Optimal Crop Management Systems under Uncertainty - A combined Portfolio Optimization and Real Options Analysis

Ch. Heumesser, F. Strauss and E. Schmid[1]

***Abstract* – In the following analysis we investigate optimal crop management strategies of farmers facing uncertainty in weather events as well as market price fluctuations for the region Marchfeld in Austria. We employ a portfolio optimization approach based on the Conditional value at Risk (CVaR) as risk metric to find optimal crop management options in adapting to climate change. Previous analysis (cp. Strauss et al., 2009) showed that crop production portfolios with winter wheat and sunflower as well as minimum tillage are optimal in the Marchfeld region. Although irrigation, which is a major crop management activity in the Marchfeld region, is not part of the optimal crop production portfolios, we will investigate irrigation investment decisions using a real option analysis. In this study, we investigate when the optimal timing to invest in irrigation systems occurs and the profit distributions resulting thereafter. Our analyses are based on bio-physical outputs simulated with EPIC (Environmental Policy Integrated Climate) including climate change until 2040 as well as production and investment costs from the standard gross margin catalogue, and expert interviews.**

INTRODUCTION

Agricultural production is a dynamic process affected by different sources of uncertainty, among the most essential being weather and climate uncertainty, price fluctuations in commodity markets as well as technology advancement. The Marchfeld is one of the most important crop production and driest regions in Austria. The annual temperature is predicted to increase in the next three decades by approximately 1.6 °C whereas the development of precipitation is assumed to remain unchanged (Strauss et al., 2009). Therefore, it is indispensable to develop adaptation strategies to climate change in agricultural production. Our analysis provides an assessment of optimal crop management systems and the impact of risk aversion on crop choices. Regions with annual average precipitation of less than 600 mm – average precipitation in Marchfeld amounts to 500 mm – are considered to rely on irrigation systems (cp. Eitzinger et al., 2009) to produce cash crops including vegetables, corn and sugar beets. We assess optimal investment plans in irrigation systems given weather (i.e. precipitation) and market price uncertainties for the Marchfeld.

Strauss et al. (2009) employed a portfolio optimization model to identify optimal agricultural management options under risk in Marchfeld by applying the Conditional Value at Risk as risk measure (CVaR, see Rockafellar and Uryasev, 2000). This analysis shows that the simulated crop yields and therefore the profits decrease over time. Crops usually grow at or near their thermal optimum, so even a minor temperature increase during the growing season can reduce crop yields. Furthermore, evaporation of soils is likely to increase due to projected temperature trends and unchanged precipitation amounts leading to higher water stresses in crop production. Winter wheat and sunflower with minimum tillage constitute an optimal portfolio (Strauss et al., 2009). The results indicate that irrigation is not an interesting option in crop management portfolios under climate change, as marginal variable costs of irrigation – which is capital and labour intensive – are higher than marginal revenues. However, irrigation is a major crop management activity in the Marchfeld region. The results of Strauss et al. (2009) are based on climate scenarios where the distributions of precipitation are similar to the past.

In this analysis, alternative precipitation patterns are considered as well as vegetable crops, which require studying crop management portfolios in more detail. Thereby we investigate in particular the optimal timing of investment in irrigation systems by applying a real options approach (Dixit and Pindyck, 1994) for a given optimal crop management portfolio.

DATA AND METHOD

Our model framework consists of four models: the climate change model (Strauss et al., 2010), the bio-physical process model EPIC (Environmental Policy Integrated Climate; Williams, 1995; Izaurralde et al., 2006), the portfolio optimization model, and the real options model.

