Agricultural Finance Review

Emerald Article: Portfolio effects and the willingness to pay for weather insurances

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Article information:

To cite this document: Oliver Musshoff, Norbert Hirschauer, Martin Odening, (2008), "Portfolio effects and the willingness to pay for weather insurances", Agricultural Finance Review, Vol. 68 Iss: 1 pp. 83 - 97

Permanent link to this document:

<http://dx.doi.org/10.1108/00214660880001220>

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Portfolio Effects and the Willingness to Pay for Weather Insurances

Oliver Musshoff, Norbert Hirschauer, and Martin Odening

Abstract

Since the mid-1990s, agricultural economists have discussed the relevance of index-based insurances, also called "weather derivatives," as hedging instruments for volumetric risks in agriculture. Motivated by the question of how weather derivatives should be priced for agricultural firms, this paper describes an extended risk-programming model which can be used to determine farmers' willingness to pay (demand function) for weather derivatives. The model considers both the derivative's farm-specific risk-reduction capacity and the individual farmer's risk acceptance. Applying it to the exemplary case of a Brandenburg farm reveals that even a highly standardized contract which is based on the accumulated rainfall at the capital's meteorological station in Berlin-Tempelhof generates a relevant willingness to pay. Our findings suggest that a potential underwriter could even add a loading on the actuarially fair price which exceeds the level of traditional insurances. Since transaction costs are low compared to insurance contracts, this finding indicates there may be a relevant trading potential.

Key words: production program planning under risk, rainfall risk, weather derivatives, willingness to pay

In the recent past, weather derivatives have been increasingly discussed as a novel instrument to hedge production risks in agriculture (e.g., Richards, Manfredo, and Sanders, 2004; Berg and Schmitz, 2007; Turvey, 2005; Odening, Musshoff, and Xu, 2007). They are also frequently referred to as index-based weather insurances. Unlike conventional (yield or) damage-related insurances, the hedge from weather derivatives results from payments tied to weather variables (temperature, rainfall, etc.) that are measured objectively at a specified location. Weather derivatives avoid the moral hazard and adverse selection problems associated with conventional insurances.

Though promising applications of weather derivatives in agriculture exist, it is difficult at present to assess the relevance of weather markets for agribusiness in the future. One reason is the problem related to the pricing of weather derivatives. Since weather cannot be traded, it is not possible to construct a riskless hedge portfolio. Two implications follow from this fact: first, standard no-arbitrage arguments are invalid (Richards, Manfredo, and Sanders, 2004), and second, the risk that remains for the holder of the weather derivative (the basis risk) must be taken into account.

Evaluation of the basis risk requires knowledge about the individual risk preferences. Cao and Wei (1999) and Richards, Manfredo, and Sanders (2004) suggested applying consumption-based capital asset pricing for that purpose (cf. Lucas, 1978). This modeling framework makes it possible to determine the equilibrium price of a weather derivative

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assuming a representative investor and a liquid secondary market for the derivative. A somewhat less ambitious approach is to calculate the willingness to pay (WTP) for weather derivatives.

The objective here is not to fix a market price *ex ante*, but to determine a boundary for the price from the viewpoint of an individual buyer—a farmer. In this context, Xu, Odening, and Musshoff (2007) used an indifference pricing model to identify the minimum sales price and maximum purchase price for a weather derivative that is traded over the counter. If the minimum sales price is below the maximum purchase price, there is a trading potential.

The calculation of the WTP is closely related to the hedging effectiveness of the weather insurance since the volatility of the production revenues enters the utility function of the decision maker. The effectiveness of a hedging instrument can be understood very generally as its capacity to reduce the volatility (variability) of some objective value (e.g., the total gross margin) at a constant expectation value.

Various studies on weather derivatives indicate that the basis risk which remains despite the use of weather derivatives can be rather high in agriculture. The causes of a high basis risk are the geographical distance between the location of production and the reference weather station (geographical basis risk) as well as a low correlation between the weather index and the success of the production even at the location of production (production basis risk or local basis risk).

Berg and Schmitz (2007), for example, examined a weather derivative tailored for a potato producer in Lower Saxony and found a hedging effectiveness of approximately 40%. Odening, Musshoff, and Xu (2007) found an effectiveness of approximately 33% for a weather derivative specifically geared for a wheat producer in Brandenburg. Using a downside-risk

measure, which is not directly comparable to the variance, Vedenov and Barnett (2004) likewise report a low risk-reduction potential for weather derivatives explicitly designated for the operating conditions of maize, soybeans, or cotton producers in the USA.

