Precipitation or water capacity indices? An analysis of the benefits of alternative underlyings for index insurance

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A B S T R A C T

Eastern Germany is often hit by drought causing income risk for crop farmers. Index-based risk management instruments could help crop farmers to reduce their farm income risk. Such instruments have some important advantages over damage-based insurance, like e.g. less moral hazard and adverse selection. At the same time they typically have a high level of basis risk. Up to now, mainly precipitation-based weather derivatives have been discussed as an appropriate risk management instrument for farmers in Germany. As a potentially more effective alternative, we propose water capacity-based index insurance. In order to show the benefits of a precipitation-based and water capacity-based index insurance, several contract designs are compared. Using a whole farm risk program planning approach, we show that for an average agricultural producer in Eastern Germany water capacity-based index insurance offers greater benefits than precipitation-based index insurance.

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1. Introduction

Agricultural production is subject to many different types of operational risk. These include price risks due to supply and demand fluctuations as well as yield risks caused, for example, by plant diseases or weather fluctuations. Price and yield risks can be intensified by financial risks, i.e., some production factors such as debt capital and leased land are combined with cash outflows, which are independent from the farm's success. German farms are usually organized as individual enterprises. Thus profit fluctuations always have a direct impact on the farmer’s income. Vrolijk and Poppe (2008) found that families in the German federal state of Brandenburg have to deal with one of the highest variations in the family income of crop-farmers in Europe.

One of the reasons behind these statistics might be that Brandenburg is periodically hit by drought and that the predominant sandy soil leads to poor water retention. Although the climatic circumstances in Brandenburg could be better, crop farming is the main line of agricultural production. Because of the high income fluctuations, farmers in Brandenburg might need to hedge their risk.

There are a lot of different on-farm risk management instruments which often provide a reasonably good risk hedge. Classical on-farm risk management instruments are the use of less risky technologies achieving diversification in the production program or holding overcapacities in e.g. machines (cf. Hardaker et al., 2007, 268ff). Demand for market-based risk management instruments is likely to grow with decreasing price support in the European Union and climate change. Price risks can be hedged with different instruments such as forwards and futures contracts. However, the hedging of yield risks is rather limited in Germany. Only insurance contracts against weather extremes, like hail, are common. In the US there is a federally supported, nationwide crop insurance program which includes index insurance based on regional yield. This means the farmers receive indemnity payments if the regional level of yield of a specific crop falls under a certain level (Skees, 2008). Other frequently discussed underlyings for index insurance are weather-based indices. This type of insurance is also called weather derivative.

In the energy industry, firms throughout the world use temperature-based weather derivatives to hedge revenue fluctuations. Index-based insurance show some important advantages such as low moral hazard and adverse selection, which are common problems of damage-based insurance (Turvey, 2001). That is one of the reasons why index insurance could be offered with a lower premium load.

For crop farmers in Germany, yield risk due to rainfall variation is a major problem. Therefore, it can be expected that precipitation-based weather derivatives will show better results in hedging yield risk than temperature-based weather derivatives (Berg and Schmitz, 2008). A Swiss firm is offering weather derivatives based on different weather variables, like precipitation, measured at different German weather stations. However, there has been little uptake of these weather derivatives by German farmers. The question
arises of why does not a business such as farming, which depends so much on weather, hedge yield risks with weather derivatives. The answer may be found in the so-called basis risk. That means that the indemnity payments of the derivatives do not fit precisely to the yield losses of a farmer (Woodard and Garcia, 2007).

The objective of this paper is to analyze water capacity as a new and innovative underlying for index insurance, to compare this index with existing precipitation-based index insurance and to calculate the utility and the hedging effectiveness of both types of index insurance contracts for farms in Germany. When carrying out this kind of analysis, it has to be considered that farms in Germany typically do not focus solely on one crop. The decision problem for a crop farmer therefore is to choose a portfolio of different coping activities. Each of these coping activities causes different risks and expected profits. Considering this fact, we use an extended whole farm risk programming approach to evaluate the benefits from the whole-farm point of view. We include the farmer’s risk attitude in this approach, by setting his/her already accepted risk as an upper limit and by maximizing the total gross margin at the same time (Musshoff and Hirschauer, 2007). That allows us to determine the income increase caused by the introduction of a new risk management instrument. To our knowledge, this paper is the first one in which water capacity index-based insurance is investigated with respect to its benefits for crop farmers in general and within an extended whole farm risk programming approach in particular.

In the present paper, first of all, an overview of index-based insurance systems is provided (Section 2). Subsequently, Section 3 explains the methodology and the data. Afterwards, results are presented in Section 4. In Section 5 results are discussed and limitations in the methodology as well as limitations in the application are contrasted. Finally, the findings are concluded and prospects of future research are provided in Section 6.

