The role of weather derivatives and portfolio effects in agricultural water management

Matthias Buchholz[1] and Oliver Musshoff[1]

[1]Department of Agricultural Economics and Rural Development
Georg-August-Universität Göttingen
Platz der Göttinger Sieben 5
37073 Göttingen, Germany

matthias.buchholz@agr.uni-goettingen.de

Extended abstract

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Background and objectives

Restrictive irrigation water policies established due to e.g. environmental concerns or water scarcity appear to result in declining farm income and arising risk exposure in terms of yield uncertainty (cf., e.g. Dono *et al.*, 2010; Giannoccaro *et al.*, 2010; Lenouvel and Montginoul, 2010; Viaggi *et al.*, 2010; Finger, 2012; Garrido *et al.*, 2006). In order to mitigate the economic disadvantages caused by restrictive water and irrigation policies, farmers may reallocate the available irrigation water between crops, adjust the crop-specific irrigation intensity or alter crop portfolios to better balance risks (Buchholz and Musshoff, 2013).

In addition to on-farm risk management instruments, such as irrigation, a variety of market-based agricultural insurance products that aim to hedge weather related risks are offered to farmers in nowadays. More recently, a new class of index-based weather insurance, also known as weather derivatives, has been a promising field of research for coping with weather risks in agricultural production (cf., e.g. Turvey, 2001; Vedenov and Barnett, 2004; Woodard and Garcia, 2008). Although agricultural insurance in general and weather derivatives in particular as well as irrigated agriculture are used to mitigate the consequences of weather-related risks, surprisingly little effort has been made to investigate these different types of risk management instruments in a joint analysis (Barham *et al.*, 2011; Dalton *et al.*, 2004; Foudi and Erdlenbruch, 2012; Lin *et al.*, 2008; Mafoua and Turvey, 2003).

Although, the studies mentioned above consider possible interdependencies between the risk management instruments ‘irrigation’ and the analyzed ‘insurance products’, possible adjustments with regard to the choice of crop portfolios are not directly taken into account.

Bearing in mind that farmers usually grow a multitude of crops which respond differently to unfavorable weather conditions or restricted irrigation capabilities, an integrated approach is necessary if various strategies for hedging weather risks are available (Berg and Schmitz, 2008).

With this in mind, the present study addresses these limitations and suggests the additional consideration of weather derivatives to the field of agricultural water management in general, and policymakers as well as farmers in particular. More specifically, the two following research questions are the purpose of this investigation:

1) How does the provision of weather derivatives affect risk-efficient portfolio crop choice and, thus, the irrigation water demand at the farm level?
2) Can index-based weather derivatives be used to mitigate the economic disadvantages as well as the arising risk exposure for farmers resulting from a reduction in water quotas or increased water prices?

In doing so, we are – to the best of our knowledge – the first that contributes a whole-farm risk programming approach that allows for the adjustment of the crop portfolio, the purchase of weather derivatives and water reallocation between crops combined in an integrated framework.

Methods and data

In order to analyze irrigation and weather derivatives as complementary risk management instruments in a whole-farm context, we apply a quadratic risk programming approach that is based on an expected value - variance framework (EV). Here, we define the expected value as the expected total gross margin. More specifically, the optimization problem considered here is formulated to maximize the decision maker's certainty equivalent for a given set of farm-specific constraints and varying irrigation water policy scenarios. Aside from the crop-based production activities, the farmer has the ability to sign different types of weather derivatives which are incorporated as additional activities into the EV model.

Although being highly exposed to weather related risk, thus far, farmers in general, and specifically in Germany have rarely used weather derivatives (cf., e.g. Kellner and Musshoff, 2011; Smith and Glauber, 2012). To show the potential of these insurance products, we design standardized index-based weather derivatives which are hypothetically offered to the farmer over-the-counter (OTC). Crop water demand is not only dependent on the amount of precipitation, but also on temperature as one driver of evaporation. We therefore consider both, a precipitation-based and a temperature-based weather derivative corresponding to drought and heat. The actuarial fair premium is estimated by means of the burn rate method (Jewson and Brix, 2005). To account for the underwriter's profit margin and transaction costs that inevitably incur when derivatives are offered on a commercial basis, we add a load of 20 % of the fair premium on the price of the weather derivatives. From the farmers' perspective, the loading results in a negative expected gross margin of the weather derivatives in the amount of the loading representing the true costs of these insurance products.

The aforementioned approach is applied to a representative cash crop farm situated in the northeastern part of Lower Saxony which is also known as Germany's major irrigation area. Crop yields and the corresponding irrigation water applications are based on irrigation field trials carried out in the considered region between 2006 and 2012 (LWK, several years). Daily average precipitation and temperature data was recorded directly at the trial site and is also available. Therefore, geographical basis risk is almost completely excluded from the analysis. Using the crop yield and weather data, we compute time series of the crop-based production activities' single gross margins net of the variable irrigation costs as well as of the payoff of the weather derivatives for the period from 2006 to 2012. In order to correct for statistical bias, bootstrap simulations are applied (Efron and Tibshirani, 1993).

