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

Matthias Buchholz*, Oliver Musshoff

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

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ABSTRACT

Both rising competition for water resources and increasing environmental concerns have placed the need for an enhanced water resources management on the policy agenda. However, a stricter regulation of irrigation water tends to result in declining farm income and arising risk exposure. With this in mind, we investigate the potential of index-based weather insurance, which is also referred to as weather derivatives, to cope with the economic disadvantages for farmers resulting from a reduction in water quotas and increased water prices. By means of a whole-farm risk programming approach, we systematically compare crop portfolios without and with the possibility of purchasing standardized weather derivatives based on precipitation and temperature indices. In an application to a representative cash crop farm in the northeastern part of the German federal state of Lower Saxony, we found that the use of weather derivatives offsets the loss in farmers' certainty equivalent resulting from moderate reductions in water quotas and water price increases. Our results also indicate that the provision of weather derivatives may substantially alter farm plans as well as the optimal irrigation water demand.

1. Introduction

Globally, irrigation has substantially contributed to reduce negative economic consequences associated with the absence of precipitation indicating that risk aversion among farmers is one reason for shifting from rainfed agriculture to irrigation (Perry et al., 2009). However, growing population pressures, improved living standards, and the increasing awareness of environmental concerns have placed the need for an enhanced water resources management on the policy agenda (Johansson et al., 2002).

In regard to indicating essential water savings, a vast amount of literature reveals that a stricter regulation of irrigation water – e.g. by means of water pricing schemes or water quotas – results in diminishing farm income (cf., e.g. Dono et al., 2010; Giannoccaro et al., 2010; Lenouvel and Montginoul, 2010; Viaggi et al., 2010). Moreover, crop yield variability appears to increase involving further risks for farmers (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 referred to as weather derivatives, has been a promising field of research for coping with weather risks in agricultural production. Unlike traditional crop insurance, weather derivatives are used to hedge risk caused by weather events, such as heat or drought, instead of the loss inherent to these weather events (Turvey, 2001). To do so, an index is designed that is based on an underlying weather index, such as growing degree days, which is measured objectively at a specific weather station for a certain period of time. Thus, the payoff of the derivative is independent of the farm-specific yield shortfall occurring in the case of unfavorable weather conditions. This procedure avoids moral hazard and minimizes adverse selection problems that commonly apply to traditional crop yield insurance (Vedenov and Barnett, 2004). However, there is the disadvantage that the payoff of the weather derivative does not perfectly correspond to the actual shortfall in the underlying exposure (Woodard and Garcia, 2008). This is generally referred to as basis risk which mainly comprises a geographical basis risk related to different weather conditions at the reference weather station and the production site as well as to a local basis

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* Corresponding author. Tel.: +0049 0 551 39 4439; fax: +0049 0 551 39 22030.
E-mail addresses: mbuchho@gwdg.de (M. Buchholz), omussho@gwdg.de (O. Musshoff).

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risk entailing the fact that the weather variable which determines the payoff of the derivative is not the only parameter relevant to explain a shortfall in crop yields.

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. The existing studies fall into three distinct categories: analysis of discrete farm plans (A), optimizing approaches with one single production activity in an expected utility maximizing framework (B) and econometric analyses (C).

(A) Barham et al. (2011) compare discrete combinations of multiple-peril crop insurance and varying levels of irrigation in a stochastic simulation setting for a cotton farm in Texas. Their findings show that the crop insurance is particularly beneficial at lower irrigation levels.

(B) By means of comparing the benefits of multiple-peril crop insurance and the investment in supplemental irrigation for potato production in Maine, Dalton et al. (2004) find that the analyzed insurance schemes are inefficient to reduce the risk exposure resulting from weather-related production risks. Lin et al. (2008) investigate irrigation strategies for maize production in Georgia in case of varying water prices and the availability of a precipitation-based weather derivative. Their results reveal that the derivative performs relatively poorly in terms of increasing the estimated certainty equivalent revenues and has no impact on the amount of irrigation water used.

(C) Mafoua and Turvey (2003) provide a conceptual regression model using annual cross sectional data from New Jersey. They demonstrate that precipitation-based weather derivatives may enable farmers to hedge against irrigation costs in drought years. Foudi and Erdlenbruch (2012) reveal in a more recent study with French farmers based on a probit model that the adoption to irrigation is lower when farmers purchase yield insurance. Thus, the offered yield insurance, as they further conclude, may serve to decrease the amount of water used for irrigation.

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 can – depending on the geographic region and climate conditions – generally chose from various crop types 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). Likewise, there is evidence that agricultural insurance could generally affect the optimal input usage as a result of changing crop portfolios and alterations with regard to the crop-specific input intensity which can be referred to as ‘extensive’ and ‘intensive margin’ effects (cf., e.g. Seo et al., 2005).

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, this paper is – 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. Moreover, our investigation relies on a unique panel of crop-specific irrigation field trial results. That is, yield uncertainty is incorporated into our model based on micro data, rather than on expert opinions or crop modeling techniques predominantly used in this research strand. The analysis is applied to a representative cash crop farm situated in the north-eastern part of the German federal state of Lower Saxony that is highly dependent on irrigation using withdrawn groundwater.

The remainder of the paper is structured as follows: In Section 2, we explain the risk programming approach as well as the design and pricing of the weather derivatives. Subsequently, Section 3 reveals a description of the database including the case study farm as well as the applied bootstrap simulations. Whole-farm model results for the investigated water policy scenarios are presented in Section 4 and, finally, the paper ends with conclusions (Section 5).

2. Methodological procedure

2.1. The risk programming approach for jointly analyzing irrigation and weather derivatives

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 (EV) framework. Here, we focus on the expected total gross margin of the farm plan $E(TGM)$ which is subject to the expected single gross margins $E(GM(IR)_j)$ per unit of the production activity j and the water price WP per unit of the expected amount of irrigation $E(IR_j)$. Furthermore, x_j denotes the underlying activity levels.

$$E(TGM) = \sum_{j=1}^{J} \left(E\left(GM\left(IR_j\right)\right) - WP \times E\left(IR_j\right)\right) \times x_j \tag{1}$$

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. Supposing a linear combination of the single activities and normally distributed single gross margins, the variance of the expected total gross margin $VAR(TGM)$ can be calculated by using the weighted activity levels x_j, standard deviations $\sigma(IR)_j$ as well as the correlation coefficients ρ_{jk} (cf., e.g. Markowitz, 1952, p. 81):

$$VAR(TGM) = \sum_{j=1}^{J} \left(x_j \times \sigma(IR)_j\right)^2 + 2 \times \sum_{j=1}^{J}\sum_{k<j}^{J} x_j \times \sigma(IR)_j \times x_k \sigma(IR)_k \times \rho_{jk} \tag{2}$$

Farmers’ preferences are frequently described by means of a negative exponential utility function $U(\cdot)$ with constant absolute risk aversion (CARA) and a degree of risk aversion being represented by the risk aversion coefficient λ (Brockett et al., 2006; Komarek and MacAulay, 2013; Mahul and Vermersch, 2000; Seo et al., 2005; Turvey, 2012):

$$U(TGM) = 1 - e^{-\lambda \times TGM}, \quad \text{with} \quad \lambda \geq 0 \tag{3}$$

Resorting to CARA has the advantage that the portfolio choice and the optimal level of irrigation are independent of the