Put, call or strangle? About the challenges in designing weather index insurances to hedge performance risk in agriculture

Juliane Doms

Juliane.Doms@landw.uni-halle.de

Institut für Agrar- und Ernährungswissenschaften, Lehrstuhl Unternehmensführung im Agribusiness, Martin-Luther-Universität Halle-Wittenberg, Karl-Freiherr-von-Fritsch-Str. 4, 06120 Halle (Saale), Deutschland

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Abstract

Due to an expected increase of extreme weather events caused by climate change, weather index insurances (WII), which can be used to hedge weather-related income fluctuations, are shifting into the spotlight. Most previous studies focus on the index design as it is an important part of a weather index insurance. Nevertheless, also of main importance is the general contract structure. This holds especially true for farms in regions, which are not characterized by extreme climatic conditions. In the present study, it is investigated whether precipitation and soil moisture index based put- and call-options as well as strangles reduce the volatility of total gross margins (hedging efficiency) of 20 German farms in regions with moderate natural conditions. In particular, the hedging efficiency of standardized and customized WII are analyzed. It could be found that customized contracts are better suitable to reduce performance risk than standardized contracts. Further, although the hedging efficiency varies considerably from farm to farm and depends highly on the contract type, the analyzed customized call-options and strangles clearly outperform the customized put-options.

Keywords

Performance risk, risk management, weather index insurances, contract structure, hedging efficiency, historic simulation

1 Introduction

Crop growth is determined by natural conditions to a great extent. In Germany, long dry spells in early summer have repeatedly caused serious yield losses in the last decades. In 2015, for instance, farmers had to face a 30% depression of average corn yields compared to 2014 (BMEL 2015; SCHÖNTHALER ET AL. 2015). Due to an expected increase of extreme weather events such as droughts as e.g. in 2015 or floods caused by climate change (ASSENG ET AL. 2015), weather index insurances (WII), which can be used to hedge weather-related and thus yield-related income fluctuations (performance risk), are shifting into the spotlight. Instead of insuring crop yield losses caused by e.g. hailstorms, the movement of an index is insured, which is a proxy for weather- respectively yield- related income losses. The index displays the weather-yield dependency and should display the weather conditions on a farm best, which cause yield-related income volatility. A payoff per index point is triggered independent of the yield loss incurred, if the index deviates from a specified threshold, the strike level (THE WORLD BANK 2011).

A major advantage of index-based insurances over indemnity insurances is that no adverse selection and moral hazard problems appear due to the independence of the insurance payments from on-farm actions (COLLIER ET AL. 2009). However, farmers may face a considerable degree of basis risk. Basis risk appears if the losses, which arise from the movement of the index and are covered by the WII, deviate from the farm specific income losses. This can be e.g. due to a deviation of the weather conditions at the measuring location (e.g. next weather station to a farm) from on-farm weather conditions which determine crop yields (spatial or geographical basis risk). Furthermore, other factors than the weather may influence yields (production basis risk) (WOODARD AND GARCIA 2008; RITTER ET AL. 2014). A main point of interest in the weather index insurance research is the minimization of this basis risk (cf., e.g. VEDENOV AND BARNETT 2004;

[1] Institut für Agrar- und Ernährungswissenschaften, Lehrstuhl Unternehmensführung im Agribusiness, Martin-Luther-Universität Halle-Wittenberg, Karl-Freiherr-von-Fritsch-Str. 4, 06120 Halle (Saale), Germany, juliane.doms@landw.uni-halle.de

ODENING ET AL. 2007; NORTON ET AL. 2012; ELABED ET AL. 2013; LEBLOIS ET AL. 2014; DALHAUS AND FINGER 2016). As the index, which aggregates a specified weather or hydrological variable over a specified hedging period[2], is an important part of a weather index insurance, most previous studies focus on the index design (cf., e.g. LEBLOIS ET AL. 2014; CONRADT ET AL. 2015; TURVEY 2001; KELLNER AND MUSSHOFF 2011). They try to construct an index, which fits best to on-farm weather conditions and highly explains yields of a crop most important for the farm's economic success (COLLIER ET AL. 2009).

