Paper prepared for the 123rd EAAE Seminar

PRICE VOLATILITY AND FARM INCOME STABILISATION

Modelling Outcomes and Assessing Market and Policy Based Responses

Dublin, February 23-24, 2012

Optimizing whole-farm management considering price and climate risks

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Abstract

We investigate impacts of climate change (CC) and likely increases in price risks on income, income variability, utility and on adaptation responses in crop production in Western Switzerland. To this end, a bio-economic model is used that combines a crop growth model with an economic decision model non-parametrically using genetic algorithms. Our analysis focuses on the farm-level, which enables us to integrate a much wider set of potential adaptation responses in our analysis. The model is applied to four scenarios that represent likely changes in environmental conditions due to CC as well as increasing price risks due to market liberalization, and combinations thereof. It shows that CC has the larger influence on farm-level income and utility as well as on management decisions. In contrast, the increasing price variability has only small impacts on input use. However, both CC and increasing price volatility contribute to an increasing farm-level income risk.

Keywords: Genetic Algorithms, Agricultural Modeling, Climate Change, Price risks

JEL classification: Q12

1. INTRODUCTION

Agriculture is a risky business. Besides production risks coming from unpredictable nature of weather, price and markets risks and institutional risks (e.g. changes in agricultural laws, changes in the agricultural policy) also technological risks play an important role in agriculture.

Typically, farmers have several self-insuring options and risk-mitigation potentials to protect against income volatility. Probably the most important risk reducing measure is the diversification of farm activities. Such diversification strategies do not only mitigate price risks but also fluctuations in outputs due to production risks (e.g. Mishra and El-Osta, 2002). Diversification options of an agricultural enterprise include on-farm diversification strategies (e.g. range of crops, livestock and other natural resource based activities undertaken) as well as off-farm diversification strategies like non-farm activities (Cramb et al., 2004). If returns from different activities are negatively correlated with each other, they provide a so called natural hedge for the farmer (cp. Finger and El Benni, 2012). Furthermore, also the chosen input intensity (nitrogen fertilization amount, irrigation intensity, pesticides, etc.) has an effect on the production risks and thus on the farmer's income volatility. For instance, higher nitrogen fertilization amounts tend to increase the yield variability (see Finger, 2012 for discussions and examples). In contrast to the nitrogen fertilization amount, a higher irrigation intensity is expected to decrease the variability in crop yields, i.e. production risks (e.g. Lehmann et al., 2011; Finger et al., 2011). Thus, farmers can avoid production risks by adjusting their management schemes. Besides their influence on the allocation of on-farm resources to different activities, price risks are also expected to influence input decisions (e.g. Sandmo, 1971). More specifically, risk-averse decision makers are expected to invest less in inputs if the returns from these investments are more uncertain, e.g. due to highly uncertain output price levels, and thus reduce profit variability.

In summary, farmers have several simple and cheap - but efficient - options to reduce the influence of price and production risks on their farm income. This is in particular the case if risk mitigation potentials are jointly analyzed at the whole-farm level, and not at the level of specific activities. However, most studies investigating production and price risk effects on management decision in cropping systems do not focus to more than one crop simultaneously (e.g. Finger, 2012; Rajsic et al., 2009; Rosegrant and Roumasset, 1985). Nevertheless, the full potential of adjusting crop specific management schemes to changing production and price risks is only tapped if all activities of a farm are considered simultaneously. This also affects the impact of specific constraints that are relevant at the farm-level and have to be considered in agricultural modeling approaches. In a whole-farm model, it is possible to reduce resource allocation (e.g. fertilizer, workload, machinery) for a single activity which offers potentials for (or even gives incentives to) an increasing use of these resources in other activities, while balances of nutrient, working time, etc. at the farm-scale are still balanced. However, if only one crop is considered, such tradeoffs cannot be taken into account. Furthermore, not the interannual variation in returns of a single farm activity but of the whole-farm income is essential from the farmer’s perspective. The variability in the whole-farm income, however, is always lower than for the most risky farm activity, if the farm has more than one type of business activities. Thus, single-crop investigations may over-estimate the role of production and price risks in agricultural decision making.

Our analysis addresses the case of Swiss agriculture. This example provides interesting insights and is relevant even though interannual income variability at farm-level is currently rather small if compared with other countries, because significant changes in risk exposure are expected. On the one hand, climate-related production risks and price risks are much smaller than in other European countries (e.g. Finger, 2012). On the other hand, governmental direct payments make up a large percentage of the farm revenue and thus stabilize the farmer’s income (e.g. El Benni and Finger, 2012). Nevertheless, Swiss farmers are expected to be exposed to higher production and markets risks in the next decades: First, climate change (CC) is expected to increase yield variability in Swiss crop production (e.g. Torriani et al., 2007). Second, further market liberalization measures are assumed to increase the price volatility of agricultural outcomes (Mahul, 2003). More specifically, crop price volatility in the neighboring countries of the European Union is markedly higher, which may cause a sharp increase in price risks in Switzerland for market integration (e.g. Finger, 2012). Because changes in production and price risks may not affect all crops homogenously (e.g. Lehmann, 2010), taking a whole farm perspective may offer interesting insights in potential risk mitigation options.

Based on this background, this study aims to represent whole-farm management decisions using a bioeconomic modeling approach. This bioeconomic model links the process-based crop growth model CropSyst with a farm-scale economic decision model, representing a risk-averse decision maker. The linkage between the crop growth and the economic model is established by using genetic algorithms (GAs). The developed model is used to simulate optimal management decisions with regard to crop acreage, nitrogen fertilization and the irrigation strategy for an exemplary arable farm located in Western Switzerland. To analyze the potential influence of changes in production and price risk on farmers' income, income volatility and farm management decisions, the model is driven by a set of different CC and price risks scenarios.