One might be tempted to conclude from a low hedging effectiveness that the farmers' potential demand would be low. Yet, 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 (i.e., its performance or hedging effectiveness). Derivatives which are based on simple indices and which display low effectiveness lead to a lower WTP on the part of farmers. However, as a result of their lower transaction costs, they can also be provided at lower prices. We cannot, therefore, *a priori* conclude that weather derivatives with a low hedging effectiveness are "inapplicable" or that they do not have a trading potential. On the contrary, at a low price, weather derivatives with low hedging effectiveness can represent very efficient hedging instruments for farmers.

The objective of this paper is to analyze whether a high basis risk is in fact detrimental to the demand for weather derivatives in agriculture. We assume the perspective of an underwriter who is interested in assessing the WTP, and thus the potential demand of farmers in terms of price-quantity combinations. When determining WTP, empirical information regarding the potential buyers must be taken into account. This includes the farmer's individual risk tolerance and the farm-specific risk-reduction potential of the weather derivative.

We describe an extended risk-programming approach which can be used to determine the amount of derivatives a rational farmer would purchase at various prices (theoretical demand). An exemplary cash crop farm in

northeast Germany is used for illustration purposes. This farm is assumed to have the opportunity to hedge weather risks through a standardized rainfall put option. In contrast to many previous, comparative-static approaches (with/without derivative comparisons) which attempted to find an optimal weather derivative, we consider a derivative with a very simple standard design.

We have two reasons for this choice. First, there is no a priori specified production program to which we could fit the derivative because we allow for a dynamic adjustment of the production program after the innovative hedging instrument "weather derivative" has been made available to the farmer. Second, given associated transaction costs, it is implausible that an underwriter will customize weather indexes for single farms. In addition to the determination of the demand for derivatives at various prices, we also specify the optimum (or maximum turnover) price from the viewpoint of a monopolistic underwriter.

Hence, our contribution is twofold from a methodological perspective. First, we explicitly take into account portfolio effects which might have a significant impact on WTP (Brckett et al., 2006). Specifically, the whole farm rather than a single production activity is considered. This is accomplished within a risk-programming framework.

Second, the well-known problem of eliciting individual risk attitudes is tackled. On the one hand, knowledge about the risk attitude of decision makers is necessary in order to calculate risk premiums; on the other hand, such information is rarely available. To overcome this difficulty, risk-aversion coefficients are usually either parameterized or taken from the literature. Both procedures are rather unsatisfactory. Here we circumvent the problem by using implicit information on the risk attitude which is revealed in the realized farm production program.

A Demand-Oriented Evaluation of Weather Derivatives

The Model for a Farm-Specific Evaluation of Weather Derivatives

The starting point for the evaluation procedure suggested here is a risk-programming approach used to determine the farmer's optimum production program under risk:

$$\begin{aligned}
 (1) \quad & \max_{x_t^j} E(TGM_t) = \sum_{j=1}^J E(GM_t^j) x_t^j \\
 \text{s.t.:} \quad & \sum_{j=1}^J a_t^{i,j} x_t^j \leq b_t^i \quad \text{for } i = 1, 2, \dots, I, \\
 & \sqrt{\sum_{j=1}^J (x_t^j \sigma^j)^2 + 2 \sum_{j=1}^J \sum_{k < j} x_t^j x_t^k \sigma^j \sigma^k \rho^{j,k}} \leq \bar{S}_t, \\
 & x_t^j \geq 0.
 \end{aligned}$$

The objective function coefficients $E(GM_t^j)$ designate the expected gross margins per unit of production activity j for the target year t . The activity levels x_t^j which lead to the maximum objective function value are determined while taking the restrictions into account. The right-hand-side values b_t^i designate these restrictions for the target year, and $a_t^{i,j}$ designate the capacity requirements per unit of activity. The additional restriction $\bar{S}_t$ denotes the maximum permissible standard deviation of the total gross margin. If the single gross margins or error terms are normally distributed, the standard deviation of a production program's total gross margin can be calculated using the weights (levels) of the individual activities x_t^j , the correlation coefficients $\rho^{j,k}$, and the standard deviations σ^j and σ^k . By maximizing the expected total gross margin $E(TGM_t)$ for different upper limits of the standard deviation $\bar{S}_t$, the farm-specific risk efficiency line can be determined.¹

¹ In the remainder of this paper, the time index t will not be used when it is possible to exclude it without generating confusion.

Figure 1. Risk Efficiency Line with and without a Hedging Opportunity

We now include the weather derivative to be evaluated (or, more precisely, the "purchase of this weather derivative") in the set of possible activities of the optimization model, together with the classic production activities. For a given derivative price (which is parameterized later), we then repeatedly solve the optimization problem for different standard deviation restriction levels. Farm-specific risk efficiency lines are thereby generated for varying derivative prices.