2. Overview of index-based risk management instruments

Index insurance are common instruments in the agricultural production of many countries around the world. The underlying indices are usually taken out of two categories namely cumulated yield indices and indices based on the source of losses (e.g. weather). Cumulated damage indices can be found in livestock insurance in Mongolia (Mahul and Skees, 2007) and in Kenya (Chantarat et al., 2009). Furthermore, they are commonly applied in crop insurance contracts like area-yield-insurance (Miranda, 1991; Coble et al., 2003). Within the US federal crop insurance program different systems, which are related to regional yield indices, can be found. Here, for each crop a special contract based on historical yields is made (Barnett et al., 2005). Weather-based index insurance or weather derivatives have one or more weather variables (e.g. precipitation and/or temperature) as a so-called underlying. As mentioned in the introduction there are many examples of the use of weather derivatives in industrialized countries. In developing counties, index-based weather hedging instruments are commonly used to insure family farm income (Anderson, 2003). There are a lot of index insurance projects. In Malawi, for example, we find the “Lilongwe Farmer Maize Production Index” applied by a World Bank project (Hess and Syroka, 2005), which is based on rainfall deficit in maize production. Furthermore, there is another project that is based on low rainfall in Malawi insuring maize and groundnuts (Gine and Yang, 2009). There are also indices, like in the Millennium Villages Project on the African continent, which have more than just precipitation as an underlying. But here the index insurance covers risk caused by catastrophic or irregular risk events (Hellmuth et al., 2009). Most of the projects in developing countries do not see the farmers themselves as possible clients for the insurance, but a higher local institution. There are also many subsidized insurance products for farmers that are even more attractive to buy. Or the products are linked to other services like, e.g. micro credits (Skees and Barnett, 2006; Gine and Yang, 2009).

Index-based insurance show some advantages over damage-based insurance. Expensive on-farm damage estimation is not necessary because the indemnity payments are paid on objectively measured indices. An important advantage of index insurance, especially for developing countries, is the fact that no single farm assessment and no damage estimation is required (Barnett and Mahul, 2007). Another favorable aspect is that the problems of moral hazard and adverse selection do not appear very significant in connection with index-based insurance contracts (Vedenov and Barnett, 2004). In multi-peril crop insurance, some types of costly franchise, implemented to reduce the moral hazard, can usually be found (Barnett et al., 2005). This is one of the reasons why index insurance might be cheaper than damage based insurance schemes in some cases. The most important disadvantage of index insurance contracts is that the gross margin of the crops and the payoff from the index insurance are often far away for a perfect negative correlation. This problem arises from the so-called basis risk. “Basis risk is defined as the risk that the payoffs of a given hedging instrument do not correspond to shortfalls in the underlying exposure. Basis risk, for any given hedging horizon, can be categorized into three types: local, geographic, and product.” (Woodard and Garcia, 2007, p. 4).

Taking all advantages of index insurance, the question arises, which type of index should be used to create insurance products for a certain region? To lower the risk significantly, a high negative correlation between the gross margin and the payoff from risk management instruments are important. Regarding an insurance based on the regional yield the problem arises that the independent regional yields have to be measured for the calculation of the indemnity payments. It usually takes a lot of time to collect all necessary data to build the regional yield for the insured crops in 1 year.

An easy way to create an index-based insurance is to take the amount of precipitation during a certain period as underlying index. Precipitation indices are commonly used and simple (cf. Stoppa and Hess, 2003; Cao et al., 2004). The precipitation data is quickly available and therefore possible payments from a derivative can be delivered easily. It is also very easy for the demander of such instruments to comprehend the payment flow. The most important disadvantage of weather derivatives is that if they are based on just a single weather variable they show a comparatively high basis risk. As rainfall, for example, is only one single relevant factor in plant growth, the basis risk of production emerges. In the relevant literature, many mixed indices of temperature and rainfall can be found (e.g. Buyan and Lee, 2002; Vedenov and Barnett, 2004; Turvey, 2001; Turvey, 2002; Breustedt et al., 2008). These mixed indices usually lower the basis risk, but in turn the insurance becomes less comprehensible for the insured farmer as complicated indices arise (Leblois and Quirion, 2010).

An additional problem arises from the fact that weather might locally differ, especially the amount of rainfall. Thus if a weather station is (far) away from the fields where the crops are produced, the correlation between the gross margin of the crops and the indemnity payment decreases. Consequently, geographic basis risk arises. The basis risk could hence be lowered by a dense network of weather stations. However, here a low level of sold insurance contracts per weather station could be a problem that prevents the creation of a flourishing market. All insurance products need a trading partner. Transferring risk to a hedging partner has a lower transaction cost if there are many contracts of the same insurance
products. That means for the index-based insurance that the more equal insurance contracts can be sold, the easier a hedging partner can be found.