2. METHODS

We use a bioeconomic whole-farm model to assess the impact of climate and price risks on farm-level income, income variability, utility and management decisions with regard to optimal crop allocation as well as optimal crop specific nitrogen fertilization amount and optimal irrigation strategies. This bioeconomic whole-farm model comprises three different sub-models: The mechanistic crop growth model CropSyst, an economic decision model at farm scale and the generic weather generator LARSWG. The structure of the modeling approach and the linkages between these sub-models are presented in Figure 1, and can be described as follows:

Figure 1. Overview of the modeling approach

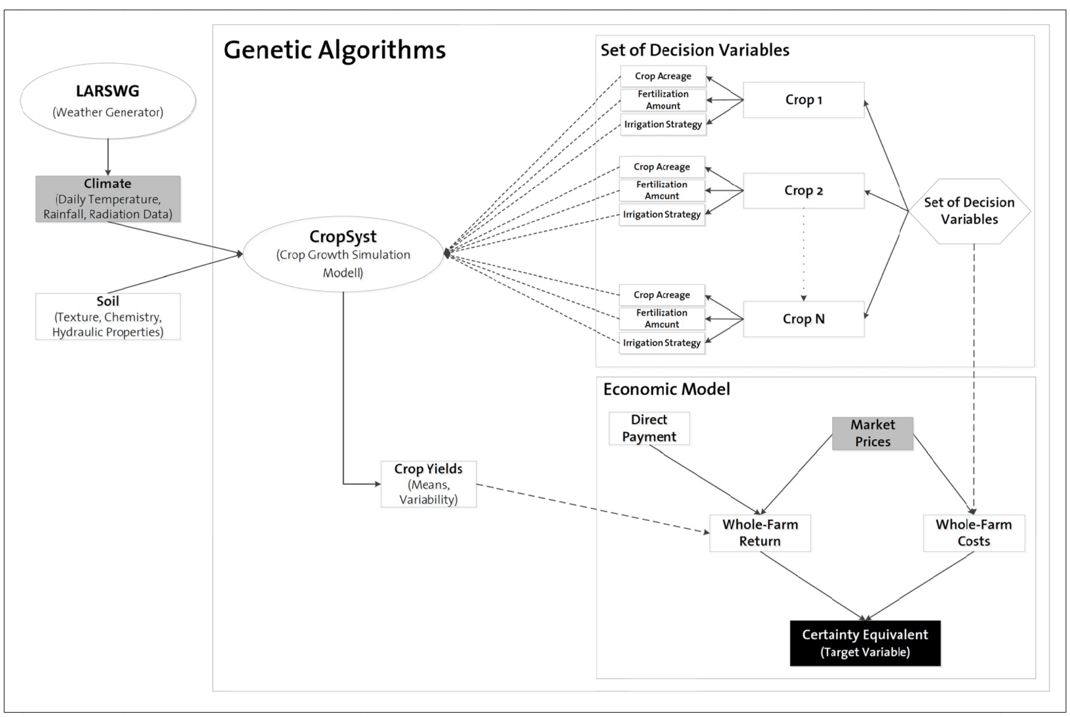

Figure 1 gives an overview of the employed modeling approach. The risk-related input factors (i.e. climate variables and market prices) are colored in gray.

First, different sets of decision variables (i.e. nitrogen fertilization amount, irrigation strategy, crop acreage, see upper-right panel of Figure 1) are generated for each crop. These sets of variables are considered as potential solutions for an optimal (i.e. maximizing the farmer's utility) farm management scheme. The decision variables are then passed to CropSyst (middle panel of Figure 1), where they are used as management input variables for climate specific crop yield simulations. The weather input files for CropSyst are generated by the stochastic weather generator LARSWG (left panel of Figure 1). To represent production risks due to uncertain weather conditions, the yield simulation procedure for a specific set of decision variables is executed 25 times, using different weather states generated with LARSWG. The simulated (25) crop yields are then fed into the economic model in order to compute the whole-farm return of a specific set of management decisions and the related costs (e.g. fertilization amount, drying costs) (bottom-right panel of Figure 1). Note that this step already includes information on production risks, as 25 different yield levels are input for the economic calculation steps. In order to take additionally price risks into account, all yield events are combined with price levels generated from multivariate distribution of crop prices in Switzerland (details are presented below). Finally, values for farm-level mean revenues as well as values for interannual revenue variation are used to calculate utility levels (representing a risk-averse decision maker) at farm-scale. This entire modeling structure is embraced by GAs. GAs are an optimization technique which aims to find the set of decision variables that maximizes farmers' utility. To this end, the most promising sets of decision variables are used to create subsequent generations (e.g. by crossover and mutation) that lead potentially to higher utility levels. Thus, the starting point described above initiates a loop structure that approaches the final solutions. Technical details on the GAs are presented at the end of this section. GAs work non-parametrically, i.e. avoid any estimation of production and yield variability functions. Thus, this approach allows to fully represent the highly complex and nonlinear relations between target variable (utility) and the decision variables, which cannot be represented by mathematical functions.