Closely linked with the question of the index design and also of main importance is the general contract structure (e.g. put-, call-option or strangle) (JEWSON AND BRIX 2005). This is, because the payoff depends not only on the movement of the index but also on the general contract type. Regarding the design of WII a distinction can be made between a standardized and a customized contract design. A standardized WII is designed based on e.g. knowledge of the weather conditions that mainly influence crop growth in a particular region. The index design is only based on weather and/or hydrological data that are objectively measured e.g. at the weather station next to a farm. The strike level, which triggers a payoff dependent on the contract type, equals mostly the mean of the historic weather or hydrological data used for the index design (cf., e.g. MUßHOFF ET AL. 2008; WOODARD AND GARCIA 2008). The tick size – monetizing the deviation of the index from the strike level – equals a value in € per index point that is randomly determined. Contrary to this, for the design of customized weather index insurances farm specific yield data as well as weather or hydrological data are included in an optimization procedure. Using this procedure the index, strike level and tick size are determined aiming to hedge the weather and thus the yield-related losses of a farm as best as possible (cf., e.g. BERG AND SCHMITZ 2008; CONRADT ET AL. 2015; DALHAUS AND FINGER 2016).[3]

To hedge performance risk in drought-threatened regions mostly precipitation based put-options are analyzed such as for India, Malawi or Ethiopia (cf., e.g. HESS AND SYROKA 2005; GINÉ ET AL. 2007; BARNETT AND MAHUL 2007). Put-options trigger a payoff if the specified index falls below the strike level. Contrary to this, call-options hedge deviations of the index only above the strike level (JEWSON AND BRIX 2005). To the author's knowledge, rarely the focus is only on call-options (cf., e.g. KHALIL ET AL. 2007). A few studies compare the risk reducing potential of put- and call-options as the farms in the study region do not face only one specific weather event (cf., e.g. TURVEY 2001; RICHARDS ET AL. 2004; SUN ET AL. 2014).

The choice of a specific contract structure presumes that regions are known for specific extreme climatic conditions such as drought in summer. But, not only farms located in regions with extreme climatic conditions are interested in hedging weather-related performance risk. Farms which are located in regions with moderate climatic conditions might also purchase WII. This is, because farmers in these regions usually did not make other (preventive) risk management decisions such as investing in an irrigation system in case of expected drought events.

The choice of a contract is much more difficult in these cases, because the source of risk is not obvious. If in one year e.g. drought in summer may cause weather-related performance risk and in other years wet conditions are a major source of risk, a strangle might be an appropriate contract structure. A strangle is a combination of a put- and a call-option (JEWSON AND BRIX 2005: 24). To the best of my knowledge, no previous study analyzed and compared the risk reducing capacity (hedging efficiency) of weather index based put- and call-options and of a weather index based strangle.

[2] The hedging period can be specified based on calendar dates, e.g. from 1th of May to 30th of June or phenological phases, e.g. period shooting of the crop with greatest concern to income (cf., e.g. ZENG 2000; JEWSON AND BRIX 2005: 11ff., DALHAUS AND FINGER 2016).

[3] In the present study the term "customized" refers only to the farm specific adaptation of the strike level and the determination of the optimal number of contracts to be purchased by the farmer.

In the light of the described background, the aim of this study is to analyze how weather index based put- and call-options as well as strangles reduce performance risk of 20 German crop farms in North Rhine-Westphalia and Lower Saxony. The regions are selected as they are not known for extreme climatic conditions. For the analysis, a whole farm approach is used to consider that farmers usually realize more than one production activity and take into account the portfolio effects resulting from the different production activities. Real farm data from 1994 to 2014 from the 20 crop farms are applied to calculate the hedging efficiency of the analyzed WII in a historic simulation. In particular, the hedging efficiency of standardized and customized weather index based put- and call-options and strangles is analyzed. The hedging efficiency is defined as the percentage change of the volatility of farm specific total gross margins with and without weather index insurance.

The main contribution of the present study to the growing weather index insurance research is the comparison of the risk reducing capacity of the three contract types put-option, call-option and strangle. Furthermore, additional knowledge is provided by the analysis of the hedging efficiency of standardized and customized put-options, call-options and strangles on single farm level using real data of farms not struggling with extreme climatic conditions over a period of 21 years.

The paper is structured as follows: in section 2 the applied methodology as well as underlying data are described. The results are presented in section 3 and conclusions are drawn in section 4.