Figure 1 depicts a stylized version of a risk efficiency line with and without a hedging opportunity. In this illustration, we presuppose a derivative price at which it would be rational for a (risk-averse) farmer to purchase a certain amount of weather derivatives. At prohibitively high derivative prices, the production function with a derivative coincides with the production

function without a derivative. Figuratively speaking, the risk efficiency line with a hedging opportunity is to the left above the production function without a hedging opportunity. It should be noted that the production programs yielding the maximum total gross margin with and without hedging opportunity are identical (point C) if the weather derivative has a positive loading.

The greater the area between the risk efficiency line with and without a hedging instrument, the higher the "quality" of the derivative understood as its farm-specific risk-reduction potential. A simple measure for this farm-specific performance would be the ratio between the area below the risk efficiency line with a hedging opportunity and the area below the risk efficiency line without a hedging opportunity. The farm-specific risk-reduction potential depends on

two components: first, the level of the (negative) correlation between the future payoff of the derivative and the gross margins of the classic production activities, and second, the costs of the derivative.

However, the actual usefulness of the hedging instrument for the individual decision maker considered here can be assessed only after taking his individual risk attitude into consideration. Due to well-known problems of empirically estimating consistent risk attitudes, Musshoff and Hirschauer (2007, p. 22) suggest optimizing program decisions within an expected value-variance (EV) approach and reverting to the concept of second-degree stochastic dominance (SSD) in the context of the optimization of production programs: "... neither trying to elicit nor knowing the individual farmers' risk attitudes and risk premiums, we concern ourselves only with second degree stochastically dominant solutions, i.e., with the more limited attempt to find out whether expected payoff could be increased without increasing the empirically observed variance." The latter refers to the risk tolerance which is implicitly expressed by the production program selected empirically by the farmer. The optimization model described in (1) employs this approach to evaluate weather derivatives.

Point A of Figure 1 indicates the empirically observed production program of a bounded rational farmer. A comparison of the optimized production program without a hedging opportunity (point B) with the optimized production program with a hedging opportunity (point D) shows how much the expected total gross margin can be increased after introducing the weather derivative—without increasing the farmer's risk.

For two reasons, the proposed risk-programming approach identifies only a lower limit of the benefit derived from a weather derivative. First, we determine the potential increase of the total gross margin given the standard deviation of the

total gross margin accepted by the farmer. In other words, since SSD is implicitly used, the distance $\overline{DB}$ can be interpreted as the lower limit of the additional benefit which can be obtained by a rational farmer by using the weather derivative.

Second, we underestimate the benefit for the farmer because we resort to an EV approach. At first glance, the assumption of a normal distribution for the total gross margin seems plausible in the context of portfolio optimization due to the central limit theorem. However, the plausibility of a normally distributed total gross margin decreases with increasing hedging effectiveness. Weather derivatives in the form of options cause a systematic reduction of a distribution's left-hand-side probabilities (and thus a right-skewed distribution). Assuming nonetheless a normal distribution, one underestimates the hedging effectiveness since the total variability is misinterpreted as a symmetric deviation from the mean.

In brief, we can summarize that the *area* between the two risk efficiency lines describes the general capacity of the hedging instrument to reduce risk on a specific farm. By contrast, the (minimum) additional benefit of the hedging instrument for an individual farmer can be deduced by an SSD-based comparison of two *points* on the two production functions.

Specification of the Weather Derivative Considered

Grain farmers in northeast Germany are heavily exposed to rainfall risk. However, no hedging instruments have been offered in Germany until now to insure farmers against drought-related volume risks. To illustrate our evaluation procedure, we therefore hypothetically presuppose in the following that an underwriter has offered rainfall derivatives. More precisely, we exemplarily use a put rainfall option whose payoff F_T is defined as follows:

$$(2) \quad F_T = \max\{\bar{I} - L_T, 0\}V.$$

The underwriter presumably chooses the cumulative rainfall measured at the Berlin-Tempelhof weather station between April 1 and June 30, 2006, as weather index I_T . The farmer can purchase the option on July 1, 2005. On June 30, 2006, i.e., at its maturity of $T = 1$ year, the option provides an "insurance payment" for the farmer if the measured rainfall index I_T falls short of the strike level $\bar{I} = 151.6$ mm.² The tick size V defines a monetary value of €1 per mm shortfall of the strike level.

The actuarially fair premium is determined on the basis of the actuarial standard procedure (cf., e.g., Jewson and Brix, 2005, p. 135), i.e., using the burn analysis (historical simulation). In other words, based on the weather records at the reference weather station in Berlin-Tempelhof between 1980 and 2005, we calculate the payoff of the contract which would have been produced if the weather derivative had been available during that period of time. Using the risk-free interest rate (here 5% p.a.), we find a fair premium of €16.85 per option contract.

The price at which the underwriter offers the weather derivative results from the actuarially fair premium plus a loading for his transaction costs, risk premium, and requested profit. If we unrealistically assumed that the derivative price equaled the fair premium, the activity "purchase of the weather derivative" would generate an expected gross margin $E(GM^D)$ of zero for the farmer. With the more realistic assumption of a positive loading, the expected gross margin of this activity is simply the negatively signed loading. At a derivative price of €20, for instance, we could thus say that the "insurance effect" costs the farmer only $(20 - 16.85 =) €3.15$ per contract.