This proposed modeling approach is applied to an exemplary arable farm in Western Switzerland, located in the Broye catchment (see Lehmann et al., 2012, for details). The farmer as decision maker in the model can choose between 6 production activities: winterwheat, winterbarley, winter rapeseed, grain maize, potatoes or sugarbeets. These are the most important crops in Swiss agriculture. For each of these crops, the developed whole-farm model optimizes crop acreage, as well as crop specific nitrogen fertilization amounts and irrigation strategies. All considered management strategies are summarized in Table 1. To account for restrictions with regard to crop specific agronomic limitations as well as with regard to limitations imposed by the agricultural policy in Switzerland (i.e., cross-compliance requirements) and farm structure in the study region, we impose the following constraints in the model:

- The total farm acreage amounts to 30 hectares, corresponding to a representative crop producer in the study region.
- The cross compliance obligations of the direct payment system in Switzerland limit the maximum share of several crops: Winterwheat is limited to a maximum acreage of 50%,

the sum of all cereals (without grain maize) is limited to 66% of the total arable surface, the maximum crop share of grain maize is 40% and the maximum crop share of winter rapeseed, potatoes and sugarbeets is 25% of the total surface of arable land (BLW, 2011).

- The farm has to comply with a balanced nitrogen supply and demand at farm level as revealed by the official Swiss nutrient balance method "Suisse Bilanz" (BLW, 2011). In this nutrient balance approach a maximum nitrogen amount is specified for each crop whereas the nitrogen demand and supply has to be balanced at farm-level.
- The farmer is obliged to cultivate a minimum of four different crops in order to receive governmental direct payments (BLW, 2011).
- The farmer's maximum available work time per season amounts to 2800 hours. We assume a total workload for winterwheat, winterbarley and winter rapeseed of 41 hours per hectare, for grain maize the working time per hectare is assumed to amount to 37 hours and for potatoes and sugarbeets the total workload is set to 258 and 94 hours per hectare, respectively (AGRIDEA and FIBL, 2010).
- The nitrogen fertilization amount of potatoes and sugarbeets is restricted to a maximum quantity of 150 and 130 $kg \cdot ha^{-1}$, respectively. Higher nitrogen fertilization dosages have a negative influence on the quality of the potato and sugarbeet harvest and are therefore not reasonable.

Table 1: Considered management variables

Decision Variable	Crop	Management variable and unit[1]	Range (min-max) considered in the modeling approach	Variable increment (possible steps considered in the model)	Number of Alternatives
1	Winterwheat	Crop acreage in % of total arable surface	0-50	1	51
2	Winterwheat	Nitrogen fertilization amount in $kg \cdot ha^{-1}$	0-200	10	21
3	Winterwheat	Irrigation strategy (trigger point of irrigation)[1]	0-1	0.1	11
4	Winterbarley	Crop acreage in % of total arable surface	0-66	1	67
5	Winterbarley	Nitrogen fertilization amount in $kg \cdot ha^{-1}$	0-200	10	21
6	Winterbarley	Irrigation strategy (trigger point of irrigation)[1]	0-1	0.1	11
7	Winter rapeseed	Crop acreage in % of total arable surface	0-25	1	26
8	Winter rapeseed	Nitrogen fertilization amount in $kg \cdot ha^{-1}$	0-200	10	21
9	Winter rapeseed	Irrigation strategy (trigger point of irrigation)[1]	0-1	0.1	11
10	Grain maize	Crop acreage in % of total arable surface	0-25	1	26

11	Grain maize	Nitrogen fertilization amount in kg·ha^{-1}	0-200	10	21
12	Grain maize	Irrigation strategy (trigger point of irrigation)[1]	0-1	0.1	11
13	Potato	Crop acreage in % of total arable surface	0-25	1	26
14	Potato	Nitrogen fertilization amount in kg·ha^{-1}	0-150	10	16
15	Potato	Irrigation strategy (trigger point of irrigation)[1]	0-1	0.1	11
16	Sugarbeet	Crop acreage in % of total arable surface	0-25	1	26
17	Sugarbeet	Nitrogen fertilization in kg·ha^{-1} amount	0-150	10	16
18	Sugarbeet	Irrigation strategy (trigger point of irrigation)[1]	0-1	0.1	11

[1] The trigger point of irrigation represents the level of soil moisture that automatically triggers irrigation, and ranges from 0 (permanent wilting point) to 1 (field capacity).

In the following paragraphs each sub-model in the bioeconomic model is briefly described and its settings are presented.

2.1. Crop Growth Model

We use CropSyst (Version 4.13.09) in order to simulate climate and management dependent yields for each of the six crops. CropSyst is a process-based crop growth model that simulates biological and environmental above- and belowground processes of a single land block fragment using daily weather data, information of soil and crop characteristics as well as a specific management scheme at a daily scale. Stöckle et al. (2003) provide a detailed overview on the model and its components as well as on applications of the model CropSyst was already applied for Swiss crop production under current and future climatic conditions (e.g. Torriani et al. 2007; Finger et al., 2011). For this study, a CropSyst calibration for the study region of Klein et al. (2011) was used (details on specific assumptions made are also available upon request from the authors).