2 Methodology and data

2.1 Farm and weather data

Individual farm data from 20 German crop farms over the period from 1994 to 2014 are provided by the chamber of agriculture in North Rhine-Westphalia and Lower Saxony. In particular, information about the realized production programs and the single gross margins for each of the farm's activities were made available. Only main production activities such as winter wheat, barley, corn or sugar beet are included in the data set. Special crops such as strawberries or asparagus are not included. 12 of the study farms are located in the *Lower Rhenish Basin* (German: Niederrheinische Bucht) – a physical geography in the south of North Rhine-Westphalia. The other 8 farms are situated in the southeast of Lower Saxony mainly in the physical geography *Lower Saxon Fertile Plain* (German: Niedersächsische Börden) (see Figure A 1, Annex).

Their farming conditions can be described as "moderate" in terms of precipitation compared to the conditions in other regions such as parts of Brandenburg or Bavaria, which are exposed to too low (< 500 mm) or too high precipitation (>1.000 mm) on average (see Figure A 1, Annex).[4] Besides this, loamy soils with ground points ranging from 60 to 90 according to the German soil classification system[5] predominate on the investigated farms. Their soil quality can be thus defined as good compared to areas with mainly sandy soils such as in Brandenburg. The farm acreage in 2014 was 243 hectares on average (min: 67 ha. max: 455 ha). The farms are heterogeneous not only regarding the farm size but also the realized production programs.

For the insurance design weather data are provided by the German weather service (German: Deutscher Wetterdienst). Due to the importance of water for crop growth in Germany (BERG AND SCHMITZ 2008) two different kinds of hydrological data are used for this analysis. In particular, daily precipitation data of the weather station next to each farm from 1994 to 2014 are used, which are free and public available and can be directly downloaded from the ftp-server (DWD 2016b). The farm-weather station distance varies from circa 2km to 26km (linear distance) depending on the location of the next weather station with complete time series.

[4] The focus is only on precipitation due to the importance of water for crop growth and an expected increase of droughts or floods.

[5] The range of the soil qualities is from 7 ground points (= bad soil) to 100 ground points (= very good soil).

Following KELLNER AND MUSSHOFF (2011), daily soil moisture data expressed as the percentage of a soil's water holding capacity from 1994 to 2014 are used. The plant available water at a given point in time equals the quantity of water stored in a specific soil (OSMAN 2013: 72f.). This is the available amount of water for plant growth. Therefore, soil moisture based index insurances are assumed to have a higher correlation to plant growth than precipitation based index insurances (DÖRING ET AL. 2011; KELLNER AND MUßHOFF 2011). The farm specific soil moisture data were calculated by the DWD using the soil water household model METVER (MÜLLER AND MÜLLER 1988a, 1988b). Besides meteorological and phenological information also the soil quality of the study farms is included in the model. The soil moisture is computed based on winter wheat. Winter wheat is chosen as it is the only crop cultivated by each study farm over the whole observation period and is therefore highly important for their economic success.

Yearly crop specific phenological phases are the basis to determine the hedging period yearly as this approach was found to improve the hedging efficiency of WII (CONRADT ET AL. 2015) compared to hedging periods based on fixed calendar month (cf., e.g. VEDENOV AND BARNETT 2004; TURVEY 2005). Hence, referring to phenological phases means that start and end date vary according to the vegetation process within one year. The hedging period is determined equal to the phenological phase shooting of winter wheat due to the importance of winter wheat for the economic success of the study farms. The phase shooting is the main growth phase of winter wheat including a high water demand (LÜTKE ENTRUP AND SCHÄFER 2011: 328ff.; DWD 2016c). Hence, drought or wet during this phase is assumed to be highly important for the economic success of farming. Consequently, a high influence on performance risk is assumed. Following DALHAUS AND FINGER (2016), annual start and end dates of the hedging period are determined by using free and public available entry dates of the phenological phase shooting of winter wheat observed by volunteers and reported to the DWD (DWD 2016a).[6] The observation area of the phenological reporter next to each farm is chosen, for which data from 1994 to 2014 were available. The distance of the farm to the phenological observation reporter is minimum circa 0km and maximum 90km. Over the observation period, the average entry date of the phase shooting is the 12th of April in the Lower Rhenish Basin and the 27th of April in the Lower Saxon Fertile Plain. The end date of the phase is determined as the day prior to the entry date of the next phenological phase heading and is on average equal to the 25th and 27th of May, respectively.

2.2 Concept of the analyzed weather index insurances

The WII is explicitly designed to hedge the movement of an index that is correlated with the yield-related volatility of historic total gross margins. This index is based on drought or wet conditions during the main growth phase of winter wheat – the phenological phase shooting – due to the importance of winter wheat for the farm's performance. By assuming the same initial situation for all study farms a certain degree of comparability can be ensured.