Collecting and Evaluating Farm-Specific Data

Before we can analyze the impact of the above-described weather derivative for a specific farm business by using the risk-programming approach, we must quantify the restrictions that are in force on this farm. In addition to capacity limitations and crop rotation restrictions, this includes the empirically observed standard deviation which is used in the risk-programming model as an upper bound, thus limiting the search to the set of SSD solutions. Furthermore, the expectation value and the variability of the single gross margins of the different activities must be quantified statistically. This includes, in addition to the "classical" production activities, the activity of "purchasing a weather derivative."

The crop farm showcased here is situated approximately 40 km west of the reference weather station in Berlin-Tempelhof. With an approximate acreage of 700 ha and four employees (including the manager), its main crops are winter and summer wheat, winter rye, winter and summer barley, winter canola, corn, non-food canola, and set-aside land. In addition to the factor endowment (workers and land), information is collected regarding the crop rotation restrictions, the expected number of available fieldwork days and hours during the critical working time periods, and the number of working hours required for the single activities during these critical periods of time. To determine the variability of the total gross margin accepted by the farmer, the empirical production program for the production period 2005/06 was also captured.

At the assumed time of production planning (fall 2005), the single gross margins GM_i^j to be obtained in the target year (after the harvest in 2006) were not known. The single gross margins from 1980 through to the planning date in 2005 represent the database for the quantitative

²We assume the strike level is chosen corresponding to the average three-month rainfall in April/May/June from 1980 to 2005.

assessment of the uncertainty.³ We carry out a linear time-series analysis in order to identify the ARIMA(p, d, q) model which best fits the single gross margin time series (cf. Box and Jenkins, 1976).

According to the time-series analysis, all single gross margins follow first-order autoregressive [AR(1)] processes with normally distributed error terms. With an AR(1) process, the future value of the random variable results from an expected value $E(GM_{it}^j)$ plus an error term χ_{it}^j . The former is commensurate with a constant α_0^j plus the preceding observation value GM_{it-1}^j weighted with a factor α_1^j (cf. Pindyck and Rubinfeld, 1998, p. 535):

$$\begin{aligned} (3) \quad GM_{it}^j &= E(GM_{it}^j) + \chi_{it}^j \\ &= \alpha_0^j + \alpha_1^j GM_{it-1}^j + \chi_{it}^j, \\ &\text{with } |\alpha_1^j| < 1. \end{aligned}$$

The expected value of the single gross margins as well as the standard deviation and the correlation of the error terms are fed into the optimization model. The gross margin of the activity "purchasing a weather derivative" is represented in our risk-programming model as a normal distribution. To determine the distribution parameters, we use the would-be payoffs from 1980 to 2005, i.e., the payoffs that would have been realized if the weather derivative had existed during that period.

Using the format of a classical optimization tableau, Table 1 summarizes the information obtained from the time-series analysis and from the data regarding the restrictions and factor requirements. In the tableau, we have printed an expected value of zero for the gross margin of the activity (purchasing a) "weather derivative."

Knowing this is equivalent to the unrealistic assumption that the underwriter takes no loading on the fair premium, we use this value as a placeholder. It denotes the starting point of variant calculations which parameterize the loading in order to determine the price-quantity combinations (price-dependent contract volume) demanded by a rational farmer.

We furthermore show the standard deviation of €100,493 which the farmer implicitly accepted with his own 2005 program as an upper bound for the permissible variability. This value will also be parameterized. And finally, with regard to the correlation matrix, it should be noted that the correlation between the single gross margins of the crop activities (with the exception of corn) is clearly positive, whereas the correlation with the "insurance payment" of the weather derivative is negative.

Findings

Including weather derivatives in his portfolio enables the farmer to diversify his actual production activities to a lesser extent—i.e., the farmer can increase the weight of the more profitable (and at the same time riskier) activities in his program without increasing the variability of the total gross margin. Table 2 shows the corresponding findings produced by the variant calculations of the risk-programming model. The expected total gross margin (columns 2–6) and the hedging effectiveness (columns 7–10) are depicted depending on the systematically varied upper bound of the standard deviation (rows 1–9)⁴ and depending on the systematically varied expected gross margins (or loadings) of the derivative $E(GM^D)$.

³ Due to the discontinuity of the time series in the Brandenburg farm under consideration which was caused by the German reunification at the beginning of the 1990s, we use auxiliary gross margin time series instead of individual farm data for the period 1980–1992. These time series are synthesized by using site-specific yield data and West German prices. The individual gross margins from 1993 to 2005 are farm-specific.