2.2. Stochastic Weather Generator

Daily weather input variables required for CropSyst simulations (daily minimum and maximum temperature, rainfall occurrence and amount and daily total solar radiation) of present and future expected climate conditions at the climate station Payerne (PAY, 6°57'E, 46°49'N, 490 m a.s.l.), which is located in the Broye catchment, are generated by the stochastic weather generator LARSWG (Semenov and Barrow, 1997; Semenov et al., 1998). The Baseline scenario, representing current climatic conditions, refers to the period 1990-2009. In addition, we also employ a scenario for future climate (CC scenario ETHZ-CLM) that represents the nominal time frame 2036-2065 assuming the A1B emission scenario and is based on the global circulation model HadCM3 and the regional climate model CLM. The resulting changes in temperature, precipitation and radiation regimes are summarized in Table A1 in the Appendix. Most importantly, this climate scenario indicates higher temperatures throughout the year (with particular increases in mid-summer) as well as marked decreases of summer precipitation (e.g. precipitation in the months July and August decreases by up to 30%). Further information on the employed climate scenarios and downscaling approach are presented in Lehmann et al. (2011, 2012).

2.3. Economic Model

The simulated crop yields are integrated in the economic model where for each crop the profit margin – depending on the simulated crop yields and chosen management decisions – is calculated. Accordingly, the profit margin at farm level is the result of all crop specific profit margins multiplied by the crop acreage. To represent the utility maximization problem of a risk-averse decision maker, information on both mean and variability of profit margins are combined in a certainty equivalent (CE) maximization approach. The CE denotes the non-random level of payoff which is rated by the farmer (in terms of utility) equivalent to an uncertain (i.e. random) level of payoff.

This farm-level CE, which is the final objective variable in our model, is computed as follows:

$$CE = E(\pi) - RP \qquad (1)$$

Where E(π) is the expected profit margin at farm level and RP is the risk premium, both expressed in CHF. The RP is the sure amount of money the decision maker is willing to pay to eliminate risk exposure (Di Falco et al., 2007). According to Pratt (1964), the RP can be approximated by Equation 2:

$$RP \approx \frac{1}{2} \cdot \frac{\gamma}{E(\pi)} \cdot \sigma_{\pi}^{2} \qquad (2)$$

Where γ is the coefficient of relative risk aversion and σ_{π}^{2} is the variance (CHF) of the profit margin at farm level π (CHF). For this study, we assume γ to be 2 which corresponds to a moderate risk-averse decision maker and implies decreasing absolute risk aversion (Di Faclo and Chavas, 2006).

The expected profit margin $E(\pi)$ and the variance of the profit margin at farm level σ_{π}^{2} is derived from the annual profit margins at farm level. The profit margin at farm level is defined as follows:

$$\pi = \sum_{i=1}^{N} a_i \cdot \left(\rho_i + DP_i + c_{fix,i} + c_{irrig,i} - c_{\mathrm{var},i}\right) \qquad (3)$$

Where π is the profit margin (CHF · ha^{-1}) at farm level, a_i is the cultivated surface of crop I (ha), ρ_i is the revenue of the crop i (CHF · ha^{-1}) and DP_i are the governmental direct payments

(CHF · ha^{-1}) for the crop i. $c_{fix,i}$ stands for the fixed costs (CHF · ha^{-1}) (excluding irrigation systems), $c_{irrig,i}$ for the fixed costs of the irrigation systems (CHF · ha^{-1}) and $c_{var,i}$ for the variable costs (CHF · ha^{-1}) of the crop i. Note that $c_{irrig,i} = 0$ if no irrigation is applied. More details of the here employed assumptions on revenues and costs are given in Table 2.

Table 2: Revenue and costs

Revenue	Winter-wheat	Winter-barley	Winter rapeseed	Grain maize	Potato	Sugarbeet
Crop price levels (in CHF · t^{-1}). Averages for the period 2002-2009 (*Standard deviation in parentheses*)[1]	0.514 (*0.034*)	0.379 (*0.036*)	0.787 (*0.104*)	0.379 (*0.052*)	0.454 (*0.030*)	0.054 (0.006)[2]
Direct payment						
Direct payment (CHF · ha^{-1})[2]	1680	1680	2680	1680	1680	3580
Fixed costs						
Seed (CHF · ha^{-1})[3]	218	143	108	268	3585	407
Plant protection (CHF · ha^{-1})[3]	265	265	250	220	800	525
Plant growth regulant (CHF · ha^{-1})[3]	41	41	0	0	0	0
Contract work and machinery costs (CHF · ha^{-1})[3]	783	783	787	844	2591	1409
Fixed irrigation costs						
Irrigation system costs (CHF · ha^{-1})[4]	447	447	447	447	447	447
Variable costs						
Nitrogen fertilizer (CHF · kg^{-1} · N^{-1})[3]	1.4	1.4	1.4	1.4	1.4	1.4
Other fertilizer costs (CHF · kg^{-1} · N^{-1})[3]	0.72	0.73	0.94	1.54	3.49	1.41
Hail insurance (% of Crop Yield Revenue)[3]	2.4	2.4	5.6	3.6	2.4	2.4
Cleaning, drying costs (CHF · t^{-1})[3,5]	39.5	32.5	58.5	71.3	1.5	0
Other costs (CHF · t^{-1})[3]	6.7	1.2	16.3	0	0.5	12
Variable irrigation costs (CHF · mm^{-1} · ha^{-1})[4]	1.00	1.00	1.00	1.00	1.00	1.00
Interest rate (%)[3]	3.0	3.0	3.0	3.0	3.0	3.0

[1] Source: FAOSTAT 2002-2009. [2]Since in Switzerland in the year 2009 the reference sugarbeet price decreased by more than 30%, we used German sugarbeet prices. In order to account for higher prices levels of agricultural products in Switzerland we multiplied the German prices by a factor of 1.3. This procedure ensures that mean prices and coefficients of variation remain as observed in Switzerland. [3]Source: AGRIDEA and FIBL (2010). [4]Source: Spörri (2011). [5]Note that the cleaning and drying costs depended on the yield levels at harvest which have a higher water content than the final yields.

