Crop production portfolio optimization in managing climate-induced risks in Austria

Portfoliooptimierung für klima-induziertes Risikomanagement in der österreichischen Nutzpflanzenproduktion

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Summary

We assess climate change impacts on level and variability of crop yields and profits. We identify optimal crop production portfolios capturing the trade-off between profit expectation, variability and risk aversion. Crop yields with alternative management practices are simulated with the bio-physical process model EPIC (Environmental Policy Integrated Climate) for a historical period (1975-2005) and five climate change scenarios (2010-2040). A non-linear mean-standard deviation model is applied to optimize spatially explicit crop production portfolios. Under climate change, optimal portfolios result in higher average crop yields and profits of 2 to 18%. Risk aversion, climate change and specific site conditions (i.e. semi-aridity, brown earth) result in more diversified crop production portfolios.

Keywords: portfolio optimization, risk management, climate change

Zusammenfassung

Wir untersuchen die Einflüsse des Klimawandels auf Höhe und Variabilität von Pflanzenerträgen und Profiten. Zudem ermitteln wir optimale Bewirtschaftungsportfolios, um die Zielkonflikte von Profiterwartung, -schwankung und Risikoaversion zu erfassen. Die Pflanzenerträge mit verschiedenen Bewirtschaftungsmaßnahmen werden mit dem bio-physikalischen Prozessmodell EPIC (Environmental Policy Integrated Climate) für die Vergangenheit (1975-2005) und fünf Klimawandelszenarien (2010-2040) simuliert. Wir verwenden ein nicht-lineares Mean-Standard Deviation Modell zur

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Optimierung räumlich expliziter Bewirtschaftungsportfolios. Im Klimawandel führen optimale Portfolios zu durchschnittlich höheren Pflanzenerträgen und Profiten (zwischen 2 und 18%). Zunehmende Risikoaversion, Klimawandel und bestimmte Standortbedingungen (Semi-Aridität, Braunerde) steigern die Portfoliodiversifizierung.

Schlagworte: Portfoliooptimierung, Risikomanagement, Klimawandel

1. Introduction

Farmers are exposed to a variety of risks from different sources such as production and market risks, financial and legal risks and human resources risks. The Organisation of Economic Co-operation and Development (OECD, 2009) suggests that information on production risks may typically be easier available to farmers than information on market risks as farmers usually have good records about their past production. However, long term changes, such as climate change, may decrease trust in historical records (Alpizar et al., 2011). Even though farmers are used to adapt to changing environmental conditions, a better understanding of dealing with climate-induced variability of agricultural outputs remains important. For instance, considerable modifications in farm management and land use may be needed in order to reduce climate-induced risks (Rivington et al., 2013). Thus, the aim of our analysis is twofold. First, we assess the impacts of regional climate change scenarios on level and variability of crop yields and profits in Austria. Secondly, we identify optimal crop production portfolios, which aim at reducing climate-induced variability in profits for alternative levels of risk aversion. Therefore, we employ an integrated modeling approach, consisting of a statistical climate change model, a bio-physical process model and a portfolio optimization model. Portfolio optimization models have been identified as particularly useful to assess climate-induced risks and to suggest robust crop management practices (Marinoni et al., 2011). For instance, Paydar and Qureshi (2012) identify risk minimizing portfolios of land and water management strategies to respond to climate-induced uncertainty in irrigation water supply. As our analysis is spatially explicit, we are able to assess the impacts of bio-physical characteristics such as soil type and average annual precipitation sums on optimal portfolio choices.

The article is structured as follows. In section 2, we describe the integrated modeling framework, in section 3 we present and discuss the results and in section 4 we draw some conclusions.

2. Integrated modeling framework

2.1 Bio-physical process model

The bio-physical process model EPIC (Environmental Policy Integrated Climate; WILLIAMS, 1995) is applied to simulate average annual dry matter crop yields and environmental outcomes for alternative crop management practices for a historical period (1975-2005) and a future climate change period (2010-2040). The simulations are performed for 40,244 pixels, which represent the Austrian cropland on a 1 km pixel resolution. Five climate change scenarios are generated by the statistical climate change model for Austria until 2040 (ACLiReM, Austrian Climate Change Model using Linear Regression) and serve as input to EPIC. Each scenario consists of the same rising trend in temperature (+1.5 °C until 2040), but considers alternative assumptions on precipitation sums and distributions: (i) mean annual precipitation sums remain the same as in the past; (ii) decrease or (iii) increase by 20% in 2040 compared to the historical period; seasonal precipitation distributions encompass a shift (iv) from summer to winter and (v) vice versa such that the mean annual precipitation sums resemble historical values (STRAUSS et al., 2013). These scenarios cover the currently expected range of climate trends until 2040 in Austria and, at the same time, reflect the prevailing uncertainty about future developments. The resulting CO_2 fertilization effect is taken into account in the EPIC simulations.

