Land Use Policy 35 (2013) 119–130

Contents lists available at SciVerse ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

The impact of climate and price risks on agricultural land use and crop management decisions

Niklaus Lehmann[a,*], Simon Briner[a], Robert Finger[b]

[a] Institute for Environmental Decisions, Agrifood & Agri-environmental Economics Group, ETH Zurich, Sonneggstrasse 33, CH-8092 Zurich, Switzerland
[b] Agricultural Economics and Rural Policy Group, Wageningen University, Hollandseweg 1, NL-6706 KN Wageningen, The Netherlands

ARTICLE INFO

Article history:
Received 16 July 2012
Received in revised form 9 May 2013
Accepted 16 May 2013

Keywords:
Agricultural land use
Climate change
Price risks
Whole-farm model
Bioeconomic modelling
Genetic algorithm

ABSTRACT

This article aims to investigate the impacts of climate change and of lower and more volatile crop price levels as currently observed in the European Union (EU) on optimal management decisions, average income and income risks in crop production in Western Switzerland. To this end, a bioeconomic whole-farm model has been developed that non-parametrically combines the crop growth model CropSyst with an economic decision model using a genetic algorithm. The analysis focuses on the farm level, which enables us to integrate a wide set of potential adaptation responses, comprising changes in agricultural land use as well as crop-specific fertilization and irrigation strategies. Furthermore, the farmer's certainty equivalent is employed as objective function, which enables the consideration of not only impacts on average income but also impacts on income variability.

The study shows that that the effects of EU crop prices on the optimal management decisions as well as on the farmer's certainty equivalent are much stronger than the effects of climate change. Furthermore, our results indicate that the impacts of income risks on the crop farm's optimal management schemes are of rather low importance. This is due to two major reasons: first, direct payments make up a large percentage of the agricultural income in Switzerland which makes Swiss farmers less vulnerable to market and climate volatility. Second, arable crop farms in Switzerland have by law to cultivate at least four different crops. Due to these diverse cropping systems and high government direct payments risk does neither under climate change, market liberalization nor combinations thereof, play a very decisive role in arable farming in Switzerland.

Introduction

Production and price risks are important aspects in farmers' decision-making (Saunders et al., 1997; Angus et al., 2009). While market or price risk reflects the variations in prices of agricultural outputs and inputs (Harwood et al., 1999), production risks mainly occur because crop growth highly depends on its environment (e.g., weather conditions and pest pressure) that can rapidly change. Both production and market risks, however, affect the income variability in agriculture. To cope with production and market risks, farmers typically have several on-farm, self-insuring options and risk-mitigation measures to protect against income volatility. One of the most important on-farm risk-reducing strategies is to diversify farm activities, for example by expanding the portfolio of different agricultural land uses (Mishra and El-Osta, 2002). Diversification strategies not only mitigate price risks but also fluctuations of overall farm outputs due to production risks (Mishra and El-Osta, 2002). Besides such large-scale strategies, also adjustments of crop-specific management decisions potentially mitigate income variability (Sandmo, 1971). In general, risk-averse decision makers are expected to invest less in inputs if the returns from these investments are more uncertain and thus increase income variability. For instance, higher nitrogen application on grassland tends to increase yield variability (for discussions and examples, see Finger, 2012). In contrast, more intensive use of irrigation decreases the variability of crop yields, thereby reducing production risks (Finger et al., 2011; Lehmann et al., 2013). Responses of farmers to changing market and production conditions are highly relevant for agricultural and environmental policy makers because the induced changes in land use as well as changes in input allocation have direct impacts on food supply, environmental loads from agriculture and the landscape.

Whole-farm models are appropriate tools to assess the impact of price and climate scenarios on farmers' management strategies, average income and income variability (Pannell et al., 2000). This is because the full potential of adjusting crop-specific management schemes for risk management is only tapped if all activities of a farm are considered simultaneously. In contrast, single-crop investigations may over-estimate the role of production and price risks

---

* Corresponding author. Tel.: +41 44 632 28 32; fax: +41 44 632 10 86.
E-mail address: nlehmann@ethz.ch (N. Lehmann).

0264-8377/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.landusepol.2013.05.008

in agricultural decision-making. In addition, the assessment at the farm level is also of great importance since risk management strategies often are dependent on specific constraints with regard to farm resources (e.g., land and working time) and environmental obligations (e.g., nutrient balances). Most available studies, however, focus on single-crop management decisions (Rosegrant and Roumasset, 1985; Rajsic et al., 2009; Finger, 2012; Lehmann et al., 2013). Other studies use whole-farm models but address only the optimal land allocation among different crops without considering crop-specific management decisions such as nitrogen fertilization or irrigation intensities (Chavas and Holt, 1990; Sckokai and Moro, 2006; Musshoff and Hirschauer, 2009).