Deficits in crop yield are not only caused by precipitation or temperature. In agricultural science different kinds of indices for the determination of drought-based losses (e.g. Narasimhan and Srinivasan, 2005) or of the yield productivity can be found (e.g. Ritter et al., 2004; Kerkides et al., 1996). Apart from weather events, these indices usually take into account different kinds of soil qualities. As a result they have a higher correlation to plant growth. But all of these mentioned are not used as underlyings for index-based insurances.

In Germany the German meteorological service (“Deutscher Wetterdienst”) measures and calculates the available water capacity for different German regions (e.g., north of Brandenburg). The available water capacity mainly depends on the soil quality (concerning, for instance, rock fragments, organic matter, bulk density, rooting depth) and on the evapotranspiration deficit (concerning, for example, the precipitation rate and the specific crop) (cf. Cazemier et al., 2001; Archer and Smith, 1972). It expresses the amount of water stored in the soil as well as the available water amount for plants, i.e., the difference between the field capacity and the permanent wilting point. The calculation of the water-capacity index is based on the so-called agrometeorological model for calculating the actual evapotranspiration. Basis of this scheme is an extended approach of the “Penman–Monteith equation” (Löpmeier, 1994; Friesland and Löpmeier, 2007; cf. Allen et al., 1998).

For calculating the water capacity it is necessary to follow meteorological input data and to measure automatically air temperature, humidity, global radiation, wind velocity, precipitation and cloud cover once an hour. The soil input data has to be checked once individually for each region. The following parameters are implemented in the model: soil type, water content, root distribution, soil evaporation of initial input evapotranspiration and standing water at soil surface initial value. Besides the soil type, which is a fixed parameter, all of the other soil parameters are measured on a daily basis. The water capacity index applied in this paper is calculated on the basis of winter cereals. Usually, the available water capacity is expressed in % or inches. These types of measurements can be found in many countries, albeit sometimes with different types of indices. In order to lower the basis risk and make use of the advantages we try the water capacity as an underlying for index insurance.

3. Methodology and data

At first, we describe the methodology of the extended whole farm risk program planning approach, which can be used, to determine the benefits of different risk management instruments from a whole-farm point of view. After this, the historical simulation, which can be used to determine the hedging effectiveness of different risk management instruments is exposed. Subsequently, the data used in this study is presented. Finally, the analyzed index insurance is specified.

3.1. Methodical procedure

Using an extended whole farm risk program planning approach, we can determine the optimal portfolio or production program of a farmer with different types of risk management instruments. Here, we used the standard deviation of the total gross margin to measure risk, so it is designed as an expected-value-standard-deviation-approach. An expected-value-standard-deviation-approach is frequently used in whole-farm-risk-optimization (cf. Baumol, 1963). The standard deviation is defined as the square root of the distance of each gross margin from the mean. Usually, the tradeoff between expected value and standard deviation is determined by an individual risk aversion coefficient. The disadvantage of the procedure arises in determining the weighting coefficient of risk measure. Anonymous data do not give enough hints to ascertain this factor, because one cannot ask the farmers about their attitude towards risk. Even with the use of single farm data, it is not easy to investigate risk attitudes of decision makers (cf. Hudson et al., 2005).

The whole farm risk programming approach used in this article can be described as follows:

Maximize: \[ E(TGM) = \sum_{j=1}^{J} E(GM_j) \cdot x_j \] (1)
The aim of the approach is to maximize the expected value of the total gross margin $E(TGM)$, which is composed of the expected values of the gross margin of each crop $E(GM_i)$ weighted by the amount of hectares on which the crop is produced ($x_j$). The variable $b^r_i$ describes the capacities which might be used in the intended year. Capacities are modeled here in this as restrictions, like, e.g., available agricultural area, labor or sugar quota. To include different attitudes towards risk into our approach, we took the already accepted risk in terms of the standard deviation SD(TGM) derived from an empirically observed production program. This can be an already implemented as well as a planned production program.

As it can be seen in Fig. 1, we start at the empirically observed production program (point A). From here, we maximize the total gross margin meaning that diversification is the only risk management instrument used to reach a higher expected value of the total gross margin by staying at the same level of risk (point B). Without taking into account risk, the farmer could have reached an even higher value than expected, but here, he/she would have to accept more risk (point C). Because we do not know the exact trade-off between the expected value and the standard deviation of the total gross margin, we just look for point B. This point dominates point A because of the second-degree stochastic dominance. If other risk management instruments are implemented now, it is possible to reach higher risk efficiency lines and thus arrive at point B. At point B the farmer pays the difference between the expected value of B and C as so-called “risk reduction cost”. In other words, the farmer has to give up a specific amount of the expected value to reduce the risk and lowering the standard deviation (Musshoff and Hirschauer, 2009).