⁴ In order to generate four equal intervals between the empirical standard deviation and the standard deviation needed to achieve the maximum total gross margin, the standard deviation was varied in steps of €1,883.

Table 1. Optimization Tableau Displaying the Information from the Farm Considered

		Activities										Additional Activities: Seasonal Labor				Factor Endow- ment
		Winter Wheat	Summer Wheat	Winter Rye	Winter Barley	Summer Barley	Winter Canola	Corn	Non- food Canola	Weather Derivative	Land Set- Aside	March and April	May and June	July to Sept.	Sept. to Nov.	
Objective Function Coefficient $E(GM^i)$		410	290	367	365	317	610	13	559	0	75	15	-15	-15	-15	
Activity Level x^i																
Acreage		1	1	1	1	1	1	1	1	0	1	0	0	0	0	703
Labor Requirement	March and April	0.31	2.60	0.28	0.31	2.55	0.36	2.60	0.36	0.00	0.00	1	0	0	0	900
	May and June	0.79	0.46	0.24	0.51	0.51	0.89	0.80	0.89	0.00	0.00	0	-1	0	0	1,050
	Mid-July to mid-Sept.	2.41	2.35	2.18	2.05	2.04	3.50	0.00	3.50	0.00	2.00	0	0	1	0	1,350
	Mid-Sept. to mid-Nov.	2.89	0.39	2.60	2.82	0.00	0.65	2.20	0.65	0.00	0.00	0	0	0	-1	1,200
Crop Rotation Restrictions	Wheat I	0.47	0.47	-0.54	-0.54	0.54	-0.54	0.54	-0.54	0.00	-0.54	0	0	0	0	0
	Wheat II	-0.85	-0.85	0.15	0.15	0.15	0.15	0.15	0.15	0.00	0.15	0	0	0	0	0
	Rye	0.41	-0.41	0.59	-0.41	-0.41	-0.41	-0.41	0.41	0.00	-0.41	0	0	0	0	0
	Barley	0.40	-0.40	0.40	0.60	0.60	0.40	-0.40	0.40	0.00	-0.40	0	0	0	0	0
	Canola	-0.22	-0.22	-0.22	0.22	-0.22	0.78	-0.22	0.78	0.00	0.22	0	0	0	0	0
	Land Set-Aside	0.10	0.10	0.10	0.10	0.10	0.10	0.10	-0.90	0.00	0.90	0	0	0	0	0
Standard Deviation		165	146	133	166	135	260	170	228	25	0					100,493
Correlation Matrix	Winter Wheat	1.00	0.85	0.74	0.66	0.71	0.53	0.17	0.57	0.32						
	Summer Wheat		1.00	0.69	0.56	0.81	0.53	0.32	0.57	-0.38						
	Winter Rye			1.00	0.68	0.64	0.66	0.08	0.67	-0.31						
	Winter Barley				1.00	0.63	0.52	-0.02	0.48	-0.25						
	Summer Barley					1.00	0.51	0.14	0.53	-0.41						
	Winter Canola						1.00	0.24	0.98	-0.27						
	Corn							1.00	0.19	-0.18						
	Non-food Canola								1.00	-0.27						
	Weather Derivative									1.00						

Note: A loading of the weather derivative of zero is a placeholder. In fact, the derivative price will be parameterized.

Table 2. Risk Efficiency Lines and Hedging Effectiveness for Varying Loadings of the Weather Derivative

	[1] Std. Dev. (in €)	Expectation Value of the Total Gross Margin (in €) for Varying Loadings of the Weather Derivative ^a					Hedging Effectiveness (in %) for Varying Loadings of the Weather Derivative			
		[2] w/o ($E(GM^D) = -\infty$)	[3] Loading = 0 ($E(GM^D) = 0$)	[4] Loading = 2 ($E(GM^D) = -2$)	[5] Loading = 4 ($E(GM^D) = -4$)	[6] Loading = 10 ($E(GM^D) = -10$)	[7] Loading = 0	[8] Loading = 2	[9] Loading = 4	[10] Loading = 10
1	92.962	271.280	286,880 (100.110)	284,050 (98,554)	281,580 (97,457)	275,710 (94,885)	7.1	5.7	4.6	2.0
2	94.844	275.620	289,370 (102,160)	286,570 (99,902)	284,310 (98,671)	279,610 (96,591)	7.2	5.1	3.9	1.8
3	96.727	279.920	291,250 (103,980)	288,480 (101,360)	286,360 (99,767)	282,650 (97,929)	7.0	4.6	3.0	1.2
4	98.610	284.170	292,940 (105,760)	290,190 (102,930)	288,170 (101,100)	285,230 (99,116)	6.8	4.2	2.5	0.5
5	100.493	287.410	294,300 (107,320)	291,770 (104,510)	289,860 (102,620)	287,510 (100,570)	6.4	3.8	2.1	0.1
6	102.376	289.610	294,700 (108,024)	292,850 (105,670)	291,430 (104,160)	289,610 (102,380)	5.2	3.1	1.7	0.0
7	104.258	291.520	294,700 (108,024)	293,640 (106,540)	292,690 (105,490)	291,520 (104,250)	3.5	2.1	1.2	0.0
8	106.141	293.280	294,700 (108,024)	294,220 (107,210)	293,760 (106,680)	293,280 (106,140)	1.7	1.0	0.5	0.0
9	108.024	294.700	294,700 (108,024)	294,700 (108,024)	294,700 (108,024)	294,700 (108,024)	0.0	0.0	0.0	0.0