Crop yields are simulated for a combination of crop management practices: three crop rotation systems (crs1-3), three levels of fertilization intensities (high, moderate, low) and optional irrigation (combined with high fertilization intensity). In the historical period we consider only typical crop rotation systems (crs1) derived from historical land use. In the future period we (i) consider the same crop management practices as in the historical period to assess the pure effect of climate change and (ii) add additional crop rotation systems (crs2-3) to allow for a broader portfolio. Crop rotations are derived from the empirically based model CropRota at municipality level and are assigned to the cropland pixels (SCHÖNHART et al., 2011). The assignment procedure is repeatedly performed to generate three alternative crop rotations at pixel level.

2.2 Calculation of crop profits

Annual crop profits are calculated by cropland pixel, crop management practice and climate change scenario according to Equation 1:

$$\pi_{i,m,s} = \sum_{c} (y_{i,c,m,s} * p_c - k_{c,m} + d_m) \qquad \forall\, i,m,s \qquad (1)$$

where π are annual profits in €/ha, y are the simulated annual crop yields in t/ha, p the average commodity prices in €/t, k the average variable production costs in €/ha and d the policy premiums in €/ha. The index i denotes cropland pixels in Austria (I = 40,244), c the crops in sequence of the particular crop rotation, m represents alternative crop management practices including alternative crop rotations, fertilization rates and irrigation (M = 12), s refers to the five climate change scenarios with 30 years of simulation each resulting in 150 annual climate conditions in the future period (S = 150) and 30 in the historical period (S = 30). Commodity prices represent the mean of the period 2010-2012 provided by STATISTICS AUSTRIA. Variable production costs include purchases of seeds, pesticides, fertilizers, fuel, water and electricity, costs of repair, insurances as well as labor costs and are taken from the standard gross margin catalogue and from own data sources. Additionally, we consider agricultural policy premiums such as 290 €/ha of a uniform Single Farm Payment and agri-environmental premiums for reduced fertilization (50 €/ha) and mineral nitrogen fertilizer abandonment (115 €/ha).

2.3 Portfolio optimization model

We use a non-linear mean-standard deviation model (similar to E-V model; MARKOWITZ, 1987) to determine optimal crop production portfolios depending on the farmers' level of risk aversion. The model maximizes a weighted sum of expected profits discounted by the standard deviation using a risk aversion parameter (FREUND, 1956; STRAUSS et al., 2011). We consider four risk aversion parameter levels (θ) from risk neutral (θ = 0) to low (θ = 1.0), moderate (θ = 2.0) and high risk aversion (θ = 2.5). Optimal crop production portfolios are identified per cropland pixel for the historical and the future period, the latter including five climate change scenarios. The mean-standard deviation model is defined in Equation 2 and separately solved for each pixel *i* and risk aversion parameter level (θ).

$$
\begin{aligned}
&\underset{x}{Max}\, F_i = \sum_{m,s} x_{i,m}\, E(\pi_{i,m,s}) - \theta\Big[\frac{1}{S}\sum_{m,s}\big(\pi_{i,m,s} - E(\pi_{i,m,s})\big)^2\Big]^{\frac{1}{2}} && \forall\, i \\
&s.t. \sum_{m,s}\big(A_{i,m,s}\, x_{i,m}\big) = b_i && \forall\, i \quad (2)
\end{aligned}
$$

where F is the objective function value, x is the portfolio variable representing the share of crop management practices, m, in the portfolio of each cropland pixel i; π denotes annual profits (see Equation 1), E refers to the expected value of alternative annual climate conditions (S) and θ is the risk aversion parameter. In the constraint, b denotes the total cropland area available in pixel *i and A* represents the Leontief production function, which converts land resources and other inputs into crop commodities. The optimization is subject to the condition that the portfolio shares have to sum up to 100%.

