparison. Special attention will be given to quantifying the basis risk, which will be divided into the previously mentioned components (i) local basis risk and (ii) geographical basis risk. The separation of the basis risk, which to our knowledge has not been treated previously in literature, will provide important findings for the design of weather derivatives and their potential for usage in agriculture. Thus, the questions dealt with here will be relevant both for farmers and for potential sellers of weather derivatives.

The remainder of the article is structured as follows: in Section II, the database and methodical procedure are described. In Section III, the analysis of the hedging effectiveness of rainfall options for a representative cash crop farm in Northeast Germany is carried out. The article ends with conclusions for the design of weather derivatives (Section IV).

II. Data and Methodical Procedure

Grain production in Northeast Germany, Brandenburg in particular, is highly affected by rainfall risk. During the important grain-yield months of April to June, the rainfall sum in Brandenburg was between 64 and 258 mm over the last 20 years (at an average of 141 mm and a SD of 46 mm) – measured at the Berlin–Brandenburg central weather station in Berlin–Tempelhof. The grain yields have fluctuated similarly, due to the sandy soil possessing little water-storing capacity and a lack of artificial irrigation facilities. Currently there exists no opportunity of insuring against yield losses caused by rainfall. During the drought years 2000 and 2003, disaster relief was even granted by the government on account of the extreme harvest failures, in order to protect farms against insolvency. Of course, such government supports are not always be guaranteed. Therefore, there is a pronounced interest among affected farmers for a routine form of hedging weather-related risks.

For a farm-specific analysis of the hedging effectiveness of weather derivatives, a representative cash crop farm with approximately 850 ha of acreage operating in the Federal State of Brandenburg, more precisely in Ketzin, is considered. The farmer wishes to be insured against weather-related yield losses in wheat production. Wheat is the major production activity with a crop proportion of more than one–third. Without a weather station or a suitable contractual partner, it is difficult for the farmer to obtain a derivative which refers directly to the weather on site of production. Nonetheless, it is assumed that derivatives which refer to the rainfall measured at the weather station in Berlin–Tempelhof are available on the OTC market. Ketzin is situated about 39 km west of Berlin–Tempelhof. Both causes of basis risk which have previously been outlined are evident here: on the one hand, a number of weather variables influence the wheat yield while the payoff of the derivative and the indemnity payments is solely derived from rainfall. On the other hand, Ketzin is 39 km away from Berlin–Tempelhof, which means that the rainfall in each location can be completely different in principle. Thus, even if the agricultural production were only dependent on the rainfall, indemnity payments and yield failure could still be different on account of the spatial distance.

In order to evaluate the hedging effectiveness of weather derivatives, a weather variable must first be specified and the production function must be estimated in which the weather is not – as is usual – a part of the error term, but a noncontrollable (though measurable) production factor. Derivatives, which refer to the weather variable in the production function, are then specified. Before the hedging effectiveness of weather derivatives can be quantified, the derivatives – which do not yet exist but which could be available in principle – must be priced. The elements of a farm-specific analysis of the hedging effectiveness of weather derivatives are summarized in Fig. 1.

On the specification of the weather variables

Previous publications on rainfall-related derivatives have tended to refer to an accumulation index (cf Skees *et al.*, 2001; Turvey, 2001; Stoppa and Hess, 2003; Vedenov and Barnett, 2004). The cumulative rainfall index I_T^C corresponds to the rainfall sum within a specific time period:

$$I_T^C = \sum_{t=1}^{x} y_t \tag{1}$$

here, y_t indicates the rainfall on day t and x indicates the length of the accumulation period.

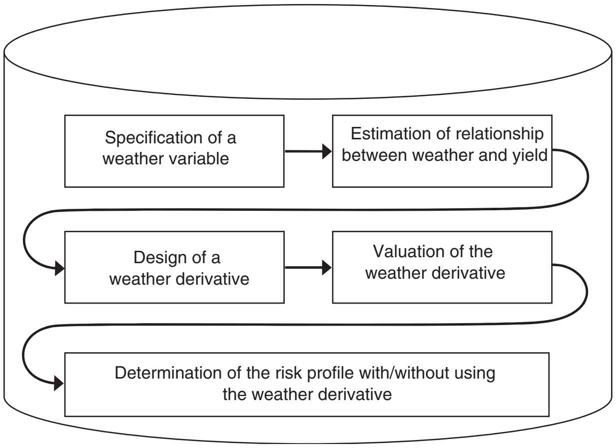

Fig. 1. Elements in a farm-specific analysis of the hedging effectiveness of weather derivatives

