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# Nitrogen use and the effects of nitrogen taxation under consideration of production and price risks

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ABSTRACT

Production and price risks affect optimal nitrogen use as well as the effects of nitrogen taxation if farmers' risk aversion is taken into account. We apply a bio-economic model to investigate the influence of risk aversion on nitrogen use in Swiss maize production. Income risks for farmers are expected to increase in the future, for instance, due to higher price variability caused by market liberalization or by higher yield variability caused by climate change. We investigate the influence of changes in these sources of risks on optimal levels of nitrogen use and its influence on the effects of nitrogen taxation. Our empirical analysis for Swiss maize production shows that risk-aversion leads to lower levels of nitrogen application than for risk-neutral farmers. Furthermore, nitrogen taxes lead to higher reductions of nitrogen use if farmers are risk-averse and these farmers face lower abatement costs. Thus, analyses on the effect of nitrogen taxes that are solely based on profit maximizing behavior may underestimate nitrogen reductions and overestimate abatement costs. Taking expected shocks in price and yield variability into account, we find that these differences between risk neutral and risk-averse decision makers will increase further. External influences on production and price risks can thus influence the effects of agricultural policies on farmers' decision making. Thus, considering farmers' risk-preferences as well as potential increases in farmers' income risks can improve agricultural policy making.



## 1. Introduction

Crop production causes external effects that harm the environment. For instance, losses of applied nitrogen fertilizer, either gaseous or due to leaching, contribute to water pollution and climate relevant emissions (e.g. Pretty et al., 2001; von Blottnitz et al., 2006). Farmers usually do not have incentives to take these environmental externalities into account in their decision making process (Choi and Feinerman, 1995). As a consequence, the optimal levels of nitrogen use may differ substantially from the farmers', societal and environmental perspective, respectively (e.g. Zekri and Herruzo, 1994).

Governmental regulation and incentive schemes can help to reduce these differences. In particular, nitrogen taxes have been found to be a useful instrument to reduce nitrogen application and thus nitrogen losses to the environment (Rougoor et al., 2001). The effects of a nitrogen tax are often evaluated with regard to farmers' income losses (abatement costs) and reductions of nitrogen application. In the assessment of optimal rates of nitrogen application as well as in the assessment of nitrogen taxes, the representation of farmers' goal function in bio-economic models is often focused on (the maximization of) net farm profits (e.g. Berntsen et al., 2003; Hartmann et al., 2008; Kienzler et al., 2011; Kuhn et al., 2010; Meyer-Aurich et al., 2010; Rajsic and Weersink, 2008; Zekri and Herruzo, 1994).

While this is usually a valid assumption for many questions of field- and farm-level decision making, an augmentation of this model by taking risk considerations into account may be required in the modelling of nitrogen application decisions. This is due to the fact that nitrogen application represents a decision with uncertain outcome. More specifically, if making the fertilizer decision, the farmer faces uncertainty about the magnitude of yield increase due to nitrogen application and uncertainty about the price he will receive for this yield. Thus, farmers' risk preferences can affect the potential costs and environmental effects of agricultural policy measures toward reductions of nitrogen use (e.g. Chowdhury and Lacewell, 1996; Isik, 2002; Lambert, 1990; Rajsic et al., 2009; Semaan et al., 2007; Weersink et al., 1998). Ignoring risk considerations may therefore lead to erroneous predictions how farmers respond to nitrogen taxes (Chowdhury and Lacewell, 1996). Including risk considerations in the ex-ante policy evaluation is therefore a useful and necessary extension of deterministic assessment methods (e.g. Isik, 2002; Rougoor et al., 2001; Swinton and Clark, 1994). A risk considering framework implies furthermore that exogenous increases in farmers' income risks can have implications for the effectiveness of policy measures.

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Based on this background, this article aims to add a dimension to the discussion on nitrogen taxation by investigating the effects of policy measures in presence of risk aversion and in presence of shocks in the risk farmers' face. This is motivated by the fact that market liberalization and changing climatic conditions may change the risk environment in which policy measures affect farmers' decision making. To this end, we demonstrate the influence of price and yield risks on the effects of a nitrogen tax using a bio-economic model for maize (*Zea mays L.*) production in Switzerland. Maize is chosen as a case study because it is among the crops with the highest leaching potential.