Based on this background, we combine the process-based crop growth model CropSyst with an economic decision model to develop a whole-farm model that accounts not only for land allocation but also for crop-specific management decisions. The developed bioeconomic whole-farm model is used to maximize a farmer's utility while optimizing farm scale management decisions under different climate and price scenarios. Thus, we use a normative approach based on the neoclassical theory, which perceives economic agents as utility optimizers (Buysse et al., 2007). The outcome of the economic decision model is therefore a management scheme that results in the highest utility levels for farmers. To express farmers' utility levels, the certainty equivalent (CE) at the farm level is used. The CE depends not only on the total average farm income but also on income variability that accounts for different sources of risk. In previous research, the combination of process-based crop growth models with economic models has been suggested to investigate the influence of climate change (CC) and production risks in cropping systems (for discussions, see Challinor et al., 2009; Reidsma et al., 2010; Finger et al., 2011; Olesen et al., 2011). One of the main advantages of process-based crop growth models is their ability to simulate plant growth under scenarios that exceed the current conditions (Finger, 2009). Thus, process-based crop growth models are suitable tools for the simulation of crop yields under CC scenarios. Yet, crop models generally do not consider market- and policy-driven adaptive responses to crop management (Risbey et al., 1999). By linking crop growth models with economic decision models, however, adaptation decisions of farmers to changing market and policy conditions can be taken into account. In this study, the linkage of the crop growth model CropSyst with the economic decision model and the optimization routine is facilitated by a genetic algorithm (GA). To analyze the influence of changes in climate and market prices on farmers' income, income volatility and farm management decisions, different climate and price scenarios are considered.

The developed model is applied to a representative arable crop farm located in the Broye watershed in the Western part of Switzerland. This region already faces high variability of rainfall within the growing season, which leads to a high crop yield variability and triggers the frequent use of irrigation (Robra and Mastrullo, 2011). The frequent use of irrigation causes environmental problems, such as low water levels in the region's surface water bodies (Mühlberger de Preux,2008). Land use and crop-specific management decisions taken by the region's farmers are thus of particular relevance for policy makers. This policy relevance is furthermore underlined by the fact that significant changes in risk exposure of Swiss farmers are expected. Currently, average crop prices are much higher, and crop price volatility is much smaller in Switzerland than in other European countries (El Benni et al., 2012; Finger and El Benni, 2012). For instance, the average price of wheat in Switzerland is about three times higher than in Germany or France (Finger and El Benni, 2012). The relative wheat price volatility (expressed as coefficient of variation) in Switzerland, however, is about fifty percent smaller than those observed in France and Germany (Finger and El Benni, 2012). In the future, trade of agricultural products between Switzerland and the European Union might be liberalized, leading to lower and more volatile prices of agricultural goods in Switzerland. Moreover, significant changes in production risks in Swiss crop production are expected due to CC (Torriani et al., 2007). These changes, however, are expected to be heterogeneous across different crops (Lehmann, 2010).

The objectives of the presented study are threefold: First, we develop a whole-farm model that is used to identify optimal management decisions for a representative arable farm in the Broye watershed and compare our modelling results with observations from the study region. Second, we assess the impacts of CC and crop price scenarios on the optimal management decisions. Finally, we quantify the impact of CC and crop price scenarios on farmers' income and income risks while adjustments in the optimal management decisions are taken into account.

Methods

In order to optimize agricultural management decisions related to land-use and crop-specific nitrogen fertilization and irrigation intensities, a bio-economic whole-farm model is used. This bio-economic whole-farm model comprises three different sub-models: the generic weather generator LARSWG (Semenov and Barrow, 1997; Semenov et al., 1998), the mechanistic crop growth model CropSyst (Stöckle et al., 2003) and an economic decision model at farm scale. In addition, a genetic algorithm (GA) is used as optimization technique. More details on the component models and the settings of the GA are presented in the following subsections.

The structure of the modelling approach and the linkages between the sub-models are given in Fig. 1.

First, a population of candidate solutions is randomly generated by the GA (see upper right part in Fig. 1). Each candidate solution comprises a specific set of considered decision variables (i.e., nitrogen fertilization amount, irrigation strategy and crop acreage), which are taken as potential solutions for an optimal (i.e., utility maximizing) farm management scheme. These sets of decision variables are passed in a next step to CropSyst (middle panel of Fig. 1), where they are used as management input variables for crop yield simulations. To represent production risks due to uncertain weather conditions, 25 variable weather years are generated with the stochastic weather generator LARSWG.[1] Thus, crop yields are simulated for each crop and each set of management decisions for a period of 25 weather years. The 25 simulated yields of all crops are then fed into the economic model (bottom-right panel of Fig. 1) to compute the whole-farm return and the related production costs (e.g., fertilization amount, irrigation and drying costs). Besides production risks, also price risks are taken into account, and a set of stochastic crop prices is generated for the 25 years of simulations (details are presented below). Finally, the whole-farm return and production costs are used to calculate the certainty equivalent (CE) (representing the utility of a risk-averse decision maker) at the farm scale, which is the objective value in the optimization process. Once the objective values (i.e., CE) of all candidate solutions in the initial population are derived, the GA is used to select the most promising candidate solutions (i.e., candidate solutions which lead to the highest CE) and to create applying the genetic operators (i.e., mutation and crossover) a subsequent population of decision variables, which potentially lead to higher objective values. Then again, all sets of decision variables comprised in the new population are used as input variables in CropSyst and the economic decision

---

[1] Following Jame and Cutforth (1996), crop growth simulations should be conducted during at least 25-30 weather years in order to account for the risk associated with unpredictable weather conditions.