Note: For the row relevant to the decision maker considered here (row 5), the values appear in boldface italics.

^a The standard deviation which would have to be accepted for the respective total gross margin without a hedging opportunity is given in parentheses.

Row 5 of Table 2 represents the situation for a predefined standard deviation of €100,493, i.e., for the variability which has been implicitly accepted by the farmer with his own production program. Using this value as the relevant upper bound, an expected total gross margin of €287,410 can be obtained without the hedging opportunity or with a weather derivative with prohibitively high costs (column 2). At the other extreme, if the derivative could be purchased without a loading on the fair premium, the farmer could obtain an expected total gross margin of €294,300 (column 3) without exceeding his previously accepted variability. This is equivalent to a total gross margin increase of €6,890 in contrast to the situation without a derivative. In order to achieve this higher gross margin without a derivative, the farmer would have to accept a standard deviation of €107,320. This corresponds to a hedging effectiveness of $(107,320 - 100,493)/107,320 = 6.4\%$ (column 7).

A systematic comparison of the columns in Table 2 illustrates that the higher the derivative loading, the lower the increase in the total gross margin that can be obtained at a constant variability. With a loading of €2 per contract, for example, the expected total gross margin amounts to €291,770 (column 4). Without a derivative, the farmer would then have to accept a standard deviation of €104,510. The hedging effectiveness now is reduced to 3.8% (column 8).

A systematic comparison of the rows in Table 2 reveals that the additional benefit for the farm business and the hedging effectiveness provided by the weather derivative decreases with an increasing use of the "production factor" risk (decreasing marginal returns), i.e., with increasing risk tolerance on the part of the farmer. Row 9 makes this clear by referring to the extreme case: the production program which yields the maximum expected total gross margin of €294,700 is associated with a standard deviation of €108,024. For a risk-neutral decision maker who accepts this

variability, no additional benefits are generated through the possibility of hedging weather risks.

Having limited the farmer's search in our extended risk-programming model to SSD solutions, the derived increase in the total gross margin can be interpreted as the minimum utility of the weather derivative for the farmer. In addition, using the risk-programming model we can also answer the question as to what price a monopolistic underwriter should demand per contract in order to maximize his net turnover (number of contracts sold multiplied by the loading per contract). Assuming fixed transaction costs independent of the number of contracts bought by the farmer, the maximum net turnover corresponds to the maximum profit.

Varying the derivative loading, Table 3 shows the number of weather derivatives an optimizing farmer would buy who tolerates a standard deviation of $S_{\text{opt}} = €100,493$ and who resorts to SSD solutions. At a contract price equivalent to the fair premium (i.e., a zero loading), no net turnover would remain for the underwriter. The farmer, however, would obtain a €6,890 higher total gross margin than without the derivative.

Comparing the columns of Table 3 indicates there is a corresponding fall in demand as the loading per derivative increases. Purchasing weather derivatives becomes unattractive for this farmer with a loading (cost) above €12.21. In other words, the contract costs are prohibitively high. Therefore, no demand is created above these derivative costs.

As the loading of the derivative increases, the net turnover of the underwriter increases in the beginning. However, due to the farmer's increasing price elasticity of demand, the net turnover of the underwriter decreases beyond a certain loading. The optimum price from the viewpoint of a monopolistic underwriter corresponds to the fair premium of €16.85 plus a loading of €4.45 per contract.

Table 3. Effects of the Weather Derivative for the Underwriter and the Farmer at Different Loadings per Contract

	Loading per Contract ($-E(GM^D)$)							
	0	2	4	4.45	6	8	10	≥ 12.21
Demand from the farmer (no. of contracts)	1,528	1,092	791	717	490	259	96	0
Net turnover of the underwriter from the weather derivative (€)	0	2,185	3,162	3,190	2,941	2,075	965	0
Increase of the farmer's expected total gross margin from the weather derivative (€)	6,890	4,361	2,451	2,111	1,181	441	101	0
Total benefit from introducing the weather derivative (€)	6,890	6,546	5,813	5,301	4,122	2,516	1,066	0

Note: Values are calculated for the farmer considered with an upper variability bound of $S_{\text{sup}} = €100,493$ (row 5 of Table 2).