In Switzerland, the introduction of nitrogen tax in Swiss agriculture is considered as a relevant policy option if other measures do not lead to the attainment of long-term targets of reducing the loss of harmful nitrogen compounds from agriculture (Hartmann et al., 2008). Currently, Swiss agricultural policy uses nitrogen use restrictions (formulated in kg/ha for each crop), which are part of the cross-compliance obligations that farmers have to fulfill to receive direct payments. Thus, the here presented results should contribute to the formulation of improved agri-environmental policies.

Furthermore, we apply in our analysis sensitivity analyses that reveal the influence of potential shocks in farmers' income risks due to market liberalization and climate change on the optimal levels of nitrogen use and the effect of nitrogen taxes. Currently, Swiss farmers face only small income variability: Firstly, the variability of crop yields is small because climatic conditions are favorable for crop production and extreme climatic events such as droughts are rare. Secondly, price variability is much lower than in other countries because currently tariffs, quotas and other trade regulations reduce the impact of volatile world market prices on Swiss markets. However, Swiss farmers are expected to face more risky production and market conditions in the future: Climate change is expected to increase yield variability, particularly for maize (Finger et al., 2011). Furthermore, likely market liberalization (e.g. due to a free trade agreement with the European Union) is expected to increase price variability (e.g. Mahul, 2003). Therefore, we analyse the impact of increasing yield and price risks on the effects of a nitrogen tax. Because the policy relevance as well as the potential for shocks in farmers' income risks are also given in other countries, the here presented Swiss situation is much more generally applicable.

In summary, the goal of this paper is to analyse the effects of risk aversion and nitrogen taxes on nitrogen use in Swiss maize production. To this end, a bio-economic decision model that accounts for price and yield risks is employed. Furthermore, sensitivity analyses outline the influence of potential (endogenous) shocks in price and yield variability on nitrogen use and the effects of fertilizer taxes.

## 2. Methodology

In this paper, we use a bio-economic model, i.e. a linkage of biophysical and economic models, to analyse farmers' nitrogen decisions under production and price risk. This type of model has proven to be useful for this kind of applications (e.g. Kuhn et al., 2010; Semaan et al., 2007). In our bio-economic decision model we combines a crop growth model (CropSyst) with a non-linear economic model, representing a risk-averse decision maker, using crop production and yield variability functions. The here presented framework is based on the approaches presented in Finger et al. (2010, 2011). In this section, the employed biophysical, statistical and economic models are presented. Note that information on the data generation process, other data sources and assumptions made in the economic model are presented in the subsequent section.

### 2.1. Crop simulation model

To simulate observations of maize yields for different levels of nitrogen application, the deterministic crop yield simulation model CropSyst is applied for the eastern Swiss Plateau region (Finger and Schmid, 2008). CropSyst models above- and below-ground processes (e.g. the soil water budget, soil–plant nitrogen budget, crop phenology, canopy and root growth, and crop yield) on a daily time step (see Stöckle et al., 2003, for details). In CropSyst, these processes are simulated in response to crop and soil characteristics, daily weather data, and management options. Model calibration, validation and settings for Swiss maize production are presented in Torriani et al. (2007a). This model is used to simulate in an experimental design maize yields for different levels of *N*-application. Stochasticity is introduced in this modelling setup by considering a large and heterogeneous set of observed weather observations in the model. Observations simulated with CropSyst in this quasi-experimental design are used to estimate statistical relationships between nitrogen application and maize yields in a subsequent step.

### 2.2. Production and yield variability functions

In our analysis, nitrogen-yield relationships are estimated using Just and Pope (1978, 1979) production functions in which inputs are allowed to influence the mean but also the variability of crop yields:

$$\text{Yield} = Y(N) + \sigma_Y(N)\varepsilon \tag{1}$$

where $Y(N)$ and $\sigma_Y(N)$ denote the expected yield (production function) and the standard deviation of yield (yield variation function), respectively (both conditional on $N$), and where we further assume that $E(\varepsilon) = 0$ and $\sigma(\varepsilon) = 1$.