To our knowledge the farm managers of the observed farms haven't invested in weather index insurance yet, although some insurance companies offer similar types of insurance. As it is difficult to access real market offers, we design fictitious weather index insurances. Assuming that droughts gain more importance for farmers due to climate change, we design put-options to compensate drought-related volatility of farm specific total gross margins (performance risk). In case of a put-option a payoff is triggered if the index I_t falls below the strike level K_p . The payoff structure of a **put-option $\boldsymbol{P_t^p}$** in year t is

$$(1) \qquad P_t^p = V \cdot max\left(K_p - I_t;\, 0\right) \quad .$$

Where $\boldsymbol{V}$ is the **tick size**, which is determined as 1€ per index point. It is just a multiplier, which monetizes the difference between the index and the strike level (Mußhoff et al. 2008). The amount

[6] For more information about the reporting procedure see KASPAR ET AL. 2015.

of insurance contracts (hedge ratio) that one is assumed to purchase defines the degree of hedging (hedging intensity). This holds true independent of the tick size.

Besides this, the risk reducing capacity of call-options to hedge performance risk due to (strongly) wet conditions is analyzed. This is, because the moderate conditions in the study regions make it difficult to determine one specific source of performance risk. Contrary to a put-option, call-options compensate deviations of the index above the strike level. The payoff structure of a **call-option** $\boldsymbol{P_t^c}$ is characterized following equation (2):

$$(2) \qquad P_t^c = V \cdot max\,(I_t - K_c;\, 0) \quad .$$

As it is not obvious whether the farms have a problem mainly with drought or wet conditions, it might be possible that farmers might benefit if they hedge against drought-related performance risk in some years and against performance risk due to wet conditions in other. A contract that meets this need is a strangle, which combines a put- and a call-option. The payoff structure of a **strangle** $\boldsymbol{P_t^s}$ is defined as follows:

$$(3) \qquad P_t^s = V \cdot (\max(K_p - I_t; I_t - K_c; 0) \quad ,$$

whereas the strike level of the put-option K_p must be smaller than the strike level of the call-option K_c (JEWSON AND BRIX 2005).

The **value of the index in each year** $\boldsymbol{I_t}$ is equal to the precipitation sum measured at the weather station next to each farm or the average soil moisture during the hedging period - the phenological phase shooting.[7] Due to the fact that water is highly important for plant growth, the focus is on these simple indices, although mixed indices of two weather variables would might improve the hedging efficiency of weather index insurances (VEDENOV AND BARNETT 2004).

The **strike level** $\boldsymbol{K}$ is defined separately for the put- and the call-option. K_p is equal to a lower bound for the put-option and K_c to an upper bound for the call-option assuming that there is an optimal range of water availability, i.e. precipitation and soil moisture, for plant growth. The strike levels for the precipitation based weather index insurance is calculated as shown in Table 1.

Table 1: Determination of standardized strike levels (highlighted in bold) for the precipitation based index insurance

Daily water consumption of winter wheat[1)] (in mm)		Average length of phenological phase shooting of winter wheat from 1994-2014[2)] (in days)		Water consumption of winter wheat in phenological phase shooting (in mm)			
				Lower Rhenish Basin		Lower Saxon Fertile Plain	
Min	Max	Lower Rhenish Basin	Lower Saxon Fertile Plain	Min (strike level put-option)	Max (strike level call-option)	Min (strike level put-option)	Max (strike level call-option)
1.5	2.5	44	31	1.5 mm · 44 days = 66 mm **≈ 70 mm**	2.5 mm · 44 days = 110 mm **≈ 110 mm**	1.5 mm · 31 days = 46.5 mm **≈ 50 mm**	2.5 mm · 31 days = 77.5 mm **≈ 80 mm**

Source: the author based on [1)] ROTH AND WERNER (2000: 7). [2)] DWD (2016a).

The standardized strike level of the water-capacity based index insurance equals 50% as strike level for the put-option and 70% as strike level for the call-option. The determination of these strike levels rest upon information from the crop science literature (ROTH AND WERNER 2000). These strike levels hold also for the strangle. In case of the soil moisture index insurance it is not differentiated between regions.

[7] The soil moisture is farm specific. The payoff results independent of the soil moisture level at a specific day of the hedging period. Only the average soil moisture during the whole hedging period is considered.