2.4. Price risks

Besides different climate scenarios, we also consider two different scenarios with regard to the volatility in crop prices. For both scenarios, the means, variances and covariances of the crop prices in Switzerland of the period 2002-2009 obtained from the FAOSTAT database are used as basis. By means of the R package MASS 7.3-16 available from CRAN (http://cran.r-project.org), crop prices are generated by a multivariate normal distribution (Ripley, 1987). This approach ensures that correlations between prices of the different crops are represented in the decision process. The scenario Vol^0 represents current price risks, i.e. crop prices for the 25 simulation years are generated assuming identical means and covariances of the prices as observed in the period 2002-2009. For the scenario Vol^+, representing potential future price risks, all values in the covariance matrix of crop prices are quadrupled whereas the average crop prices are kept at the observed levels. Therefore, Vol^+ can be seen as scenario where the volatility (expressed as standard deviation) in crop prices is twice high as observed in the period 2002-2009. The doubling of price standard deviations represents the currently observed difference between price volatilities in Switzerland and, for instance, the European Union for most crops considered (e.g. Finger, 2012). The average prices and the correlation patterns between the prices of different crops, however, are in both scenarios similar. Thus, we focus on impacts of more volatile prices only, and do not address changes in mean price levels that are beyond the scope of this paper.

In summary, we run 4 different scenarios with the above presented modeling approach to represent two different climatic and two different price volatility scenarios, which are presented in Table 3.

Table 3: Overview of the applied scenarios

	Observed price volatility	**Doubled price volatility** (higher price risk, e.g. due to market liberalization)
Baseline scenario	Baseline - Vol^0	Baseline - Vol^+
ETHZ-CLM scenario (changing production risk due to climate change)	ETHZ-CLM - Vol^0	ETHZ-CLM - Vol^+

2.5. Genetic Algorithms

We use GAs as optimization technique since the relations between the CE and the decision variables cannot be represented by mathematical functions, as these relations have a highly complex and nonlinear nature. GAs, on the other hand, which are based on the biological concept of genetic reproduction (Mayer et al., 1999) and belong to the heuristic optimization techniques, can handle any kinds of objective functions and constraints defined on discrete, continuous, or mixed search spaces (Gen and Cheng, 1997). For this work, we use the C++ based GA package Galib (Wall,1996) and apply a steady-state GA. We set the control parameters to the GAs as follows: genome size = 8 bits; population size = 500; proportion of replacement = 0.5; selection routine = roulette wheel; mutation probability = 0.05; crossover probability = 0.5; and a sigma truncation scaling (Wall, 1996) is used as fitness function. The GA stops when a generation's best fitness value does not change anymore after a sequence of 1500 generations.

3. RESULTS

Figure 2 shows the average farm-level profit margins and coefficients of variation as well as the CEs for the 4 scenarios considered. It shows that the applied CC scenario decreases the CE and the average profit margins of the farmer. In contrast, increasing price risks have virtually no effect on average profit margins and only slightly negative effects on the CEs. Thus, accounting for a wide range of risk mitigation options reduces the effects of increasing price risk on the farmers' utility.

On the other hand, CC clearly reduces both mean profit margins and CEs. Nevertheless, farm-level income volatility (expressed as the coefficient of variation of farm-level profit margins in Figure 2) increases by 32% and 37% under higher crop prices in the Baseline and ETHZ-CLM scenario, respectively. Thus, income risks are expected to increase even if a wide set of risk-mitigation potentials have been considered.

Figure 2. Climate change and price risks impacts on the farmer's certainty equivalent, average profit margin and income variability

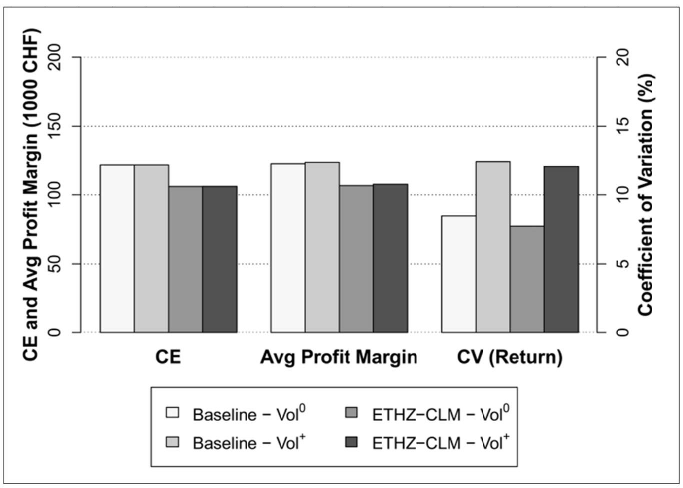

Figure 2 shows the certainty equivalent (see CE), the average profit margin (see Avg Profit Margin) and the income volatility expressed as the coefficient of variation (see CV) of the profit margin at farm level for the four different scenarios.