Alternatively, the rainfall deficit index I_T^D is suggested here, which expresses the timing of rainfall in addition to the quantity[1]:

$$I_T^D = \sum_{\tau=1}^{z} \min\left(0, \sum_{t=(\tau-1)\cdot s+1}^{\tau\cdot s} y_t - y^{\min}\right) \quad (2)$$

This index measures the shortfall of the rainfall sum in an s-days period relative to a reference level $y^{\min}$. This shortfall is cumulated over z periods. Hence, the construction principle is similar to that of degree-day-indices, which are widely used for the specification of temperature derivatives (cf e.g. Zeng, 2000a; Alaton *et al.*, 2002).

On the estimation of the production function

For the considered cash crop farm yield data for winter wheat over a period from 1993 to 2006 are available. Fourteen observations seem to be a poor database for the estimation of the yield model. However, a longer time series is not available for the new federal states in Germany in general and Brandenburg in particular, since production took place under totally different conditions prior to German reunification. Furthermore, it should also be noted that the yield data survey was not performed in accordance with the wheat variety, even though certain wheat varieties are better suited to regions with low rainfall such as Brandenburg and are preferred there for cultivation. Using statistical tests, no significant trend can be found for the wheat yields.

Using daily rainfall data measured at the weather station in Berlin–Tempelhof, the rainfall indices described in Equations 1 and 2 for the years 1993 ($T-14$) to 2006 ($T-1$) are calculated. To specify the relationship between the rainfall sum or rainfall deficit index observed in Berlin–Tempelhof I_b and the wheat yield observed for the farm in Ketzin $\tilde{Q}_b$, a linear-limitational (Leontief) production function seems most suitable[2]:

$$\tilde{Q}_b = \begin{cases} a_0 + a_1 \cdot I_b + \varepsilon_b & \text{if } I_b < a_2 \\ a_3 + \varepsilon_b & \text{otherwise} \end{cases}$$
$$\text{with } b = T-14,\ T-13, \ldots, T-1 \text{ and}$$
$$\varepsilon_b \sim N[0, \sigma_\varepsilon] \quad (3)$$

'$\sim$' makes it clear that the yield at the farm location in Ketzin is meant, whereas the weather index is related to weather data measured in Berlin–Tempelhof (I_b instead of $\tilde{I}_b$). a_0, a_1, a_2 and a_3 describe the parameters of the production function to be estimated. When $a_1 > 0$, then drought-related yield losses are to be expected for the rainfall index below a_2 mm. If values for the rainfall index are above a_2 mm the expected wheat yield corresponds to a_3 dt/ha. ε_b indicates the normally distributed error term with a SD of σ_ε. It should be noted that this error term expresses both the local basis risk and the geographical basis risk: on the one hand, the yield-explaining weather index only refers to rainfall in a specific accumulation period. On the other hand, the production function is determined on the basis of yield data at the site of production and the weather event at the reference weather station.

There is some back coupling between the estimation of the production function and the precise specification of the rainfall indices, since weather variables are sought which are correlated as highly as possible to production output. Variant calculations are used to examine which reference period delivers the 'best' rainfall sum index and which reference period allows the 'best' rainfall deficit index. In order to do so, systematic variations for x as well as for z and s are carried out. $y^{\min}$ was selected so as to provide a maximum correlation between the wheat yield and the deficit index.

Table 1 shows the parameter estimates and the explanatory power for selected production functions. Measured at R^2, the best rainfall sum index for the

[1] This definition may appear unusual since the rainfall deficit index will take negative values. However, the definition is convenient for the present application because then the relationship between yield and rainfall deficit index is similar to that between yield and rainfall sum index.

[2] Several further functional forms for the yield model have been tested; in particular a quadratic and a logarithmic production function. Nonetheless, the linear-limitational production function showed the best fit in terms of R^2 for the empirical data and both rainfall indices. It should be noted that this result cannot be generalized. Vedenov and Barnett (2004) point out that a suitable yield-rainfall-model is dependent on type of variety and region.