The price of the insurance equals the actuarially fair premium. Following WOODARD AND GARCIA (2008), the fair premium is determined using burn analysis. That means, the fair premium is the expected value of the payoffs of the WII. Hence, our WII is income-neutral. No loading for e.g. bureaucratic expenditures is added as the focus is on the hedging efficiency and not on the impact of WII on the income level. This holds for all analyzed contracts - standardized and customized contract variants equally.

2.3 Procedure of historical simulation

Historic simulation is applied to analyze the hedging efficiency of the described weather index insurances ex-post. In total, six different weather index insurances are analyzed (precipitation and soil moisture based put- and call-options and strangles). Following GOLDEN ET AL. (2007), the hedging efficiency is defined as the percentage change of the standard deviation of hypothetical total gross margins with WII compared to the standard deviation of the historic total gross margins (TGM) without WII. The standard deviation is a risk measure used to quantify the volatility of the farm's TGM over the whole observation period.

The farm specific historic annual TGM without WII from 1994 to 2014 are computed using the individual farm data mentioned in 2.1. As the size of the study farms varies, the TGM are normalized per hectare to be independent from farm size. The calculation is as follows:

$$(4) \qquad TGM_{without}^{norm} = \left(\sum_{j=1}^{J} GM_j \cdot u_j \right) \cdot FS^{-1} \qquad .$$

Where GM_j is the single gross margin of each cultivated crop j and u_j the hectares cultivated of each crop, J is the total amount of cultivated crops and FS the whole cultivated area – the farm size in hectares – within one year. The annual TGM per hectare are inflation-adjusted and additionally corrected for a linear trend.

To calculate the annual hypothetical TGM with weather index insurance from 1994 to 2014 for each farm, the insurance is added as an additional activity to the realized production program:

$$(5) \qquad TGM_{with}^{norm} = \left(\sum_{j=1}^{J} GM_j \cdot u_j + GM_{WII} \cdot h \right) \cdot FS^{-1} \qquad .$$

GM_{WII} is the single gross margin of the insurance contract resulting from subtracting the fair premium from the payoff P. h equals the hedge ratio, which is standardized to one contract per hectare.

The hedging efficiency is determined as follows

$$(6) \qquad Heding\ efficiency = \frac{\sigma_{without} - \sigma_{with}}{\sigma_{without}}$$

(cf.. e.g. GOLDEN ET AL. 2007), with $\sigma_{without}$ describing the volatility of historic TGM without the insurance and σ_{with} the volatility of TGM_{with}^{norm} resulting after implementing the WII.

2.4 Customization of the analyzed weather index insurances

Additionally to the analysis for the standardized weather index insurances with the predefined parameters (strike level and hedge ratio) described in section 2.2 and 2.3, the strike level and hedge ratio are optimized to fit the activity “purchase of weather index insurance” best to the individual farm data. A risk programming approach is applied. Holding the farm specific production programs and insurance parameters – except the strike level and the hedge ratio – constant, these two are optimized with the aim to minimize the volatility of the farm specific TGMs from 1994 to 2014. The RiskOptimizer of the company Palisade is used to carry out the risk programming approach. To fulfil the condition of the strike levels $K_p < K_c$, this is considered as a restriction in

the model. Besides this, the hedge ratio is restricted between 0 to 50 contracts per ha as this seemed to be a realistic number of contracts assumed that the farmer should not be primarily a hedger. It also avoids possible financing problems due to buying too many contracts. A summary of the resulting optimized strike levels and hedge ratios is displayed in table 2.

Table 2: Summary statistics of the risk programming approach

		Precipitation-index				Soil moisture-index			
		Put	Call	Strangle[1)]		Put	Call	Strangle	
				K_p	K_c			K_p	K_c
Strike level (mm/%)	Average	47.66	61.03	42.66	82.14	45.33	78.00	56.04	75.09
	Min	0.00	0.00	0.00	4.60	0.00	16.20	0.22	22.71
	Max	277.28	157.15	232.37	232.37	82.33	91.00	82.39	91.00
Hedge ratio (number of contracts/ha)	Average	6.85	5.94	5.99		11.33	37.16	32.80	
	Min	0.00	0.00	0.08		0.00	1.33	1.33	
	Max	49.62	50.00	50.00		50.00	50.00	50.00	
Fair premium (€/ha)	Average	19.62	28.25	45.85		1.23	4.84	7.54	
	Min	0.00	0.00	0.17		0.00	0.18	0.18	
	Max	207.31	85.43	162.40		7.99	59.47	52.97	
Hedging intensity (hedge ratio * fair premium in €/ha)	Average	26.20	54.83	84.73		11.16	65.88	120.63	
	Min	0.00	0.00	4.88		0.00	9.10	9.10	
	Max	208.27	203.29	233.24		59.67	250.22	476.72	

Explanatory note: [1)] The strike level K_p and K_c of the precipitation-based strangle differ in some cases on the fifth digit (see Maximum value).
Source: the author.