In other words, if the underwriter was only targeting bilateral business with the farmer considered here, the optimum price for the weather derivative, from his perspective, would be €21.30. At that price, the above-described optimizing farmer would demand 717 contracts and have—in comparison to the situation without a derivative—a €2,111 higher total gross margin. The underwriter would obtain a net turnover of €3,190. It is interesting to note that, even in the case of the simple weather derivative considered here and even at a loading of €4.45 (which is equivalent to 26.4% of the fair premium), the considered real-life farmer would create a significant demand.

Since weather derivatives avoid the moral hazard problem, we can plausibly assume that the transaction costs for (standardized) weather derivatives are relatively low—in any case much lower, e.g., than those for hail insurances which, in Germany, have a loading level of approximately 20% to 25% (BMELV, 2001, p. 26; Weber et al., 2008). In conjunction with our preliminary findings which indicate a significant demand even at relatively high loading levels, this suggests it could be advantageous both for insurers and farmers if the novel instruments were put on the market. From the perspective of the underwriter/insurer, there appears to be considerable room for maneuvering when offering the derivative at (low) costs, which would also make it appealing for farmers with a higher risk tolerance

and/or on farms with a lower hedging effectiveness than the one we have showcased.

We have so far determined—from a monopolistic underwriter's point of view—the optimal loading for a weather derivative, assuming it is the sole hedging instrument within the farmer's portfolio. However, especially in the United States, both crop yield and crop revenue insurances are available. Yield insurance, often called multi-peril crop insurance (MPCI), allows farmers to hedge against various weather-induced volumetric risks. Revenue insurance additionally incorporates price risks.

While the introduction of crop insurances has generally required smoothing through subsidies, we now include a revenue insurance within the analysis. We assume that a full compensation payment is granted if the actual wheat revenue falls below the historical farm average. Furthermore, it is assumed that the farmer is able to partially insure⁵ the wheat acreage but that the compensation payment, in order to limit moral hazard, depends on the entire revenues (from the total wheat acreage) being below average.

⁵The opportunity of a partial insurance on the revenues from winter wheat gives the farmer more flexibility and makes the instrument more flexible than farm revenue insurances offered in the United States, which only allow the farmer to insure the total acreage of the respective crop.

Table 4. Optimal Loading for the Weather Derivative and the Revenue Insurance from the Underwriter's Point of View

	Isolated View		Simultaneous View	
	[1]	[2]	[3]	[4]
Loading for Farm Revenue Insurance:	—	Optimized	Given	Given
Loading for Weather Derivative:	Optimized	—	Optimized	Optimized
<i>Farm Revenue Insurance for Winter Wheat (actuarially fair premium = € 78.80)</i>				
Loading (€ and % of fair premium)		23.68 (30.1%)	15.76 (20.0%)	23.68 (30.1%)
Demand of the farmer (no. of contracts)		148	54	32
Net turnover of the underwriter from the farm revenue insurance (€)		3,481	854	760
<i>Weather Derivative (actuarially fair premium = € 16.85)</i>				
Loading (€ and % of fair premium)	4.45 (26.4%)		2.01 (11.9%)	2.85 (16.9%)
Demand of the farmer (no. of contracts)	717		760	804
Net turnover of the underwriter from the farm weather derivative (€)	3,190		1,528	2,291
Increase of the farmer's expected total gross margin generated through the two hedging instruments (€)	2,111	2,161	4,569	3,578
Total benefit resulting from the introduction of the two hedging instruments (€)	5,301	5,642	6,950	6,629

Note: Values are calculated for the farmer considered with an upper variability bound of $S_{avg} = €100,493$ (row 5 of Table 2).

In accordance with the analytical procedure chosen for weather derivatives (Table 3), we first analyze the farmer's willingness to pay if the revenue insurance was his sole hedging opportunity. In a second step, we simultaneously introduce the weather derivative *and* the revenue insurance as potential hedging opportunities within the farmer's portfolio. We are thus able to determine, from the underwriter's point of view, the derivative's optimal loading for varying loadings of the revenue insurance.

Columns 1 and 2 in Table 4 depict the farmer's demand if the respective hedging instrument (*either* insurance *or* derivative) was exclusively available to the farmer and if it was offered with the optimal loading from the underwriter's point of view. Neglecting transaction costs, the underwriter's net turnover from the revenue insurance exceeds the net turnover from the weather derivative by approximately €290. This difference is

quite small if one takes into account the fact that transaction costs for revenue insurances can be expected to exceed those of weather derivatives considerably.