So, in the applied model the empirically observed standard deviation is just taken as an indication for the risk attitude. A farmer often does not want to (because entrepreneurs’ objectives are different from profit and risk) or cannot (because of bounded rationality) achieve the optimized production program (here in point B). Including non monetary entrepreneur’s objectives as well as bounded rationality in economic models is still a challenge (cf. Gardebroek and Oude Lansink, 2008). So, all model results are optimized without considering entrepreneur’s objectives, which can differ from profit and risk, and without considering bounded rationality. In the results we can only draw the conclusions from the comparison of point B and point B*. There are different kinds of possibilities to solve the whole farm risk programming approach. If all variables show a normal distribution, the portfolio variance can be calculated analytically (cf. Hazell and Norton, 1986). But especially in the case of weather derivatives this is not true. In order to have the opportunity to take into account different kinds of distribution parameters (besides a normal distribution), we use a MS-EXCEL-Add-in from Palisade called RiskOptimizer to solve the whole farm risk program planning problem. This Add-in combines a genetic algorithm with a stochastic simulation, which gives a high flexibility if variables do not show a normal distribution. The disadvantage of a genetic algorithm as a heuristic search procedure is that it can stall at local maxima (Mitchell, 1996). That is why each portfolio, with always the same inputs and restrictions, is optimized more than five times to confirm the results. The use of genetic algorithms is time-consuming. Solving one optimization problem defined in Eqs. (1)–(4) by using the RiskOptimizer takes about 30 h.

We implemented the different crops, index insurance contracts and seasonal work as activities in our risk programming approach.

Different limits for crop rotations were set. Likewise, land, family work and the standard deviation are used as restrictions. We calculated different variants. In the first step, the farmer only had diversification of crop activities available as a risk management tool. In the second step, weather derivatives based on the precipitation index were added. Insurance based on the water capacity index was implemented in the third step. In a last step, both types of index insurance were implemented in the whole farm risk program planning approach and competed with each other.

As it has been already mentioned we implemented the index insurance as auxiliary activities in the whole farm risk program planning approach. Like a normal insurance, index insurance needs to be bought before the damage will take place. Normally index insurance has a life time of one year. The payoff structure was a simple, so called put option:

$$P = (\max(K - I_i, 0) \cdot V)$$

The payoff ($P$) is the result of the maximum between zero and the difference between the strike level ($K$) and the index ($I_i$) multiplied with the tick size ($V$). The strike level ($K$) determines how dry or how less rainy it has to be in the specific period of time in order to get at least any payoff from the insurance. The index ($I_i$) is the measurement of how much rain or soil moisture has been measured in the specific period in which the insurance contract was purchased. If the index in the observed period is higher than the strike level, there is no payoff of the option. If the index is lower than the strike level, the policyholder receives a payoff. The level of payments is determined by multiplying the difference between strike level ($K$) and index ($I_i$) with the tick size ($V$). So, the tick size is just a multiplier. Here in this put option, the payout increases if the value of the underlying index decreases. The insurance company then pays the difference between the strike level and the measured value of the underlying. As a result, there should be a negative correlation between the payoff of the index insurance and the gross margins of the crop. The index insurance contracts are all optimized to show a highest hedging effectiveness with the crop that is, on average, the mostly planted: winter wheat.

To calculate the hedging effectiveness of weather derivatives in wheat production, we used historical simulations. We determined the hedging effectiveness of weather derivatives by comparing standard deviations of the gross margin with and without weather derivatives (according to Golden et al., 2007). We proceeded as follows:

1. Data for a historical time series of the farm’s wheat gross margin were collected.
2. The standard deviation of the historical time series was calculated to determine the production risk.
3. For the same time horizon, as considered in Step 1, a time series with the potential payoff out of the index insurance with a specific contract design was determined.
4. The time series of the wheat gross margin and the index insurance payoffs were aggregated by adding the insurance payoff of each single year to the yearly wheat gross margin.
5. The risks of the cumulated time series were determined by calculating the standard deviation.
6. Comparing the standard deviation with and without the index insurance allowed a conclusion about the hedging effectiveness or the effect of risk reduction for index insurance contracts.

Effects of different designs (e.g. different underlyings, triggers or tick sizes) of the index insurance can be calculated.

The hedging effectiveness was calculated with the payoff structure of weather derivatives for the actuarial fair premium. The actuarially fair premium was as high as the expected value of the indemnity payments. In our whole farm risk programming approach we assumed that the farmer can receive the weather...
derivatives for the actuarially fair premium with a load of 20%. A normal damage-based insurance has in general a load for, e.g., administrative cost of up to 35% (Wang et al., 1998). It was assumed that weather derivatives are less expensive, due to few problems concerning hidden information and no damage estimation.

3.2. Data

Yields and prices for each crop were extracted from the data of the German Ministry for Agriculture. Due to data availability, we focused on the administrative district of Maerkisch-Oderland, for which data from eight farms that receive at least 60% of their gross margin out of crop production were available for the years 1995/1996 to 2007/2008. The soil in Maerkisch-Oderland is predominantly sandy, and the rainfall is about 450 mm per year with high regional and yearly variability. The low precipitation during the year indicates that water is often the limiting factor for plant growth. Information on variable costs was taken from the Ministry for Agriculture in Brandenburg (MLUV, 2008, 2005, 2000, 1997).