Figure 3 shows, for all four scenarios, the optimal (i.e. CE maximizing) land allocation of the six considered crops. Again, it shows that CC has much stronger effects of the optimal crop mix than increasing price risks. CC fosters the cultivation of winter rapeseed at the expense of winterwheat. This is due to the fact that winter rapeseed productivity – compared to winterwheat – decreases less with CC, at least in the specific assumptions made in our modeling approach. In addition, the governmental direct payments for winter rapeseed are much higher than for the winter cereals. In contrast, our results show that higher price risks do not affect the optimal crop mix. More general, note that our results indicate that yield levels of all crops but winter rapeseed decrease significantly due to CC (from -4.4% (sugarbeet) to -31.6%

(winterbarley)), but yield variability increases only for winterbarley (+50.3%) and winter rapeseed (+16.4%) under CC. Decreasing yield variability under CC for the other crops is due to the facts that a) winterwheat benefits from CC in terms of production risks (e.g, due to slightly dryer and warmer springs) and b) for potatoes and sugarbeet, irrigation intensities can be increased in our approach (cp. also Figure 4).

Besides the composition of the optimal crop mix, CC and increasing price risks may also affect the optimal crop specific management schemes, i.e. nitrogen and irrigation strategies. These effects are shown in Figure 4 and Figure 5. Due to the warmer and dryer climatic conditions, the CC scenario increases the optimal irrigation amounts for potatoes and sugarbeets (see Figure 4), i.e. those crops that suffer from the distinct climatic changes in mid-summer. For the three winter crops, though, irrigation is in none of the scenarios profitable, in particular because CC does not lead to very distinct changes in the growing seasons of these crops. Higher price risks do not at all influence the optimal irrigation intensity.

Figure 3. Optimal crop land allocation

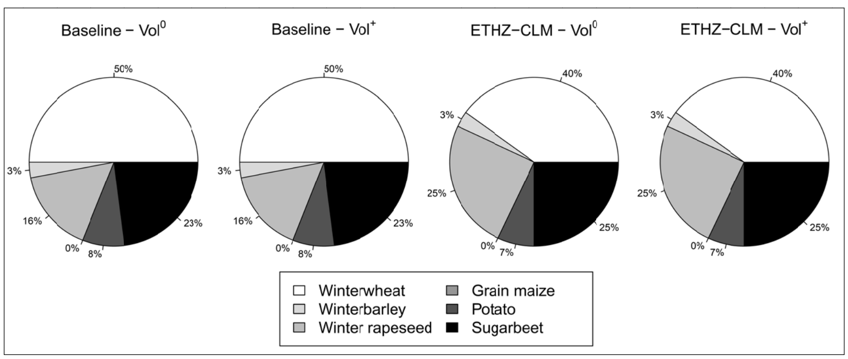

Figure 4. Optimal irrigation intensity

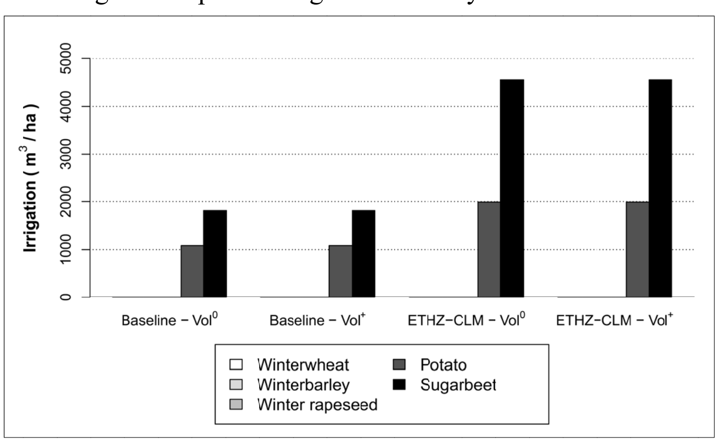

Figure 4 shows for each crop and each scenario the optimal irrigation intensity. Note that grain maize is in none of the scenarios included in the optimal crop mix.

In Figure 5 the optimal nitrogen fertilization dosages are shown for each of the four scenarios. Again it shows that the optimal fertilization amounts are much more affected by CC than by higher price risks. For all of the three winter crops CC reduces the optimal nitrogen amount, while for the potatoes and sugarbeet the optimal fertilization level does not change in any scenario. Assuming CC to occur jointly with higher price risks (right panel of Figure 5), one can see that these increasing price risks slightly increase the optimal nitrogen fertilization amount of winterwheat and winterbarley. Under the current climate conditions the optimal nitrogen fertilization levels are not affected by higher crop price volatility.

Figure 5. Optimal nitrogen fertilization amount

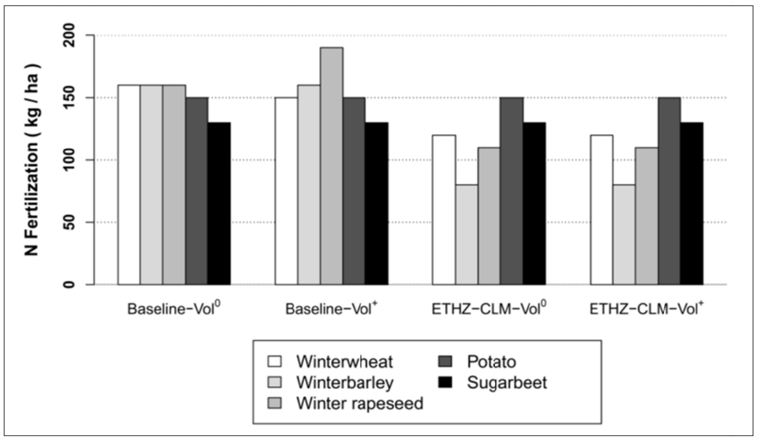

Figure 5 shows for each crop and each scenario the optimal nitrogen fertilization amount. Note that grain maize is in none of the scenarios included in the optimal crop mix.