Table 1. Estimates for different production functions

	Rainfall sum index				Rainfall deficit index				
Period	Jan.–June	April–June	May–June	June	Jan.–June	April–June	April–June	April–June	June
x	181	91	61	**30**	–	–	–	–	–
z	–	–	–	–	26	19	**13**	11	4
s	–	–	–	–	7	5	**7**	9	7
y^{min}	–	–	–	–	7.5	2.9	**7.4**	22.1	7.5
a_0	0 (0.00)	0 (0.00)	50.9 (4.91)	**54.9** (8.10)	88.5 (6.84)	137.9 (13.17)	**107.8** (8.81)	87.8 (4.96)	81.8 (15.67)
a_1	0.28 (5.23)	0.58 (7.23)	0.10 (1.20)	**0.14** (1.38)	0.38 (2.06)	3.73 (6.40)	**1.35** (3.62)	0.22 (1.45)	1.98 (3.81)
a_2	233.1	109.6	220.1	**144.3**	−39.8	−19.0	**−29.4**	−53.6	−7.1
a_3	64.6 (1.11)	64.1 (3.88)	73.7 (1.37)	**75.5** (2.68)	73.4 (2.08)	67.1 (2.38)	**68.0** (2.15)	76.0 (1.91)	67.7 (2.80)
σ_ε	10.2	11.0	11.1	**10.9**	9.9	8.7	**8.7**	10.8	9.0
R^2	0.10	0.09	0.13	**0.15**	0.30	0.47	**0.48**	0.17	0.43

Notes: The t-values are given in parentheses. The critical t-value is 1.81 or 1.37 at a probability of error of 5 or 10%. Bold values indicate the best estimates for the respective yield-rainfall-model.

accumulation period June and the best rainfall deficit index for the accumulation period April to June are obtained. It should be noted that the explanatory power between the wheat yield and the best rainfall deficit index ($R^2 = 0.48$) is considerably higher than that between the wheat yield and the best rainfall sum index ($R^2 = 0.15$).

The specification of derivatives which refer to the best rainfall sum or rainfall deficit index is described in the following.

On the specification of the weather derivatives

The revenue function of wheat production can be derived from the production function. As only volumetric risks are to be considered, it is assumed that the wheat price P is fixed by a forward contract and amounts to 10 €/dt. A derivative is now constructed respectively for the best rainfall sum index and the best rainfall deficit index in such a way that it compensates for expected revenue fluctuations precisely by corresponding payoffs. For a linear-limitational production function this can be achieved using an option. The payoff for a (European) put option corresponds to:

$$F_T = \max(S - I_T, 0) \cdot V \tag{4}$$

At expiry time T the put option generates a positive payoff F_T when the rainfall index I_T is below the strike level S. If the strike level is above the index, the payoff is zero. The tick size V monetizes the positive difference between S and I_T.

One put option relates to the cumulative index I_T^C which is measured in June 2007 at the weather station at Berlin–Tempelhof. The second put option refers to the rainfall deficit index I_T^D between the 7-day rainfall measured at the weather station in Berlin–Tempelhof and 7.4 mm cumulated during the period April to June 2007. Farmers can obtain each of the two options in July 2006. In order to design the options in such a way that their payoff is complete inversely to the expected revenues from the wheat production (per ha), strike level and tick size must be selected as follows: $S = a_2$ and $V = a_1 \cdot P$.[3] As illustrated in Fig. 2, the options deliver a payoff for yield-reducing rainfall. However, there is no payoff if the weather is suitable for yield formation.

The contract specifications for the rainfall options which are considered here are summarized in Table 2.

On the calculation of the option price

If farmers wish to insure their revenue in wheat production by using a rainfall option, they must first spend the option price. As the options are not market-traded, their price must also be determined. Unfortunately, the preference-independent valuation procedures developed in the financial option pricing theory cannot be used, since the rainfall index which

[3] It should be noted that an option cannot be designed in such a way that its payoff is correlated perfectly negatively to the expected revenue from the production, if production function did not display a linear-limitational function form. To insure the production risk for a linear production function, a future can be used. For more complex production functions, several weather derivatives can be combined. In this way, a combination of put and call options could be suitable for a quadratic production function. In the 'left area' ('right area') of the production function, the put option (the call option) insures against volumetric risks.