Using this data we have calculated the average gross margin of the eight farms. The average farm has 571 ha land for crop production available and nine crops in rotation. The cultivated crops are the following: winter wheat, winter rye, winter and summer barley, oat, triticale, fodder peas, winter canola and sugar beets. The farmer also has the opportunity to set aside his/her land. Average ley, oat, triticale, fodder peas, winter canola and sugar beets. The cultivation available and nine crops in rotation. The cultivated crops are the following: winter wheat, winter rye, winter and summer barley, oat, triticale, fodder peas, winter canola and sugar beets. The farmer also has the opportunity to set aside his/her land. Average ley, oat, triticale, fodder peas, winter canola and sugar beets.

Daily weather data as well as monthly water capacity data are available from the German meteorological service. As sources for the precipitation index we chose the weather stations “Muencheberg” and “Neuhardenberg”. The “available water capacity index” is given for the fairly large region of north Brandenburg (about 15,000 km²). The precipitation and the average available water capacity data were taken from April to June, which represents the main growth phase for winter cereals in Germany.

We tried to fit Autoregressive Integrated Moving Average (p, d, q) models to estimate stochastic processes for the different gross margin time series (Pindyck and Rubinfeld, 1998). The statistical analysis had not reveal a respective time series model; thus, we applied the MS-EXCEL-Add-in @Risk to fit the most appropriate distribution. According to the Chi-Square-, Kolmogorov–Smirnov- and Anderson–Darling tests, many different distributions (ranging from the normal distribution for tritice to the Weibull distribution for canola) were fit for all gross margins of all crops as well as for the weather derivatives.

Consequently, the value of the standard deviation SD(TGM) was taken as a constraint in the whole farm risk programming approach. In this way, we were able to consider the risk a farmer is willing to accept and use this level to define a restriction for our risk programming model. For this as well as for the calculation of the standard deviation during the optimization process, the correlation is determined by using the historical gross margins of the different crops.

First we calculated with standardized insurance products, which are not fitted for a specific application. The index \( I_t \) is calculated from the sum of the daily precipitation in Muencheberg and in Neuhardenberg or the monthly water capacity in north Brandenburg for a specific time horizon. The strike levels for standardized derivatives are built by taking the average rainfall or the average water capacity in the determined month (May or June) of the years 1995–2007. For the precipitation-based index insurance “Muencheberg” a level of 56.62 mm in May and 52.02 mm in June were observed. For the precipitation-based index insurance “Neuhardenberg” a level of 57.73 mm in May and 55.90 mm in June were observed. The water capacity-based index insurance showed a standardized strike level of 60.24% for May and 37.31% for June. The tick sizes for standardized derivatives were taken as 1 mm precipitation and 10% water capacity.

The basic crop for German farms in general and in particular for the average farm is winter wheat. In a second step, strike level and tick size of the weather derivatives, therefore, are optimized to fit winter wheat best. In order to do so, we took the historical time series of the gross margin of winter wheat and constructed three weather derivatives with the three underlying indices for the main croping season in early summer. To fit the derivatives best for the farm, we solved for the strike level and tick size to bring the best hedging effectiveness for winter wheat. Fitting was done by solving the minimum of standard deviation in the wheat time series with the index insurance. The contract’s specifications for the optimized weather derivative are outlined in Table 1.

Table 1 shows the put option with the payoff structure for the optimized derivatives (cf. Eq. (5)). Here the index insurance policies in all cases have a higher tick size and a different strike level than the standardized product. The premium displayed in Table 1 is the fair premium calculated for the optimized index insurance with a 20% load.

4. Results

4.1. Analysis of the hedging effectiveness

In the first steps of our calculation we determined the hedging effectiveness of the index insurance with standardized designs in winter wheat production. Secondly, the index insurance contracts were fitted to show the highest hedging effectiveness in wheat production for the average of the eight farms examined. In Table 2, the hedging effectiveness for standardized weather derivatives (where the strike level is given by the average precipitation rate or average water capacity) and the hedging effectiveness for the