3. Results and discussion

To discern the pure impact of climate change, we have multiplied the optimal historical portfolio shares with crop yields and profits under future climate conditions. At national level, we find that climate change induces a slight increase in average crop yields and expected profits of 2% and 3%, respectively. If soil water availability is not limiting, higher mean temperatures and CO_2 fertilization lead to higher crop yields in the future. However, crop yields and profits vary by crop, soil type, region and management. For instance, average crop yields on brown earth exceed those on chernozem, but crops grown on chernozem (in particular vegetables) typically realize higher expected profits. Allowing the selection of additional crop rotation systems (crs2-3) in the optimal crop production portfolios in the future period, we find that average crop yields and expected profits increase by 14-15% and 10-18%, respectively. Average crop yields and profits decrease with increasing risk aversion, which is confirmed by the portfolio theory suggesting that lower levels of profits have to be accepted for lower levels of risk. In comparison to risk neutrality, high risk aversion results in a decline in crop yields and profits of 3% and 4-11%, respectively (Table 1).

Tab. 1: Average annual simulated crop yields and profits

Level of risk aversion	neutral θ=0	low θ=1.0	moderate θ=2.0	high θ=2.5
ø DM crop yields	in t/ha (rounded)			
historical (crs1)	6.8	6.8	6.7	6.6
pure CC effect (crs1)	6.9	6.9	6.8	6.7
future (crs1-3)	7.8	7.8	7.6	7.6
ø profit (stdev)	in €/ha (rounded)			
historical (crs1)	486 (198)	480 (186)	469 (178)	465 (175)
pure CC effect (crs1)	499 (197)	494 (190)	482 (185)	477 (184)
future (crs1-3)	575 (204)	544 (136)	518 (118)	511 (115)

Legend: crs (crop rotation system), CC (climate change), DM (dry matter), future (period 2010-2040), historical (period 1975-2005), stdev (standard deviation)
Source: Own Calculations

In the future scenario (crs1-3), higher risk aversion is found to increase diversification of the optimal crop production portfolios (see Figure 2). With high risk aversion, the optimal portfolios contain at least two managements in 96% of the pixels and at least three in 76% of the pixels, compared to 81% and 44% in the case of low risk aversion.

A detailed analysis of future crop production portfolios shows the increasing role of irrigation combined with high fertilizer use (44-55% of the Austrian cropland, depending on the degree of risk aversion). In rain-fed agriculture, high, moderate and low fertilization rates are applied on 18-23%, 18-30% and 3-9% of the cropland, respectively. Compared to the historical period, the shares of high fertilizer use (irrigated and rain-fed) gain on importance regardless of the risk aversion level. This results in an increase in total nitrogen application by 15-17%.

Regional heterogeneities and site-conditions play a role in reducing climate-induced crop production risks. For instance, irrigation is often part of the optimal portfolios in the currently drier regions in the East of Austria, whereas low and moderate fertilization intensities are typically chosen in less-favored areas such as mountainous regions. Accordingly, the availability of spatially targeted crop management practices e.g. through agri-environmental programs is important to support the risk-reducing effect of diversification.

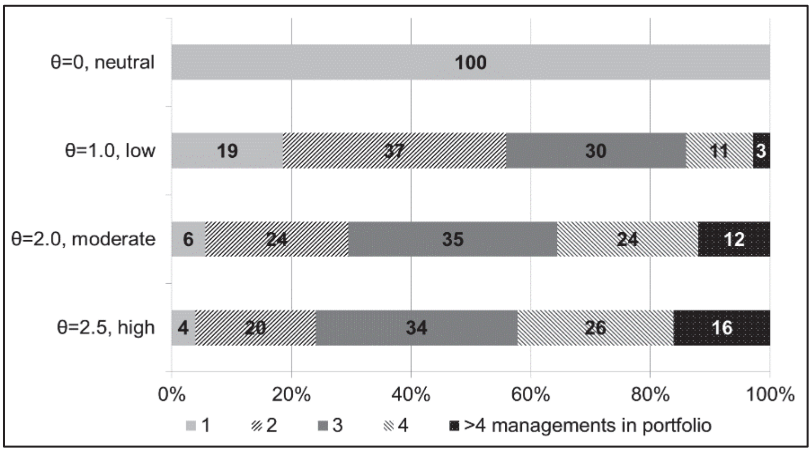

Fig. 2: Average number and share of crop management practices in the optimal portfolios per cropland pixel in the period 2010-2040
Source: Own Calculations