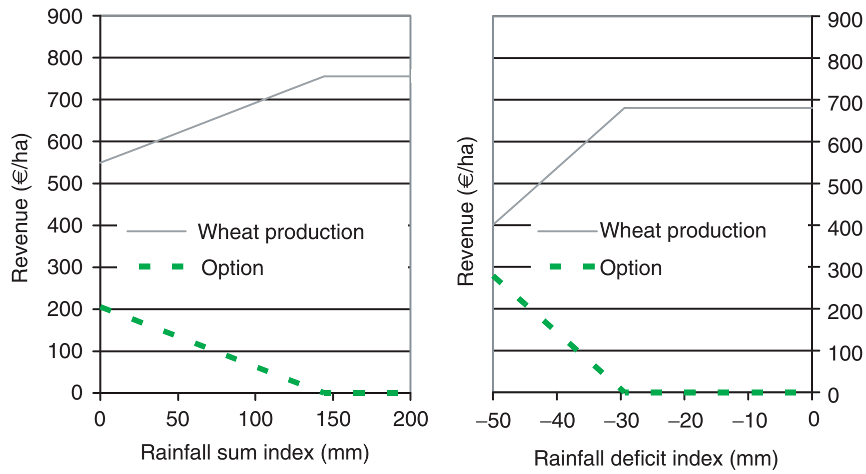

Fig. 2. Revenue from wheat production and payoff of option depending on the rainfall sum index (left) and the rainfall deficit index (right)

Table 2. Specification of rainfall options under consideration

	Option 1	Option 2
Weather index		
Designation	Cumulative rainfall index	Rainfall deficit index
Reference point	Rainfall data at the weather station in Berlin–Tempelhof	Rainfall data at the weather station in Berlin–Tempelhof
Accumulation period	June	April – June
Calculation	$I_T^C = \sum_{t=1}^{30} y_t$	$I_T^D = \sum_{\tau=1}^{13} \min\left(0, \sum_{t=(\tau-1)\cdot 7+1}^{\tau-7} y_t - 7.4\right)$
Option type	(European) put	(European) put
Strike level S	144.3 mm	−29.4 mm
Tick size V	1.4 €/index point	13.5 €/index point
Maturity Δt	1 year (01.07.2006 to 30.06.2007)	1 year (01.07.2006 to 30.06.2007)
Expiry time T	2007	2007
Payoff F_T	$\max(144.3 - I_T^C, 0) \cdot 1.4$	$\max(-29.4 - I_T^D, 0) \cdot 13.5$

forms the basis of a rainfall option is nontradable (cf Richards *et al.*, 2004; Jewson *et al.*, 2005, pp. 28–34). In order to avoid the difficulties which are therefore associated with pricing weather derivatives, the price of both options is calculated as a 'fair premium' in an actuarial sense, i.e. the profit expected from the option trade is precisely zero for both parties. Since neither a risk premium from the seller or buyer nor transaction costs are taken into account, the option price can simply be calculated as the expected payoff of the option discounted with risk–free interest rate r:

$$F_0 = E(F_T) \cdot \exp(-r \cdot \Delta t) \tag{5}$$

where Δt is the maturity of the option.

The fair premium can basically be determined by means of analytical procedures, historical simulation (burn analysis), index value simulation or daily simulation. Analytical procedures like the Black–Scholes formula require restrictive assumptions e.g. regarding the distribution for the weather variable underlying the derivative (cf Hull, 2006). Option prices determined by means of historical simulation as a nonparametric procedure can be very imprecise, because for instance the length of the data series is too short to obtain a good approximation of the theoretical distribution for the weather index (Zeng, 2000b). Using the daily simulation based on a model for the daily rainfall, the volatility of the rainfall and thus the option price are systematically underestimated (cf Dubrovsky *et al.*, 2004; Odening *et al.*, 2007). Therefore, the index value simulation is used here.

Using daily rainfall data which were measured in Berlin–Tempelhof between 1948 and 2006, the respective value for the rainfall index is calculated for each year. In the result, 59 empirical observations are available for each index. The MS-EXCEL-Add-In BEST-FIT is used to test which assumption regarding the distribution of the index is adequate.