Findings

Our results reveal that weather derivatives have the potential to substantially alter farm plans which might be accompanied by rising risk taking. Thus, confirming the well-known phenomenon that farmers incur additional production risk if agricultural insurance is available (cf., e.g. Turvey, 2012). The effect of weather derivatives on the irrigation water demand remains ambiguous. We found substitution effects that result in a partial reduction in the applied amount of irrigation. However, these water-savings are, to a large extent, offset by a water reallocation towards production activities that would otherwise be provided with less or no irrigation. At the aggregated farm level, the provision of weather derivatives could even increase the optimal irrigation demand. This may have far reaching environmental implications which require further attention and careful consideration by policymakers. Generally, the farmer exhibits a strongly pronounced demand for both the precipitation-based and the temperature-based weather derivative in all water policy scenarios.

Figure 1 depicts the economic impact of the analyzed water policy settings which is measured as percentage change in the certainty equivalent in contrast to the base scenario. A systematic comparison of all water quota and water price scenarios with and without the availability of weather derivatives, respectively, provides the following results: Considering the scenarios without weather derivative first, it becomes clear that moderate cuts in the water quota, e.g. from 80 mm to 60 mm, and slight increases in the water price of up to € 0.5/mm involve only a minor decline of -2.1 % in the certainty equivalent in both cases. Moreover, the benefit of an unlimited irrigation water use in the € 0/mm scenario without weather derivatives is rather small. On the contrary, a total ban on irrigation (00 mm) involves a sharp fall in the certainty equivalent. For a fair comparison, it should be noted that prohibitively high water prices would be required to induce a reduction in the farmer's irrigation water use to 0 mm.

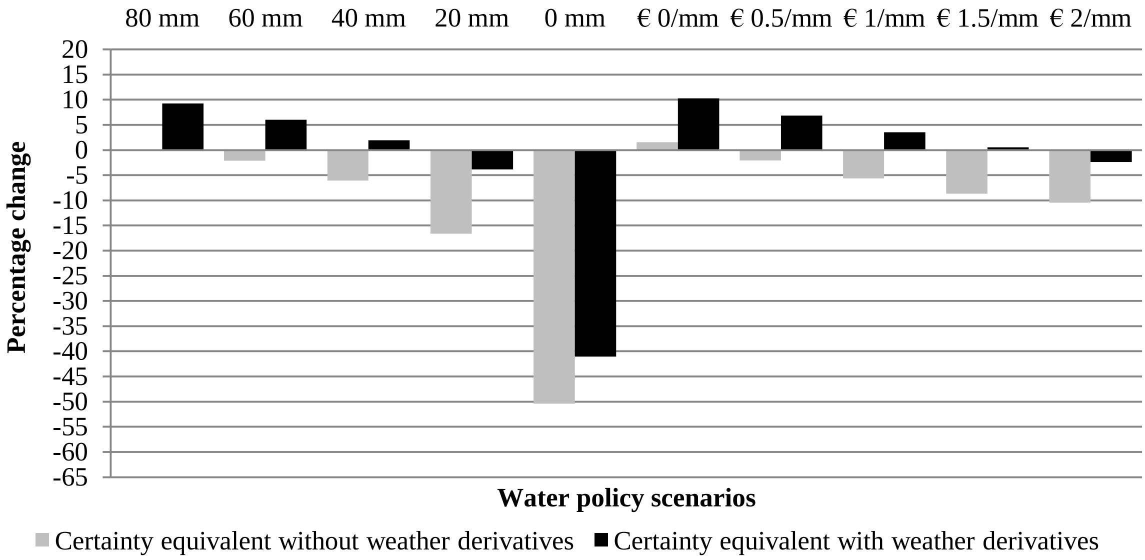

Figure 1 Percentage change in the certainty equivalent compared to the base scenario as a result of changing water policies. The base scenario refers to a granted water quota of 80 mm without the possibility of purchasing weather derivatives.

When considering the water policy scenarios in which weather derivatives can be applied, it becomes clear that the estimated certainty equivalents increase in all scenarios. In other words, the negative consequences of water use restrictions are mitigated. From a water policy impact perspective, purchasing weather derivatives enables the farmer to compensate for the loss in the certainty equivalent which results from a reduction in water quotas from e.g. 80 mm to 40 mm or from a boost in the water price to € 1.5/mm.

Limitations and implications

The analysis is confined to normally distributed total gross margins. Although being a reasonable assumption in terms of portfolio optimization, an effective weather derivative which is set as option, appears to result in a right-skewed distribution since the probability of low outcomes in the left tail is systematically reduced (Musshoff *et al.*, 2008). Thus, the total variability is falsely understood as systematic deviation from the mean. Consequently, we underestimate the risk-reducing potential of weather derivatives. In this regard, the consideration of downside risk measures appears to be interesting for future research (cf., e.g. Berg and Schmitz, 2008).

In our example, weather indices are based on locally recorded weather data. We are well aware that geographical basis risk may play a more pronounced role in other applications. However, the purpose of this study is to explore the interdependencies between the use of weather derivatives and the water demand at the farm level, and not to essentially contribute to the vast amount of literature on weather derivatives. Despite these limitations and without loss of generality, our approach highlights the need to consider diversification effects in the joint evaluation of irrigation and agricultural insurance in general as well as of weather derivatives in particular. Bearing in mind the rapid spread of agricultural insurance programs in recent years (Smith and Glauber, 2012), there remains room for additional empirical evidence.

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