To specify both functions empirically, assumptions on specific functional forms are needed. Such an assumption, however, also affects model results. To minimize the potential error arising from this choice, Finger and Hediger (2008) estimated different functional forms to similar data as employed here and made comparisons based on potential costs of misspecification. Thus, using an economic approach to the comparison of production functions, the potential underestimation of net revenues that would arise from an improper specification of the functional form has been minimized. It showed that the square root specification leads to the smallest cost of misspecification, i.e. represents a good compromise between possible extreme solutions. Based on this background, the production function estimation in our analysis assumes the following form:

$$Y(N) = \alpha_0 + \alpha_1 N^{0.5} + \alpha_2 N \tag{2}$$

The function shows decreasing marginal productivity of nitrogen if $\alpha_1 > 0$ and $\alpha_2 < 0$. If this is fulfilled, yields are monotonically increasing up to some point of nitrogen use and then monotonically decreasing, representing a unimodal function. In a second step, the absolute values of the regression residuals associated with the production function estimation, defined as $\hat{w} = Y - \widehat{Y}$, are used to estimate the yield variation function using the following specification (Finger and Schmid, 2008):

$$\sigma_Y(N) = |\hat{w}| = \beta_0 + \beta_1 N^{0.5} \tag{3}$$

The production and the yield variability function are estimated with the MM-estimator, a robust regression technique (see e.g. Finger, 2010, for descriptions), using the 'robustbase' package of R (R Development Core Team, 2008). The MM-estimator is used to reduce potential influences of outlying observations on estimation results.

### 2.3. Estimation of price variability

In addition to estimates for mean yields and yield variability, information on the variability of prices is required in our analysis. Estimating price variability based on raw price data would be misleading due to time trends and the lack of independency of observations. In particular, price variability might be over- or underestimated if the dependency structure (autocorrelation) between the observations is not considered. Thus, a time series approach is used to estimate price variability. Following Sarris (2000) and Johnston and DiNardo (1997), we find an autoregressive model of order 1, i.e. an AR(1) model, to be most adequate. This time series model is used to account for the dependency structure in the time series. To account for decreasing price levels within the considered time period, first differences are used (i.e. we consider an integrated time series of order 1).

In an AR(1) model, the sample variance estimate is corrected for the dependency structure at lag 1 as follows: $\sigma^2_{PM} = \sigma^2_{\varepsilon}/(1-\varphi_1^2)$, where $\sigma^2_{PM}$ is the variance of the maize price, $\sigma^2_{\varepsilon}$ the variance of the error terms in the AR(1) model and $\varphi_1^2$ is the squared first coefficient of the AR model. Thus, the higher the dependency (correlation) between subsequent price observations (i.e. $\varphi_1$), the higher is the difference between the sample variance and the variance estimated in the AR model (Johnston and DiNardo, 1997).

An additional input required for our analysis is the level of correlation between maize yields and yield prices, i.e. the level of the so called "natural hedge". To estimate this correlation, detrended time series of maize yields and maize prices are used. In order to test if this correlation observed at the national level is a valid assumption for farm level analysis, we employ and compare the analysis at the national and the farm-level.

### 2.4. Economic decision model

The before described information on yields and prices enter the economic model, that describes a farmers' decision making process with regard to nitrogen use. More specifically, we use a non-linear 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. For the risk-averse decision maker, the expected mean profit is reduced by the risk premium (RP), the amount of money the farmer is willing to pay to eliminate risk exposure:

$$\mathrm{CE} = E(\pi) - \mathrm{RP} \tag{4}$$

The expected (mean) profit ($E(\pi)$) is defined as revenue (expected maize yield, $Y(N)$, times expected maize price, $p_M$) minus fixed ($C_F$) and variable costs. In our analysis, variable costs comprise nitrogen costs (amount of nitrogen applied, $N$, times nitrogen price, $p_N$) as well as cleaning and drying costs (maize yield times price for cleaning and drying, $p_D$):

$$E(\pi) = Y(N)_{p_M} - C_F - N_{p_N} - Y(N)p_D \tag{5}$$

The profit maximization framework is extended by assuming that profits are stochastic due to the variability of maize yields (e.g. due to uncertain weather conditions and nitrogen application) and due to the variability of crop prices. Moreover, the correlation between crop yield and crop price has to be taken into account to calculate the variability of profits. In particular, low crop yields might imply smaller supply and thus higher crop prices ("natural hedge"). The consideration of variable cleaning and drying costs further strengthens this effect, e.g. costs are smaller for low yield levels. Following Bhornsted and Goldberger (1969), we define the variance of profit ($\sigma^2_\pi$) as follows:

$$\sigma^2_\pi = \sigma^2_Y(P_M - P_D)^2 + \sigma^2_{P_M}Y^2 + 2Y(P_M - P_D)Cov(Y, P_M) + \sigma^2_Y\sigma^2_{p_M} + Cov(Y, P_M)^2 \tag{6}$$