According to an empirical survey conducted by Weber et al. (2008), experts from European reinsurance companies estimated that 50% or more in transaction costs could be saved by using weather derivatives instead of classical insurances. Since the insurers' transaction cost levels and profit margins are well-kept secrets, we use this information to approximate the relative competitiveness of the two instruments. Even if the transaction costs for the revenue insurance amounted only to 20% of the actuarially fair premium (i.e., about €2,300 on our sample farm), it would be possible to save €1,150 in transaction costs when offering the weather derivative. Using these assumptions, the standardized weather derivative would easily outperform the farm revenue insurance.

Columns 3 and 4 in Table 4 depict a farmer's demand for the derivative and the insurance if he can use them both as hedging instruments. For this simultaneous analysis, we specify a priori a certain loading for the farm revenue insurance and then determine in the portfolio model the WTP for the weather derivative that a rational farmer would have.

Two variant calculations are carried out: one for an insurance loading of 20% which is considered to represent a lower cost limit due to the considerable moral-hazard and transaction cost problem, and one for an insurance loading of 30.1% which is considered to represent an upper limit since it is the optimal loading from the underwriter's point of view. The corresponding optimal loadings for the weather derivative are 11.9% (column 3) and 16.9% (column 4) of the actuarially fair premium. These results emphasize that a rational farmer has a considerable WTP for a standard weather derivative even if it must compete with alternative hedging instruments, at least as long as there are no subsidies (for crop insurances) which distort the price relations.

Summary and Conclusions

In this article, we propose an extended risk-programming approach to calculate a rational farmer's WTP for risk management instruments in general, and weather derivatives in particular. This approach enables us to avoid some of the drawbacks of previously suggested evaluation procedures:

- By resorting to SSD, we are able to consider the risk tolerance of the decision maker without having to elicit his risk attitude.
- By considering the production possibilities of the farm, we are able to explore the complexities and interdependencies of the farm as a system.
- We are able to examine the dynamic changes and portfolio adjustments made by an optimizing farmer following the introduction of a novel hedging instrument such as the weather derivative.

The farmer's WTP is the basis for determining the optimum derivative price from the viewpoint of a monopolistic underwriter who targets bilateral business with that farmer.

In the case of the cash-crop farm showcased here, we find a considerable WTP for weather derivatives. To avoid confusion, it should be emphasized that the price paid by the farmer for the derivative does not represent the costs of the risk management instrument "weather derivative." This information can be provided only after calculating the expectation value of the payoffs. Only the derivative loading represents its cost as a hedging instrument. The rather large optimum loading of more than 25% established in our exemplary study suggests that the question of the adequate discount rate may be rather irrelevant for assessing whether an innovative insurer should enter the market and how he should price derivatives for agricultural firms. However, the discount rate may become relevant if competition among insurers forces them to offer derivatives at increasingly attractive prices to farmers.

The optimum loading, from the underwriter's viewpoint, which was established for the exemplary farm considered here, cannot be generalized. The individual farmer's WTP depends both on his risk attitude and the farm-specific hedging effectiveness of the weather derivative. The latter is influenced by the distance between the reference weather station and the location of the farm (geographical basis risk) and the specification of the weather index (production basis risk). Future research regarding the evaluation of and the demand for weather derivatives should broaden the database and include more farms, thus shedding light, for example,

on the farmers' (aggregated) WTP in a specific region.

Nonetheless, even broadening the database of the portfolio analysis will not reveal the true market potential. That is, modeling the "theoretical" WTP of a rational farmer does not facilitate conclusions regarding the actual market potentials in certain regions and countries. This requires classical market studies accompanied by adequate product information activities.

To avoid eroding the advantages of simplicity and of low transaction costs, simple weather derivatives which relate to existing weather stations should be "tested." We expect innovative underwriters/insurers will be able to determine the size of the target group in which demand is created by using their room for maneuvering. If the derivative is offered at a relatively low price, even farmers who are located far from the reference weather station will be interested in buying it. A higher price, by contrast, will reduce the demand and the size of the target group due to the increasing geographical basis risk. Thus, by comparing different pricing strategies, the underwriter should be able to determine his optimum price for the derivative in a certain region.

From a methodical stance, it would be interesting to analyze whether relevant changes in the calculated WTP would occur if one used a downside-risk measure instead of the variance in the target function of the portfolio approach (cf. Berg and Schmitz, 2007). From the farmers' point of view, it would be helpful to investigate how different hedging instruments (traditional insurances, traditional diversification practices, forward contracts, futures, different weather derivatives) should be optimally combined in a production and risk management activities portfolio.

Or, stated more pointedly: While the present article has basically probed the question of whether using an "ineffective"

weather derivative can be economically efficient, it would be worthwhile to address the question of whether there are "ineffective" hedging instruments which are more efficient than effective ones. This would be the case if they (over-) compensated for the performance-related disadvantage (i.e., the lower risk-reduction potential) with cost-related advantages (i.e., a lower loading on the fair premium due to lower transaction costs).

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