According to the standard tests (Chi-Square, Kolmogorov–Smirnov and Anderson–Darling test), the lognormal distribution shows the best fit to empirical distribution for the rainfall sum index and the Weibull distribution delivers the best fit for the rainfall deficit index; whereas only distributions were considered which did not permit a change of sign of the uncertain variable. In the context of the index value simulation, a value is randomly drawn 10 000 times from the estimated distribution for the rainfall index.[4] In each simulation run the payoff of the option is determined in accordance with Equation 4. The discounted average payoff of the derivative corresponds to the fair premium (cf Equation 5). Using a risk-free interest rate r of 5%, the fair premium amounts to 108.1 € for the rainfall sum index and 56.8 € for the rainfall deficit index.

On the estimation of the hedging effectiveness

General procedure. The risk-reducing effect which can be attained by using weather derivatives is usually quantified by a comparison of the revenue distribution with and without having a derivative (cf e.g. Vedenov and Barnett, 2004). Without a derivative, the revenue from wheat production R_0 (in €/ha) related to the time of buying the derivative corresponds to the production function of wheat (in dt/ha) multiplied by the wheat price (in €/dt) and the discounting factor[5]:

$$R_0 = \tilde{Q}_T(I_T) \cdot P \cdot \exp(-r \cdot \Delta t) \tag{6}$$

With a derivative, the revenue R'_0 (in €/ha) is to be calculated as follows:

$$R'_0 = R_0 + F_T(I_T) \cdot \exp(-r \cdot \Delta t) - F_0 \tag{7}$$

If farmers wishing to be insured against volumetric risks using a derivative, at first, they have to pay the purchase price F_0. Afterwards, farmers receive in addition to the revenue from wheat production R_0 the payoff of the derivative F_T, whose level – just like the success of the production (cf (3)) – is dependent on the weather variable I_T.

On the separation of the basis risk. To separate the basis risk and its causes, three scenarios are considered when estimating the hedging effectiveness of rainfall options; two of these scenarios are synthesized in order to work on the specific effects. As the option is always related to the rainfall at the reference weather station Berlin–Tempelhof, the three scenarios are not distinguished with regard to the option price F_0 and the payoff of the option F_T, but only in determining the production success of wheat production in T:

- In the first hypothetical scenario it is assumed that there is no basis risk. It is supposed that the location of the agricultural production is not in Ketzin, but in the immediate vicinity of the reference weather station in Berlin–Tempelhof (Q_T instead of $\tilde{Q}_T$) and that the relationship between yield and rainfall index is not influenced by random effects ($\varepsilon_T = 0$). Technically, the wheat yield in scenario 1 Q_T^1 is derived directly from the rainfall index in Berlin–Tempelhof:

$$Q_T^1 = \begin{cases} a_0 + a_1 \cdot I_T & \text{if } I_T < a_2 \\ a_3 & \text{otherwise} \end{cases} \tag{8}$$

- In the second hypothetical scenario, the fact that the wheat production takes place 39 km away from the reference weather station is taken into account (geographical basis risk). However, it is further assumed that the relationship between yield and rainfall index at the site of production is purely deterministic ($\varepsilon_T = 0$). Technically, the wheat yield in scenario 2 $\tilde{Q}_T^2$ is directly derived from the rainfall index at the site of production in Ketzin ($\tilde{I}_T$ instead of I_T):

$$\tilde{Q}_T^2 = \begin{cases} a_0 + a_1 \cdot \tilde{I}_T & \text{if } \tilde{I}_T < a_2 \\ a_3 & \text{otherwise} \end{cases} \tag{9}$$

  The value for the rainfall index in Ketzin $\tilde{I}_T$ is derived from the value for the rainfall index in Berlin–Tempelhof I_T while taking a correlation yet to be determined into consideration (see below).