If the optimized strike level for the put-option or K_p of the strangle is 0, thus no payoff results. In case of a put-option this means that the best risk management strategy for some farms is not to purchase a put-option. The resulting optimized strike level and the optimized hedge ratio are different among the farms and depend on the insurance type.

3 Risk reducing capacity of the analyzed weather index insurances

Table 3 shows the hedging efficiency, which results from the hypothetical purchase of the described standardized weather index insurances. On average, a positive HE can only be obtained with the soil moisture based call-option and the soil moisture based strangle. 19 out of 20 farms achieve a risk reduction applying these contracts. But, looking at the farm specific results, shows that a positive HE of up to 2.92% can be achieved by purchasing a precipitation based call-option (see farm 12). This shows that the hedging efficiency is farm specific, varies from farm to farm and depends highly on the type of weather index insurance.

Nevertheless, the resulting positive HE is fairly low, which is not surprising. This is, because the farms are exposed to moderate climatic farming conditions. Hence, it was to be expected that the risk reducing capacity of standardized insurances, which conception is based on common knowledge about plant growth, is low. Instead of a low positive hedging efficiency, performance risk increases especially after the implementation of the analyzed precipitation based index insurances. This can be seen based on the resulting negative hedging efficiencies on average.

With regard to the farm specific results it is noticeable that in some cases the resulting hedging efficiency for the strangles is the same as for the call-option. The reason for this result is that using standardized contracts for some farms in none of the 21 years a payoff of a put-option results.

Table 3: Hedging efficiency (HE in %) of the standardized weather index insurances (1994-2014)

		Precipitation-index			Soil moisture-index		
		Put	**Call**	**Strangle**	**Put**	**Call**	**Strangle**
Average HE		**-0.97**	**-0.07**	**-0.98**	**-0.02**	**0.63**	**0.62**
Minimum HE		**-4.58**	**-3.92**	**-4.65**	**-0.19**	**-0.32**	**-0.32**
Maximum HE		**0.77**	**2.92**	**2.00**	**0.01**	**2.27**	**2.14**
Number of farms achieving risk reduction (positive HE) (out of 20 farms)		**4**	**12**	**7**	**1**	**19**	**19**
Farm	**1**	-4.58	-0.07	-4.62	-0.19	0.67	0.51
	2	-2.36	1.43	-0.81	0.00	1.49	1.49
	3	-0.01	-0.37	-0.35	0.00	0.38	0.38
	4	-1.64	1.47	-0.08	-0.13	2.27	2.14
	5	-2.64	0.46	-2.10	0.00	0.91	0.91
	6	-0.59	0.30	-0.25	0.00	0.54	0.54
	7	0.06	0.23	0.33	0.00	0.48	0.48
	8	-0.13	0.16	0.08	0.00	0.50	0.50
	9	-1.80	0.00	-1.80	0.00	1.18	1.20
	10	0.02	0.53	0.56	0.00	0.79	0.79
	11	-1.05	0.29	-0.64	0.01	0.82	0.85
	12	-1.01	2.92	2.00	0.00	0.29	0.29
	13	-0.58	0.00	-0.58	0.00	0.62	0.62
	14	-0.29	-1.66	-1.89	0.00	0.09	0.09
	15	0.10	0.14	0.33	0.00	0.72	0.72
	16	-0.62	-3.92	-4.46	0.00	-0.32	-0.32
	17	-1.71	-3.10	-4.65	0.00	0.37	0.37
	18	-0.68	2.05	1.42	0.00	0.26	0.26
	19	0.77	0.04	0.83	0.00	0.08	0.08
	20	-0.75	-2.21	-2.83	0.00	0.53	0.53

Explanatory note: The hedge ratio is standardized to 1 contract per ha for each farm. A positive (negative) sign of the hedging efficiency implies a reduction (increase) of the performance risk.
Source: the author. The standardized hedge ratio is one contract per hectare.