4. DISCUSSION

In this paper, we analyzed the impacts of CC and increasing price risks using a whole farm perspective. In contrast to approaches that focus on single crops, it shows that farmers also may use other adaptation strategies such as changes in optimal crop mixes. We find, however, that adaptation to CC is much more distinct than adaptation responses to increasing price risks, which contrasts other studies on these issues (e.g. Finger, 2012). This result underlines that the conclusion may change if the model scale moves from the field- to the farm-scale, i.e. if whole-farm adjustment processes are taken into account. Along these lines, it is also important to note that our results show that the impacts of increasing price risks and/or CC on farmers' utility levels and input use tend to be smaller if whole-farm modeling is applied, i.e. a larger set of potential adaptation responses is considered.

In addition to other climate scenarios that need to be addressed in further research, also additional market and agricultural policy scenarios have to be considered. This is due to the fact that likely changes in in- and output price (mean) levels have not been considered. Additionally, currently governmental direct payments make up a large percentage of a farmer's income in Switzerland. Reducing these direct payments would make farmers more dependent on market prices and therefore also more vulnerable to the volatility of the market prices. Furthermore, we assumed in our analysis that price variability increases occur homogenously across crops, i.e. for Swiss agriculture at large. However, we are aware that some crops may face higher increases in price volatility than others, which could and should be reflected in future research.

Our results critically depend on the different model components and the assumptions made. Thus, a wider set of scenarios is needed to validate the expected farm-level responses to CC and increasing price risks. More specifically, our finding that CC will induce a comparative advantage of winter rapeseed compared to winterwheat contrasts the findings of Torriani et al. (2007) who indicate contrary results for Swiss winter rapeseed and winterwheat production. Their results, however, were focused on a different location in Switzerland and use different climate scenarios, which underlines the importance of site specific CC impacts and adaptation analyses (i.e. including site specific model calibrations as well as soil and weather information). This conclusion is further supported by our finding that CC may not necessarily increases production risks. In contrast, decreasing yield variability has been found in our study for most crops. In the here assumed study region, winterwheat benefits (in terms of production risks) from CC, and for spring sown crops higher irrigation intensities are used by the farmer to mitigate increasing production risks. Large spatial heterogeneities across Switzerland with regard to responses of mean yields and yield variability to CC have been also highlighted by Lehmann (2010).

Our results also show that grain maize production is not profitable in any of the considered scenarios. The here considered Broye catchment suffers already under current climate frequently from too dry climate in mid-summer (e.g. Mühlberger de Preux, 2008), a critical period for maize production. Thus, maize production may be too risky (compared to the relatively low mean profit margins) for the here considered crop producing farm.

5. Summary and Conclusion

In this paper, we developed a bio-economic model that combines a crop growth model and an economic decision model non-parametrically using GAs. In contrast to many other studies, our analysis focuses on the farm-level. This modeling approach was used to investigate impacts of CC and likely increases in price risks on income, income variability and utility in crop production in Western Switzerland. Furthermore, adaptation responses to these changes in the market and climatic environment have been analyzed. The farm-level modeling approach enabled us to integrate a much wider set (if compared to single crop studies) of potential adaptation responses in our analysis. The model is applied to in total, four scenarios that represent likely changes in environmental conditions due to CC as well as increasing price risks due to market liberalization, and combinations thereof.

It shows that CC has the larger influence on farm-level income and utility as well as management decisions than a higher crop price volatility. More specifically, CC induces smaller income levels and an increasing irrigation intensity for spring-sown crops such as potatoes and sugarbeets. In contrast, our results indicate that an increasing price variability has only small impacts on crop choice and input use. However, both CC and increasing price volatility contribute to an increasing farm-level income risk.

Our results thus indicate that policy makers, farmers and environmental planners have to take likely increases in agricultural water need into account if planning for the future. In addition, the increases in (relative) farm-level income volatility due to CC and/or increasing price variability show that risk management options such as insurance based instruments, which are poorly developed in Swiss agriculture (Finger and Calanca, 2011, Finger and Lehmann, 2012) will become much more important in the future. In order address these needs, policy makers and other stakeholders have to assist farmers in making the necessary steps in the future.

ACKNOWLEDGEMENTS

This work was supported by the Swiss National Science Foundation in the framework of the National Research Program 61. We would like to thank MeteoSwiss for providing climate. We thank Tommy Klein and Pierluigi Calanca for providing CropSyst calibration files and climate scenarios, respectively. Additionally we thank Annelie Holzkämper for support relating to the implementation of the GAs into the optimization model.

REFERENCES

AGRIDEA and FIBL. (2010). Deckungsbeiträge 2010. (In German). Technical report, AGRIDEA, 2010.

BLW. (2011). Weisungen und Erläuterungen über die Direktzahlungsverodnung an die Landwirtschaft. (In German). Federal Office for Agriculture (BLW), Bern, Switzerland.

Cramb, R.A., Purcell, T. and Ho, T.C. (2004). Participatory assessment of rural livelihoods in the Central Highlands of Vietnam. *Agric. Syst.* 81(3): 255-272.

Di Falco, S., Chavas and J-P., Smale, M. (2007). Farmer management of production risk on degraded lands: The role of wheat varieties in the Tigray region, Ethiopia. *Agric. Econ. Res.* 36:147-156.

Di Falco, S., Chava J-P. (2006). Crop genetic diversity, farm productitvity and the management of environmental risk in rainfed agriculture*. Europ. Rev. Agr. Econ.* 33 (3):289-314.