- In the third scenario, the spatial distance between the reference weather station and the site of production as well as the stochastic relationship between yield and rainfall are taken into consideration (geographical basis risk and local basis risk). Technically, the wheat yield in scenario 3 $\tilde{Q}_T^3$ is derived from the relevant value for the rainfall index at the reference weather station Berlin–Tempelhof and

[4] Regarding the number of required simulation runs, Haug (1998, p. 40), e.g. stipulates that at least 10 000 runs should be carried out. For technical details describing how to use stochastic simulation to model a wide variety of distributions with established software packages, see, e.g. Winston (1998).
[5] We are only focussing on the risk-reducing effect of weather derivatives in wheat production, i.e. we abstract from cross effects resulting from the fact that the payoff of a weather derivative is correlated with the yields of several crops.

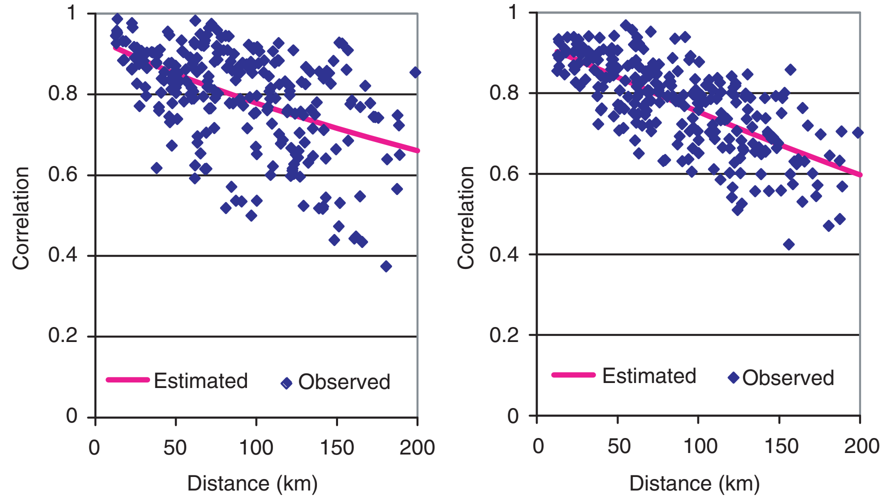

Fig. 3. Decorrelation analysis for the rainfall sum index (left) and the rainfall deficit index (right)

while taking into consideration the error term of the production function ε_T, which expresses both basis risks:

$$\tilde{Q}_T^3 = \begin{cases} a_0 + a_1 \cdot I_T + \varepsilon_T, & \text{if } I_T < a_2 \\ a_3 + \varepsilon_T, & \text{otherwise} \end{cases} \tag{10}$$

To determine the distribution for the revenues without option (cf Equation 6) and with option (cf Equation 7) in the three scenarios, the stochastic simulation (10 000 simulation runs) is used.

Decorrelation analysis. Usually, one would quantify geographical basis risk (second scenario) by means of comparing the hedging effectiveness of weather derivatives based on weather data measured at the production site versus taken weather data some distance apart. Unfortunately, for the showcased farm in Brandenburg weather data measured on the production location are not available. For that reason we have to replace actual weather data by randomly generated values using an appropriate correlation coefficient. This correlation coefficient is derived from a statistically estimated decorrelation function.

In order to estimate the correlation between the rainfall index at the site of production and the rainfall index at the reference weather station, data is used from 23 weather stations in Berlin and Brandenburg from 1983 to 2003, all located within a 100 km radius of Berlin–Tempelhof and relatively uniformly distributed over the area. The correlation coefficients $\rho_{i,j}$ between the values for the rainfall index at the weather stations i and j are determined. Then the distances $d_{i,j}$ between the individual weather stations are calculated. On the basis of the correlation coefficients and each respective distance a so-called decorrelation function can be estimated.

Rubel (1996) suggests the following nonlinear decorrelation function for modelling spatial correlation for rainfall in Europe[6]:

$$\rho_{i,j} = c_1 \cdot \exp\left(-c_2 \cdot d_{i,j}^{\;c_3}\right) \tag{11}$$

For the best rainfall sum index we find $c_1 = 0.94$, $c_2 = 0.0033$, $c_3 = 0.88$ and for the best rainfall deficit index $c_1 = 0.92$, $c_2 = 0.0012$, $c_3 = 1.11$. The R^2 is 0.24 for the rainfall sum index and 0.48 for the rainfall deficit index. The scatter diagram shown in Fig. 3 makes it clear, however, that the relationship between distance and correlation becomes more diffuse as the distance increases, that is the scatter plot reveals heteroscedasticity. It is also apparent that – as expected – the correlation between the rainfall index at two weather stations decreases with the distance. At a distance of 39 km between Berlin–Tempelhof and production location in Ketzin the rainfall sum index has an expected correlation of 0.87 and the rainfall deficit index has an expected correlation of 0.86.