The hedging efficiency resulting of the customized weather index insurances is displayed in Table 4. Contrary to the resulting hedging efficiencies of the analyzed standardized contracts, a positive hedging efficiency can be achieved on average by a hypothetical purchase of each of the customized contracts. This holds not only true on average, but also for most of the 20 farms. However, there are still some farms which achieve no risk reduction by the purchase of a WII. The number of farms achieving no risk reduction varies from one to eight farms. For these farms the best risk management strategy is to do nothing.

It becomes obvious that on average the customized call-options and strangles outperform the put-options. This indicates that the study farms either struggle generally with too wet conditions than too dry conditions or in one year with too dry conditions and in another with too wet conditions during the phenological phase shooting of winter wheat.

Especially in case of the soil moisture based call-option and strangle the average hedging efficiency (8.75% and 10.04%) is considerably higher than applying standardized soil moisture based call-options and strangles (0.63% and 0.62%). It must be noted that the customized soil moisture based strangle (HE of 10.04%) even outperforms the customized soil moisture based call-option (HE of 8.75%) on average. Using past knowledge, the insurance design can be improved and better fitted to each of the farms.

The average hedging efficiency that can be achieved by the purchase of customized precipitation based index insurances is much lower than of the soil moisture based index insurances.

The highest positive hedging efficiency of 37.98% can be achieved by purchasing the soil moisture based strangle (see farm 4). Nearly the same hedging efficiency results for the soil moisture based call-option. Contrary to this, a single purchase of a soil moisture based put-option results in a very small or no risk reduction for farm 4. Hence, this farm benefits most from the purchase of a soil moisture based strangle or call-option.

Table 4: Hedging efficiency (HE in %) of the customized weather index insurances (1994-2014)

		Precipitation-index			Soil moisture-index		
		Put	**Call**	**Strangle**	**Put**	**Call**	**Strangle**
Average HE		**0.43**	**3.23**	**3.30**	**0.56**	**8.75**	**10.04**
Minimum HE		**0.00**	**0.00**	**0.01**	**0.00**	**0.14**	**0.14**
Maximum HE		**2.42**	**10.21**	**10.21**	**3.29**	**37.83**	**37.98**
Number of farms achieving risk reduction (out of 20 farms)		**12**	**18**	**20**	**14**	**20**	**20**
Farm	**1**	0.00	4.78	4.78	0.00	4.14	4.14
	2	0.00	10.21	10.21	0.00	13.09	13.09
	3	0.02	0.22	0.22	2.00	4.66	12.75
	4	0.00	4.39	4.39	0.00	37.83	37.98
	5	0.00	7.19	7.19	0.05	4.60	4.80
	6	0.09	4.16	4.87	0.26	12.29	11.90
	7	1.40	1.57	2.36	3.29	11.67	23.14
	8	0.09	0.69	0.69	0.25	4.30	5.18
	9	0.03	9.40	2.52	0.18	7.79	8.60
	10	0.17	3.81	3.31	0.00	16.55	17.10
	11	0.00	2.24	2.24	0.01	7.60	7.87
	12	0.00	6.42	6.29	0.28	0.63	0.84
	13	1.52	0.52	1.52	1.25	9.54	12.90
	14	0.93	0.00	0.93	0.24	3.28	3.29
	15	0.33	0.47	1.29	0.08	12.62	12.62
	16	1.34	0.00	1.34	2.83	4.53	4.58
	17	0.00	0.03	0.03	0.01	4.91	4.95
	18	0.19	8.44	8.52	0.45	4.30	4.44
	19	2.42	0.06	3.18	0.00	0.14	0.14
	20	0.00	0.01	0.01	0.00	10.57	10.57

Explanatory note: Due to limitations of space the resulting optimized hedge ratios and strike levels cannot be displayed for each farm. Hence, a summary table is provided (see table 2). Detailed information might be requested by the author. A positive (negative) sign of the hedging efficiency implies a reduction (increase) of performance risk.
Source: the author.

4 Conclusion and future prospects

This paper has investigated the capability of precipitation and soil moisture index based put- and call-options as well as strangles to reduce performance risk of 20 German crop farms in regions with moderate natural conditions (North Rhine-Westphalia and Lower Saxony). A whole farm approach is used. Therefore, it takes the portfolio effects resulting from the different production activities that farmers usually cultivate into account. Real farm data from 1994 to 2014 from each of the 20 farms are applied to calculate the hedging efficiency, i.e. the risk reducing capacity, of

the analyzed WII in a historic simulation. In particular, standardized and customized weather index based contracts are analyzed.