<table>
<thead>
<tr>
<th>Payoff (P)</th>
<th>Index (L)</th>
<th>Strike level (K)</th>
<th>Premium with a 20% load</th>
<th>Table 1 Specification of the optimized index insurance.</th>
</tr>
</thead>
<tbody>
<tr>
<td>35.05 mm</td>
<td>31.00 mm</td>
<td>60.10 mm</td>
<td>€276.88</td>
<td>Precipitation-based index insurance “Muencheberg-May”</td>
</tr>
<tr>
<td>39.00 mm</td>
<td>37.00 mm</td>
<td>76.29 mm</td>
<td>€326.99</td>
<td>“Neuhardenberg-May”</td>
</tr>
<tr>
<td>max(K–I,0)</td>
<td>Y1</td>
<td>55.07%</td>
<td>€73.08</td>
<td>Water capacity-based index insurance “North Brandenburg-May”</td>
</tr>
<tr>
<td>30.00 mm</td>
<td>36.00 mm</td>
<td>28.99 mm</td>
<td>€111.60 mm</td>
<td>“Muencheberg-June”</td>
</tr>
<tr>
<td>max(K–I,0)</td>
<td>Y1</td>
<td>30.60%</td>
<td>€30.60</td>
<td>“Neuhardenberg-June”</td>
</tr>
<tr>
<td>38.00 mm</td>
<td>34.00 mm</td>
<td>17.46 mm</td>
<td>€106.00</td>
<td>Water capacity-based index insurance “North Brandenburg-June”</td>
</tr>
<tr>
<td>max(K–I,0)</td>
<td>Y1</td>
<td>42.09%</td>
<td>€42.09</td>
<td></td>
</tr>
</tbody>
</table>

It is calculated from the sum of the daily precipitation in Muencheberg and in Neuhardenberg or the monthly water capacity in north Brandenburg for a specific time horizon. The strike levels for standardized derivatives are built by taking the average rainfall or the average water capacity in the determined month (May or June) of the years 1995–2007. For the precipitation-based index insurance “Muencheberg” a level of 56.62 mm in May and 52.02 mm in June were observed. For the precipitation-based index insurance “Neuhardenberg” a level of 57.73 mm in May and 55.90 mm in June were observed. The water capacity-based index insurance showed a standardized strike level of 60.24% for May and 37.31% for June. The tick sizes for standardized derivatives were taken as 1 mm precipitation and 10% water capacity.

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optimized weather derivative specification are displayed as a decrease in standard deviation compared to the wheat time series without insurance.

After optimizing the strike level and the tick size, a considerably higher hedging effectiveness was found. The best hedging results for the winter wheat time series were obtained in combination with a water capacity-based index insurance. Here, the standard deviation is 26% in May and 27% in June which is lower than it is with a water capacity-based index insurance. Here, the standard deviation of €53,603. This is defined as the cost of risk reduction by keeping the maximum risk acceptance (point C in Fig. 1). The farmer could have reached an expected value of €124,796 by staying at the same standard deviation as in the empirically observed production program (point B in Fig. 1). This means that the farmer would have reached a higher expected value by just having a different crop rotation.

We then optimize the portfolio of the average farm data by maximizing the expected value of the whole farm without implementing the weather derivative and without taking into account the diversification effect and the weather derivatives for the whole farm. By using precipitation-based index insurance (231 contracts in total) the farmer can lower his/her risk reduction cost by €9085. This means that in point B the farmer had to give up €59,676 of his/her expected value to obtain a standard deviation of €53,603. This is defined as the cost of risk reduction.

In further steps, we implement the optimized weather derivatives in a way that we could combine the given risk reduction by the diversification effect and the weather derivatives for the whole farm. By using precipitation-based index insurance (231 contracts in total) the farmer can lower his/her risk reduction cost by €9085. That means that she/he can reach an expected value of €133,881 by maintaining a standard deviation of €53,603. If now water capacity-based instruments are implemented as new activities, 529 insurance contracts (20 for May and 509 for June) can lower the risk reduction cost from €59,676 to just €38,843 (this is represented by point B in Fig. 1). By including water capacity- and precipitation-based derivatives in the portfolio the presently analyzed farm could have reached an expected value of the total gross margin of €151,732. Moreover, a standard deviation of €53,603 is maintained, which corresponds with those in the empirically observed production program. That means that if the farmer disposes of 521 water capacity-based and of 27 precipitation-based

### Table 2

<table>
<thead>
<tr>
<th>Name</th>
<th>Strike level (K)</th>
<th>Tick size (V)</th>
<th>Hedging effectiveness (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation-based index insurance “Muencheberg-May”</td>
<td>56.62 mm</td>
<td>1 mm</td>
<td>2</td>
</tr>
<tr>
<td>precipitation-based index insurance “Neuhardenberg-May”</td>
<td>60.10 mm</td>
<td>4.1 mm</td>
<td>6</td>
</tr>
<tr>
<td>Water capacity-based index insurance “North Brandenburg-May”</td>
<td>57.73 mm</td>
<td>1 mm</td>
<td>3</td>
</tr>
<tr>
<td>Optimized</td>
<td>76.29 mm</td>
<td>3.54 mm</td>
<td>10</td>
</tr>
<tr>
<td>Precipitation-based index insurance “Muencheberg-June”</td>
<td>60.24%</td>
<td>10%</td>
<td>13</td>
</tr>
<tr>
<td>Optimized</td>
<td>55.07%</td>
<td>22.07%</td>
<td>26</td>
</tr>
<tr>
<td>Precipitation-based index insurance “Neuhardenberg-June”</td>
<td>28.99 mm</td>
<td>17.46 mm</td>
<td>8</td>
</tr>
<tr>
<td>Optimized</td>
<td>55.90 mm</td>
<td>1 mm</td>
<td>3</td>
</tr>
<tr>
<td>Water capacity-based index insurance “North Brandenburg-June”</td>
<td>111.60 mm</td>
<td>3.39 mm</td>
<td>19</td>
</tr>
<tr>
<td>Optimized</td>
<td>37.31%</td>
<td>10%</td>
<td>16</td>
</tr>
<tr>
<td>Optimized</td>
<td>30.60%</td>
<td>42.09%</td>
<td>27</td>
</tr>
</tbody>
</table>