Since the correlation coefficient is derived from the decorrelation analysis it implies an estimation error. This estimation error is not taken into account in the subsequent analysis of the hedging effectiveness. Actually, we calculate only the hedging effectiveness for an average correlation. The geographical basis risk and the hedging effectiveness of an individual farm can differ from the depicted values.

[6] The de-correlation function is invariant regarding direction. Thus, topographical differences potentially influencing precipitation are neglected. In Brandenburg, topographical conditions play to the assumption of a correlation independent of location and direction.

Table 3. Parameters for revenue distributions of wheat production without and with insurance (in €/ha)

	Scenario 1		Scenario 2		Scenario 3	
Local basis risk	Without		Without		With	
Geographical basis risk	Without		With		With	
Rainfall option	Without	With	Without	With	Without	With
Rainfall sum index						
Expected value	620	620	620	620	620	620
SD	49	0	49	27	117	104
Percentile 5 %	558	620	558	574	429	446
10 %	565	620	565	588	471	485
50 %	608	620	608	620	619	620
90 %	702	620	702	652	771	755
95 %	728	620	728	666	815	793
Rainfall deficit index						
Expected value	599	599	599	599	599	599
SD	84	0	84	51	119	83
Percentile 5 %	417	599	417	509	381	461
10 %	471	599	471	537	441	492
50 %	656	599	656	599	610	599
90 %	656	599	656	661	740	706
95 %	656	599	656	690	773	737

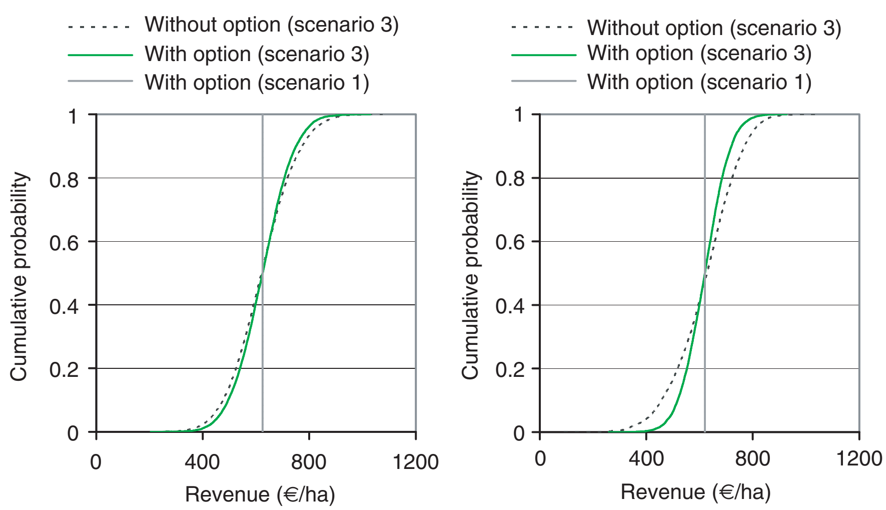

Fig. 4. Revenue distributions without and with insurance for the rainfall sum index (left) and the rainfall deficit index (right)

However, there is no systematic over- or underestimation of the results as long as the estimated correlation is unbiased.

III. Results

In Table 3 the expected value, the SD and selected percentiles of the revenue distribution are given for all three scenarios in order to assess the hedging effectiveness of the two rainfall options described above. The situation without and with insurance by a rainfall option is considered for each scenario. Figure 4 illustrates the revenue distributions for selected scenarios.

It is apparent first of all that there is no difference between the expected values for the revenue without and with the option. This is because the option price was calculated as a fair premium, therefore the insurance in average 'brings as much as it costs'. With regard to the hedging effectiveness of an option, the following can be established:

- Scenario 1: When there is no basis risk (site of production in immediate vicinity of reference weather station and deterministic relationship between yield and weather index), farmers can completely eliminate the revenue risk of wheat production by buying a put option on the rainfall sum or rainfall deficit index. This is possible because the payoff of the option is correlated perfectly negatively to the revenue from the wheat production (cf Fig. 2).