We have also estimated an ordered logistic regression model for the historical and the future period (considering only crs1) to assess how site-conditions affect portfolio diversification under climate change. The explanatory variable takes values between 1 and 4 representing the number of crop management practices in an optimal portfolio. The explaining variables are the categorical variables soil types (brown earth, chernozem, pseudogley and other soil types) and precipitation classes. We identify three precipitation classes, determined by average annual precipitation sums over the period 1975-2005. Regions with dry climates have precipitation sums smaller or equal to 650 mm, wet regions of larger or equal to 850 mm and moderate regions are in between. The regressions are conducted for both periods separately. The results for the predicted probability of adopting one or two crop management practices in an optimal portfolio depending on regional site-conditions are presented in Table 2. We focus on regions with the most extreme, i.e. dry and wet climates. The predicted probability to adopt only one crop management practice in an optimal portfolio is higher in historically wet than in historically dry regions regardless of the soil type. In dry regions, the probability to adopt two managements in an optimal portfolio is approximately 13% higher than in wet regions in the historical period. Under climate change, the probability to adopt two managements in a historically dry region is only around 4% higher than in wet regions. This can be explained by the broad range of precipitation sums considered in the climate change scenarios, which seem to lessen the need to diversify management practices in the dry regions. The probability to adopt only one management practice is on average higher on chernozem (e.g. 61/65% in the dry/wet region under climate change) than on brown earth (52/56%), whereas brown earth seems to support diversification of management practices (40/36% in the dry/wet period under climate change) compared to chernozem (33/30%). While chernozem is mainly located in the plains of northeast Austria with altitudes below 300 m, brown earth is found on heterogeneous topographic profiles (e.g. on altitudes up to 2,000 m and slopes up to 100%). This heterogeneity increases diversification in cultivated crops and optimal managements on brown earth on average.

Tab. 2: Predicted probability of 1 (2) crop management practice(s) in the optimal portfolios in % by precipitation classes (PRCP)

Period	**PRCP**	**Soil types**			
		BE	CZ	PG	Others
historical (crs1)	dry	49 (43)	52 (40)	52 (41)	50 (42)
	wet	66 (30)	69 (27)	68 (28)	67 (29)
future (crs1)	dry	52 (40)	61 (33)	55 (38)	59 (35)
	wet	56 (36)	65 (30)	59 (34)	62 (31)

Legend: crs (crop rotation system), historical (period 1975-2005), future (period 2010-2040), BE (brown earth), CZ (chernozem), PG (pseudogley)
Source: Own Calculations

4. Conclusions and outlook

Climate change and variability may increase crop production risks for farmers in Austria. We have analyzed the impact of climate-induced risks on crop production using a bio-physical process model and identified optimal crop production portfolios by applying a non-linear mean mean-standard deviation model at 1 km pixel level. The model results indicate that climate change leads to slight increases of average crop yields and profits by 2% and 3%, respectively. Considering adaptation through choices in crop rotations, fertilizer intensities and irrigation, the positive effect is amplified. However, crop production levels vary spatially due to topographic and agronomic heterogeneities in crop production. Compared to the historical period, the relative shares of irrigation and high fertilization intensity increase in the portfolios such that total dry matter output and nitrogen application increase, on average. Risk aversion leads to an increase in crop management diversification in general and to an increase in irrigation in particular. Also historically rather dry regions and regions with a high proportion of brown earth soils are found to have an increased probability of diversified management portfolios. However, the diversification effect could be less distinctive and irrigation could decrease in importance if fixed costs were considered in the analysis.

Our integrated assessment considers a number of aspects affecting production risks such as soil types, topographic and climate conditions, crop managements and risk aversion. However, our analysis has limits and can be extended in various ways: (i) alternative risk measure such as the Conditional Value at Risk (CVaR) should be applied to derive robust results; (ii) the effect of climate change and portfolio diversification on environmental indicators such as nitrogen emissions, sediment yield and soil organic carbon should be evaluated to show the trade-off between profit expectations and environmental impacts; (iii) price dynamics and other market developments should be considered to extend the analysis to market risks; and (iv) cost-effective policy measures should be assessed to support environmentally friendly crop production portfolio adaptation. Our spatially explicit results could inform the discussion on climate change adaptation requirements and risk management in Austrian agriculture.

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