A reduction of performance risk can generally be achieved by the hypothetical purchase of each of the analyzed WII. However, the resulting hedging efficiency is different from farm to farm and depends highly on the contract type.

In particular, two main results must be highlighted: First, the analyzed standardized insurances are found to be less suitable to reduce risk than the customized contracts. The hedging efficiency of the standardized contracts is much lower than expected. Instead of achieving a risk reduction, for most of the farms risk would have even increased, if the farmer had purchased a standardized contract. This appeared for all types of precipitation and soil moisture based contracts.

Second, customized soil moisture based strangles are superior to the other analyzed contract types. Next in rank are customized soil moisture based call-options. This indicates that the main problem of the study farms are changing weather patterns, i.e. too dry conditions in one year and wet conditions in another, or only too wet conditions. Hence, farmers in moderate regions might benefit most from flexible risk management strategies. Assuming similar future farming conditions, it can be cautiously concluded that farmers should prefer purchasing a customized soil moisture based strangle. However, if it is worth buying such a contract not only depends on the hedging efficiency but also on the loading added to the actuarially fair premium. Using past knowledge, a farmer can make better decisions regarding his risk management strategy in the future if the farming conditions are similar over time. It is important to note that these results hold only for the study farms and the analyzed standardized and customized contracts. Further, the results clearly show that the challenge in designing weather index insurances is not only to find the appropriate index, but also the choice of the general contract structure.

The superiority of soil moisture based index insurance was also found by KELLNER AND MUßHOFF (2011), who focused on a farm in Brandenburg. However, there is – to the author's knowledge – no other study analyzing performance risk of real farms in a comparable moderate region on a whole-farm level. Therefore more research is needed. Given that the findings are based on a small sample, the results should consequently be treated with caution. Nevertheless, a general conclusion is that farmers should make their risk management decision not based on general given recommendations. The results indicate that weather index insurances are highly farm specific. Further, for reasons of comparability, specific indexes are selected from numerous possible indexes based on assumptions regarding possible sources of yield-related performance risk. These indexes were applied to each of the study farms equally. There is need for a farm specific risk analysis before a farmer decides for a specific insurance type. This holds especially for farms in regions which are not characterized by a specific source of risk such as the analyzed regions.

Additional work should investigate whether the designed insurances reduce the performance risk of farms located in regions with extreme farming conditions. It is also of interest whether a change of the parameters of the standardized contracts might improve their risk reducing capacity. One also might analyze contracts based on other indexes such as mixed indexes.

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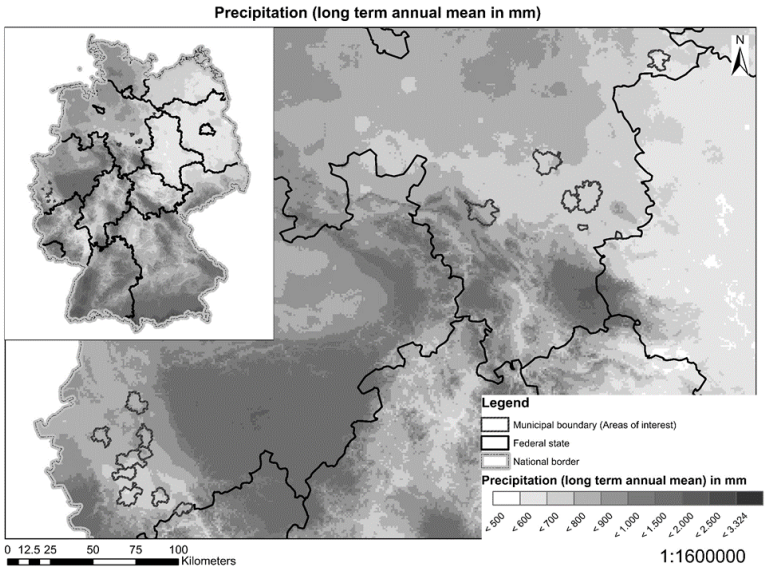
Annex

Figure A 1: Location of the study farms and climatic conditions in the study regions (long term annual mean, period 1981-2010)



Explanatory note: The areas highlighted in dark grey correspond to the municipalities where the farms are located. The number of municipalities (N=16) do not correspond to the numbers of farms (N=20) as sometimes more than one farm are located in a municipality.
Source: the author's own illustration based on (DWD 2017).