### Table 3

<table>
<thead>
<tr>
<th>Name</th>
<th>Precipitation-based index insurance “Muencheberg”</th>
<th>Precipitation-based index insurance “Neuhardenberg”</th>
<th>Water capacity-based index insurance “North Brandenburg”</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>–0.347 –0.384</td>
<td>–0.435 –0.586</td>
<td>–0.669 –0.682</td>
</tr>
<tr>
<td>June</td>
<td>–0.082 –0.336</td>
<td>–0.086 –0.374</td>
<td>–0.546 –0.628</td>
</tr>
<tr>
<td>Rye</td>
<td>–0.191 –0.095</td>
<td>–0.256 –0.406</td>
<td>–0.388 –0.513</td>
</tr>
<tr>
<td>Canola</td>
<td>–0.243 –0.354</td>
<td>–0.182 –0.176</td>
<td>–0.554 –0.670</td>
</tr>
<tr>
<td>Summer barley</td>
<td>–0.193 –0.038</td>
<td>–0.355 –0.027</td>
<td>–0.041 –0.633</td>
</tr>
<tr>
<td>Oat</td>
<td>–0.296 –0.114</td>
<td>–0.363 –0.511</td>
<td>–0.254 –0.119</td>
</tr>
<tr>
<td>Triticale</td>
<td>–0.243 –0.311</td>
<td>–0.240 –0.483</td>
<td>–0.536 –0.574</td>
</tr>
<tr>
<td>Fodder peas</td>
<td>–0.162 0.050</td>
<td>–0.272 0.056</td>
<td>–0.372 –0.279</td>
</tr>
<tr>
<td>Sugar beet</td>
<td>0.182 0.219</td>
<td>0.333 0.392</td>
<td>0.080 –0.047</td>
</tr>
<tr>
<td>Precipitation-based index insurance “Muencheberg”</td>
<td>0.566</td>
<td>0.413</td>
<td>0.731 0.619</td>
</tr>
<tr>
<td>June</td>
<td>1 0.359 0.392</td>
<td>0.448 0.346</td>
<td></td>
</tr>
<tr>
<td>Precipitation-based index insurance “Neuhardenberg”</td>
<td>1 0.339</td>
<td>0.719</td>
<td>0.628</td>
</tr>
<tr>
<td>June</td>
<td>1 0.288</td>
<td>0.269</td>
<td></td>
</tr>
<tr>
<td>Water capacity-based index insurance “North Brandenburg”</td>
<td>1 0.947</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
derivatives she/he is able to decrease the risk reduction cost from €59,676 in the empirical observed situation to €32,740 by using diversification and different derivatives to manage the risk.

All results are summarized in Fig. 2. It can be seen that all different derivatives, in combination with the diversification effects, can lead to a higher expected value for the gross margin without increasing the level of risk.

Even for average data, crop farmers in Maerkisch-Oderland might benefit from using precipitation-based weather derivatives. Although a natural hedge can be usually found by taking average data, optimized precipitation-based index insurance show a risk reduction. Derivatives based on the available water capacity can bring significantly more expected value to the total gross margin while maintaining the same level of risk. The best results can be obtained by taking all index insurance policies together, but the surplus that the average farm can generate is not considerably higher. Thus, if a farmer in Maerkisch-Oderland is able to buy water capacity-based index insurance, it will help to hedge his/her risk significantly.

5. Discussion

The results show that index insurance using water capacity as an underlying can hedge risk caused by drought much better than index insurance that are based on precipitation. These results themselves are nothing really surprising, but the dimension of the value has not been investigated before. The here applied index insurance combines two important facts: It has a simple payoff structure, so that it is easy for trading partners to comprehend the payoffs and it lowers the basis risk significantly. Although, the results show many interesting and important aspects, some further aspects need to be discussed.