Strauss et al. (2010) developed stochastic climate scenarios for the period 2008-2040, where residuals from maximum and minimum temperature have been reallocated randomly together with the observed values of the weather parameters precipitation, solar radiation, relative humidity and wind. To account for a wider range of possible precipitation

[1] Ch. Heumesser, F. Strauss and E. Schmid are from the University of Natural Resources and Applied Life Sciences Vienna, Institute for Sustainable Economic Development, Vienna, Austria (christine.heumesser@boku.ac.at, franziska.strauss@boku.ac.at, erwin.schmid@boku.ac.at).

patterns, the climate change spectrum was extended with precipitation scenarios including increases and decreases of annual precipitation sums as well as reallocations of seasonal precipitation. The climate scenarios are among other site specific data (e.g. topographical data, soil types, crop management variants) important input to the EPIC model, which simulates crop yields and environmental impacts.

We calculate profit distributions based on the simulated crop yields together with data on variable costs (BMLFUW, 2008) and mean commodity prices from 1995-2008 to derive optimal crop management portfolios for the respective climate scenarios. As crop yields vary with the climate scenarios and variable costs among crop production variants, we get different profit distributions for each crop management option.

The profit distributions are input to the portfolio optimization model and the output are optimal shares of crops and crop management variants (e.g. corn with conventional tillage or minimum tillage) that constitute diversification of crop production choices with respect to risk aversion.

We use the CVaR (Rockafellar and Uryasev, 2000) as risk measure, which is closely related to the Value at Risk (VaR). VaR of a portfolio is the lowest amount α, such that – with specified probability level β – the portfolio loss will not exceed α. CVaR is the conditional expectation of losses above that amount α. So, VaR corresponds to the β-percentile of the distribution, whereas CVaR is the mean of the values exceeding VaR. We minimize the expected value of losses exceeding a defined percentile as described in the CVaR model of Rockafellar and Uryasev (2000). CVaR can thus account for the tails of a distribution, while a standard deviation approach would consider only the spread of a distribution.

The CVaR model is linear where CVaR is minimized subject to a constraint on minimum expected profits (Rockafellar and Uryasev, 2000):

$$\underset{x,a,u}{Min}\left(a+\frac{1}{N(1-\beta)}\sum_{m,i}u_{m,i}\right)$$

$$where \;\; u_{m,i}\geq 0 \; and \; u_{m,i}\geq -(y_{m,i}\cdot p_m - c_m)x_m - a \quad \forall i$$

$$\frac{1}{N}\sum_{m,i}(y_{m,i}\cdot p_m - c_m)x_m \geq R$$

where *m* is the crop management index, *i* is the index and *N* is the number of climate scenarios, *x* is the portfolio variable giving the specification of crop, management, and fertilizer rates, $u_{m,i}=[u^1, u^2, \ldots, u^N]^T \in \mathbf{R}$ is an auxiliary variable, *a* is a threshold (with probability *β* profits will not fall short of *a*), and *β* is the confidence level. Also, the portfolio shares have to sum up to 1, all x_m and $u_{m,i}$ must be greater than or equal to zero and a constraint on minimum expected profits, *R*, has to be fulfilled. In the experiments, we employ values for this required expected profit *R* such that it is not binding.

Once the optimal crop management portfolios for different climate change scenarios are identified, we investigate in more detail the decision to adopt irrigation systems for a given crop management portfolio. Therefore, we adopt a real options framework by Dixit and Pindyck (1994) to determine an optimal investment plan for a profit maximizing farmer. In contrast to standard investment theory which focuses on the net present value (NPV), the real option framework seems appropriate because three factors are considered, which are crucial for irrigation investments: first, real options acknowledges the irreversibility of investment, that a substantial portion of the investment cost is sunk; second, it integrates the uncertainty surrounding the future profits from the investment which equally depend on the future fluctuation of input or output prices. Future profits also depend on weather uncertainties which determine the timing of irrigation adoption, and whether it is necessary to irrigate or not; and third, flexibility about the timing of investment is considered. Thus, the investor is able to wait with his investment decision until more information is available, such that a waiting value or option value is assigned.

Costs of irrigation investments are collected by interviewing experts that are differentiated by irrigation systems and capacities. The real options analysis yields the optimal investment strategy and its implied profit distribution for each irrigation system.

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