The covariance of yield and price is calculated as $Cov(Y, P_M) = corr(Y, P_M)\sigma_{p_M}\sigma_Y$, where $corr(Y, P_M)$ denotes the correlation between yield and price, and $\sigma_{p_M}$ and $\sigma_Y$ denote the standard deviation of maize price and maize yield, respectively. Following Di Falco et al. (2007), the risk premium is defined as follows:

$$\mathrm{RP} = 0.5\sigma^2_\pi\gamma/E(\pi) \tag{7}$$

$\gamma$ is the coefficient of relative risk aversion, representing the degree of risk aversion of the farmer. In particular, a risk neutral farmer is represented by $\gamma = 0$, while risk averse behavior implies $\gamma > 0$. The relative risk premium presented in Eq. (7) assumes constant relative risk aversion that implies decreasing absolute risk aversion (i.e. risk aversion decreases with increasing wealth). To derive optimal nitrogen allocation in this model, the certainty equivalent is maximized with respect to nitrogen use:

$$\underset{N}{Max}\ \mathrm{CE} = E(\pi) - \mathrm{RP} \tag{8}$$

The optimization described above (Eq. (8)) is conducted firstly for current climatic and market conditions. To analyse the effects of a fertilizer tax on nitrogen use, utility and profits, the fertilizer price is increased by 10%, 20% and 30%. These assumptions on possible nitrogen taxes are within the range of observed examples of nitrogen taxes in Europe (Rougoor et al., 2001).

To analyse potential effects of shocks in farm-income risks, sensitivity analyses of the above presented optimization problems (including the analysis of different nitrogen taxation levels) are conducted with regard to higher price and yield variability. The assumptions made in these sensitivity analyses are outlined in the data section.

## 3. Data

### 3.1. Data generation with CropSyst

CropSyst is driven by daily weather data and management information. To introduce stochasticity of crop yields in this model, we use different sets of daily weather data, i.e. representative outcomes of current climate at the eastern Swiss Plateau for the years 1981–2003 (see Finger and Schmid, 2008). More specifically, we consider daily weather data from six different locations on the Swiss Plateau as provided by the Swiss Federal Office of Meteorology and Climatology (MeteoSwiss). These locations are distributed over the eastern Swiss Plateau ranging from 06°57′ to 08°54′ longitude and are located at elevation levels between 422 and 565 m above sea level. In contrast to using only a single location, the use of observations from six different weather stations broadens the heterogeneity of weather observations within the bounds of current climate.

Besides weather data, details on crop and soil properties are important inputs for CropSyst. The assumed soil texture is characterized with 38% clay, 36% silt, and 26% sand. Soil depth amounts to 1.5 m and the soil organic matter content is at 2.6% weight in the top soil layer (5 cm) and 2.0% in lower soil layers, which follows Dubois et al. (1999). Specific assumptions made in CropSyst to reflect Swiss maize production are reported by Torriani et al. (2007a).

Regarding the crop management, only nitrogen fertilization was considered as flexible determinant in the model. More specifically, the total amount of fertilizer applied per year was varied randomly, ranging from 0 to 320 kg/ha. The so derived amounts of annual nitrogen application are randomly allocated to different sets of observed weather years (i.e. model runs) described above, leading in total to 394 observations. Nitrogen applications are made 1, 30,

**Table 1**
Descriptive statistics of data generated with CropSyst.

| Level of *N*-application (kg/ha) | Median yield (t/ha) | Median of absolute deviation (MAD)[a] of yields (t/ha) | Number of *N*-applications within a season | Distribution of *N*-applications (%) |
|---|---|---|---|---|
| 0–80 | 6.60 | 0.62 | 3 | 25:25:50 |
| 81–160 | 8.89 | 1.33 | 3 | 25:25:50 |
| 161–240 | 8.29 | 1.38 | 4 | 20:20:20:40 |
| 241–320 | 8.16 | 1.58 | 4 | 20:20:20:40 |

[a] The MAD is based on the median of absolute deviations from the sample median. To ensure constancy and comparability with, for instance, the standard deviation, a correction factor (1.4826) is used.

and 46 days after sowing (with a 25%, 25%, 50% distribution of the total nitrogen amount), respectively, following Dubois et al. (1998). The additional fourth application (if the total annual fertilizer amount exceeds 160 kg/ha) takes place 38 days after sowing (with a 20%, 20%, 20%, 40% distribution of the total nitrogen amount on the four applications). For each simulation, identical starting conditions regarding soil composition and soil available nutrients are used.