Commonly used weather derivatives are often based on only one (or sometimes two) weather features (cf. Barnett and Mahul, 2007; Berg and Schmitz, 2008). The water capacity index implements some more factors which are all important for plant growth. Some of these factors are mutually dependent on each other like, e.g. the air temperature and humidity. Precipitation is only one of these factors, so that weather derivative indices which combine more than one plant growth-factor should be better than just precipitation-based insurance. For implementing more plant growth factors more information is required. Here we find a tradeoff between collecting information about plant growth factors, which requires time and money, and the use of this information. The here applied water capacity index is very complex, but it does not need any information cost because it is an index that is already measured. For countries, which do not have such a complex index, a less complex factor might require even good results. In the literature other indices used in hydrological modeling can be found (cf. Narasimhan and Srinivasan, 2005; Mendicino et al., 2008). All these indices might be useful as an underlying for index-based insurance. But all these moisture indices are not applied for index-insurance. The use of other indices needs to be checked in the specific case.

As mentioned in the methodology section the model is not able to take into account all entrepreneurs’ objectives which can also be different from profit and risk. Thus the results can only show the theoretical and not the actual market potential of index-based insurance. In reality farmers do not act completely rational and there might be a lower actual demand for water capacity-based index insurance than the results revealed. Nevertheless, the theoretical market potential is much higher than the market potential of precipitation-based index insurance.

In agriculture, even in moderate climate zones like Germany, climate change is a hot topic. Climate change is a very complex natural process and the implications on the environment and agriculture still have not been entirely investigated. It is expected that there will be more temperature and rainfall fluctuations in the northeastern part of Germany due to the climate change (Auerbacher et al., 2010). That would also cause an increase in the yield risk and therefore an increase in the income variability of crop farmers. This in turn would raise farmers’ demand for risk management instruments. In the applied model we cannot include aspects of climate change, because the yield data time series of only 12 years does not allow us to forecast the future influence of that phenomenon on crop yields. Another aspect is that the applied model is not created to generate forecasts of more than one year’s time, according to the derivative life time. Climate change will have an impact on the index insurance contract design and pricing, but this can be handled with recalculating contracts. This might be necessary anyway; because as with “normal” insurance new information always requires recalculation.

By creating these kinds of insurance contracts, a policy holder can only be compensated for risk caused by too little rainfall or soil water. This is not an insurance against too much water, like e.g. flood insurance or rain during the harvest time. In case someone wants to create weather derivatives against too much rain, a so-called “call option” could be an adequate method. With a call option a payoff is induced when the measured index is higher than the strike level. This might be helpful during harvest time. But, because of the sandy soils in northeast Germany with low water storage capacity, too much water during the growing period in general is not a problem, nonetheless natural disaster, like floods, would be problematic. Disaster insurance is already a common and widespread instrument in Germany and, moreover, there is not really a lack of these risk management instruments. So, the focus in this paper is on drought risk.

6. Conclusion

The aim of this paper was to analyze a new underlying for index insurance in agriculture to benefit from the advantages of index insurance but to generate a lower basis risk than with precipitation-based index insurance. For this purpose we propose water capacity-based index insurance. We compared this index insurance with insurance based on precipitation and optimized both indices for winter wheat. Because farms in Germany usually have many crops in rotation, we analyze a farmer’s benefits in whole farm risk programming approach by using the precipitation and the water capacity-based index insurance.

By using water capacity as an underlying we are able to create an index insurance, which has a higher negative correlation for
near all agricultural products than precipitation-based weather derivatives. It therefore seems like water capacity derivatives could become a suitable risk hedging instrument for the whole farm. With this kind of index insurance we find an adequate risk management product for the large region in the north of Brandenburg. This index insurance shows advantages in moral hazard and adverse selection over damage-based insurance schemes. But in comparison to precipitation-based derivatives it has a significantly lower basis risk because of its high negative correlation with the cropping activities. This can be seen in the results of the decreasing standard deviation of the winter wheat gross margin time series.

By measuring the risk reduction potential in a whole farm risk program planning approach, we received some very interesting results for the whole farm. With all the optimized index insurance contracts the farmer gains a considerably higher expected value of the total gross margin. The precipitation-based index insurance provides just a bit more benefit for the farmer. This result is not surprising, because other studies have already pointed out that these contracts often show a high basis risk. In contrast, the water capacity-based index insurance shows very good results. We have just determined the theoretical and not the actual market potential for weather derivatives, but it has become clear that these instruments seem to have a large potential for index insurance markets.

To gather more information about a potential market for water capacity-based index insurance policies, we need to examine single farm data in the future. Only the analysis of this kind of data allows us to evaluate the performance of the insurance with respect to the size, the crops or the location of different farms. For this it is also necessary to use a larger study area, or different study areas throughout Germany. Although we cannot generalize the results for a wide application, they show an interesting opportunity for weather-based index insurance. Water capacity-based weather derivatives might also be an instrument for countries where more multi-dimensional indices on plant growth are measured regularly.

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References