- Scenario 2: When it is taken into consideration that the site of the agricultural production is 39 km away from the reference weather station, the revenue distribution without the option is unchanged in comparison to scenario 1, because the same distribution underlies the rainfall index in Ketzin as that in Berlin–Tempelhof (cf footnote 6). Nonetheless, the SD of the revenue in wheat production can only be reduced by about 45% using the put option on the rainfall sum index or on the rainfall deficit index. Eventually, there may be cases in which farmers obtain a payoff from the option even though no yield loss could be registered (and vice versa), because the rainfall in Ketzin is different from that in Berlin–Tempelhof. In comparison to the results from scenario 1, it is evident that the risk-reducing effect of the option decreases with increasing distance from the reference weather station.
- Scenario 3: When both the geographical basis risk and a stochastic relationship between yield and rainfall index are realistically taken into consideration, the SD of the revenue in wheat production can only be reduced by 10% by buying the put option on the rainfall sum index. That is to say, the hedging effectiveness of a put option on the best rainfall sum index is nearly completely eroded when the geographical basis risk and the local basis risk are considered; even though the option was explicitly tailored to the revenue function of the farm. Using the put option on the rainfall deficit index results in a 30% reduction of the SD. The reason for the greater hedging effectiveness of the rainfall option on the rainfall deficit index is that the explanatory power of the production function for the wheat yield depending on the rainfall deficit index is much higher than that depending on the rainfall sum index. The reduction of the hedging effectiveness of both options, in comparison to scenario 2, is to be attributed to the additional consideration of the local basis risk.

IV. Conclusions and Outlook

The model calculations have shown that by using rainfall options a very considerable risk-reducing effect can be obtained when the reference weather station is located in the immediate vicinity of the site of production and when there is a very close relationship between yield and rainfall index. That is, while not being able to avoid climate change on a farm-level, such instruments could generate valuable support for those farming under risky conditions.

However, the model calculations also demonstrated that the basis risk has an extraordinarily high influence on the hedging effectiveness of rainfall options. When the site of agricultural production is only at a relatively small distance from the nearest reference weather station (e.g. 39 km in the application available here), the hedging effectiveness is considerably reduced. If, in addition, an index which only shows a small correlation to the yield underlies the option (as is established here between the wheat yield and the rainfall sum index, which is often suggested in literature), the hedging effectiveness decreases even further.

One could be tempted to conclude from a low hedging effectiveness that the farmers' potential demand would be low. However, such an interpretation would disregard the difference between effectiveness and efficiency. The potential demand for a weather derivative results from the ratio of its costs and its benefits. Derivatives which are based on simple indices and which display low effectiveness lead to a lower willingness-to-pay on the part of the farmers. However, as a result of their lower transaction costs they can also be provided at lower prices. We can, therefore, not a priori conclude that weather derivatives with a low hedging effectiveness are 'inapplicable' or that they do not have a trading potential.

However, if potential sellers of rainfall options wish to increase the hedging effectiveness, they should permit a dense network of weather stations as reference points and a widely diversified spectrum of differently specified weather derivatives. Of course, it is inconceivable that derivatives will be offered for every weather station. The demand for products of this kind would certainly be too low. A compromize could be to select the average derived from the values of a rainfall index at several weather stations as a weather variable underlying the option. The recommendation for offering differently specified weather derivatives affects the derivative type on the one hand (cf footnote 3) and the design of the index, the tick size and the strike level on the other hand. Many reference weather stations and weather derivatives designed in very different ways result in a fragmentation of the demand.

There is a further need for research with regard to the specification of the payoff function of an option. Rainfall sum indices dominating the scientific discussion until now are not sufficiently target-orientated in the opinion of many producers. An alternative suggestion was made here in the form of a rainfall deficit index. From an agronomic viewpoint, however, it could also be advisable to incorporate not only the rainfall but also the temperature, the wind etc. in the index underlying the option. In this way, for instance, allowance could be made for a situation in which low rainfall at high temperatures would lead to higher yield losses than at lower temperatures. Another task of research concerns the question which was consciously avoided here, namely of valuing weather derivatives.

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