El Benni, N., Finger, R. (2012). The effect of agricultural policy change on income risk in Swiss agriculture. 123rd EAAE Seminar, Dublin, February 23rd-24th 2012

Finger, R. (2012). Nitrogen Use and the Effects of Nitrogen Taxation Under Considerations of Production and Price Risk. *Agric. Syst.* 107: 13-20.

Finger, R., Hediger, W., Schmid, S. (2011). Irrigation as Adaptation Strategy to Climate Change: A Biophysical and Economic Appraisal for Swiss Maize Production. *Climatic Change* 105(3-4): 509-528.

Finger, R., Calanca, P. (2011). Risk Management Strategies to Cope with Climate Change in Grassland Production: An Illustrative Case Study for the Swiss Plateau. *Reg. Environ. Change* 11(4): 935-949.

Finger, R., Lehmann, N. (2012). The Influence of Direct Payments on Farmers' Hail Insurance Decisions. *Agr. Econ.* In Press.

Finger, R., El Benni, N. (2012). How strong is the "natural hedge"? The effects of crop acreage and aggregation levels. 123rd EAAE Seminar, Dublin, February 23rd-24th 2012

Gen, M. and Cheng, R. (2000). Genetic algorithms and engineering optimization, Wiley-Interscience, USA.

Klein, T., Calanca, P. Holzkämper, A., Lehmann, N., Rösch, A. and Fuhrer J. (2011). An efficient crop model calibration procedure for use with farm accountancy data. submitted.

Lehmann, N., (2010). Regional Crop Modeling: How future Climate may impact Crop Yields in Switzerland. Master Thesis, ETH Zurich.

Lehmann, N., Finger, R., Klein, T. (2011). Optimizing Wheat Management Towards Climate Change: A Genetic Algorithms Approach. IASTED International Conference on Applied Simulation and Modelling. 22-24 June 2011, Crete, Greece.

Lehmann, N., Finger, R. and Klein, T., Calanca, P. and Walther, A. (2012). Adapting Towards Climate Change: A Bioeconomic Analysis of Winterwheat and Grain Maize. Submitted.

Mahul, O. (2003). Hedging price risk in the presence of crop yield and revenue insurance. *Europ. Rev. Agr. Econ.* 30(2): 217-239.

Mayer, D.G. Belward, J.A. and Burrage, K. (2001). Robust parameter settings of evolutionary algorithms for the optimisation of agricultural systems models. *Agric. Syst*. 69(3): 199-213.

Mishra, A. and El-Osta, H. (2002). Risk Management Through Enterprise Diversification: A Farm-Level Analysis. AAEA meetings in Long Beach, CA, USA.

Mühlberger de Preux, C. (2008). Broye: Fish or Chips? Umwelt 2/08, Dossier 26 (Landwirtschaft).

Rajsic, P., Weersink, A. and Gandorfer, M. (2009). Risk and nitrogen application levels. Can. *J. Agric. Econ.* 57(2): 223-239.

Ripley, B.D. (1987). Stochastic Simulation, Wiley, New York (1987).

Rosegrant, M.W. and Roumasset, J.A. (1985). The effect of fertilizer on risk: A heteroscedastic production function with measurable stochastic inputs. *Austral. J. Agric. Econ.* 29(2), 107-121.

Sandmo, A. (1971). On the theory of the competitive firm under price uncertainty, *Am. Econ. Rev.* 61(1):65-73.

Semenov, M.A. and Barrow, E.M. (1997). Use of a stochastic weather generator in the development of climate change scenarios. *Climatic Change.* 35:397-414.

Semenov, M.A., Brooks; R.J., Barrow, E.M. and Richardson, C.W. (1998). Comparison of the WGEN and LARS-WG stochastic weather generators for diverse climates. *Climate Res.* 10:95-107.

Spörri, M. (2011). Economic efficiency of irrigation strategies for arable crops under current and future climate scenarios, Bachelor Thesis, ETH Zurich, Switzerland.

Stöckle, C.O., Donatelli M. and Nelson, R. (2003). CropSyst, a cropping systems simulation Model. *Eur. J. Agron.* 18(3-4):289–307.

Torriani, D.S., Calanca, P., Schmid, S., Beniston, M. and Fuhrer, J. (2007). Potential effects of changes in mean climate and climate variability on the yield of winter and spring crops in Switzerland. *Climate Res.* 34(1):59-69.

Wall, M. (1996). A C++ Library of Genetic Algorithm Components. Technical report, Massachusetts Institute of Technology.

APPENDIX

Table A1: Applied changes in climate variables for the ETHZ-CLM scenario

Month	Δ Tmin (°C)	Δ Tmax (°C)	Δ Rad (%)	Δ Precip (%)
Jan	+2.51	+2.51	-3	-4
Feb	+1.82	+2.00	-4	-2
Mar	+1.91	+2.14	-4	-2
Apr	+2.06	+2.15	-2	-3
May	+1.85	+2.07	+2	-6
Jun	+2.18	+3.08	+7	-18
Jul	+2.82	+4.23	+9	-30
Aug	+3.11	+4.39	+8	-28
Sept	+2.78	+3.41	+3	-11
Oct	+2.29	+2.36	+0	-1
Nov	+2.28	+2.23	+0	-4
Dec	+2.69	+2.60	-2	-4

Table A1 shows the absolute applied changes in the monthly mean minimum temperature (Δ Tmin), in the monthly mean maximum temperature (Δ Tmax), and the relative changes in the monthly mean radiation (Δ Rad) and in the monthly mean precipitation sum (Δ Precip) for the used CC scenario ETHZ-CLM.