Descriptive statistics of the resulting dataset are presented in Table 1. It shows that the yield response to additional fertilizer application shows an inverse U-shaped relationship: nitrogen first increases, than decreases maize yields. A clear-cut relationship, however, is indicated for the influence of nitrogen application to yield variability: the higher the level of *N*-application, the higher is the variability of maize yields, though Table 1 suggests a saturated response for this relationship.

### 3.2. Coefficient estimates

In a subsequent step, the data shown in Table 1 is used to estimate production and yield variation functions (Eqs. (2) and (3)). Coefficient estimates are presented in Table 2:

Supporting the relationships observed in the descriptive statistics, the coefficient estimates for the production function show that nitrogen application increases maize yield, however, with a saturating effect (i.e. nitrogen shows decreasing marginal productivity). The estimates for the yield variation function show that yield variability (i.e. production risks) increase with nitrogen application.

### 3.3. Price data and price variability

The variability of maize prices is estimated using prices from 1991 to 2006, taken from the FAO database (FAO, 2010). Annual prices are chosen for this analysis because Swiss farmers do not use contracts and forwards yet, and so only the price after harvest is relevant. Though monthly prices are available, they usually do not differ within a year (SBV, 2010). In order to calculate coefficients of variation, the standard deviation derived from the AR(1) model is divided by the median crop price for the period 2002–2006. This period is chosen to estimate currently relevant median prices because crop prices have decreased significantly during the 1990s but remained relatively stable in the chosen period (FAO, 2010).

In order to estimate likely impacts of market liberalization on price volatility, we used the same methodology and data source to estimate price variability for Germany and France, which represent neighboring countries of Switzerland and the most important trade partners, as well as for the USA, representing the world market.

It shows that the coefficient of variation (CV) for Swiss maize prices is 0.13. For France, Germany and the USA, much higher values are indicated: 0.23, 0.24 and 0.24, respectively. The relative price variability for Switzerland is much smaller, in particular because tariffs, quotas and other trade regulations are intensively used to control national price levels.

**Table 2**
Coefficient estimates of Eqs. (2) and (3).

| Variable | Production function (Eq. (2)) | Yield variation function (Eq. (3)) |
|---|---|---|
| Intercept | 6.61 (143.69)*** | 0.43 (16.19)*** |
| $N^{0.5}$ | 0.33 (10.07)*** | 0.03 (6.35)*** |
| $N$ | −0.01 (−5.97)*** | – |
| $R^2$ | 0.38 | 0.42 |
| *df* | 391 | 392 |

*Note*: Statistics in parentheses are *t* statistics.
*** Significance at the 1% level.

To estimate price-yield correlations at the national level, maize price and yield information for the period 1991–2006 are taken from the FAO database and detrended. This procedure leads to $corr(Y, P_M) = -0.25$. In order to test if this correlation observed at the national level is a valid assumption for farm level analysis, we used Swiss farm-level yield and price data (see Lehmann, 2010, for a description). One hundred and fifty-eight available farms that reported sufficient yield and price data in the respective period are employed for this analysis. We find that the median of these farm-level correlations is −0.24, and significantly smaller than zero. In addition, no statistical significant differences to the correlation derived at the national level (−0.25) is indicated. Thus, we conclude that the national level estimate is, in this case, a valid assumption for farm level analysis.

### 3.4. Assumptions on costs, prices and benefits

In order to solve the optimization problem presented in Eq. (8), the assumptions with regard to costs, benefits, prices and risk aversion have to be specified. Fixed costs, including costs for seeds, plant protection, insurance, machinery costs and fertilizer costs (except for nitrogen), as well as direct payments and prices for maize and nitrogen are taken from Swiss agricultural profit margin calculations (AGRIDEA and FiBL, 2009). Variable cleaning and drying costs are taken from Torriani et al. (2007b). All assumptions on costs, benefits and prices are presented in Table 3.

The maximization of CE's (Eq. (8)) is conducted for a risk neutral ($\gamma = 0$) as well as for a risk averse farmer. A moderate level of relative risk aversion, $\gamma = 2$, is assumed for risk averse farmers (cp. Gardeboek, 2006, for an overview of observed risk preferences).

### 3.5. Assumptions for sensitivity analyses

To analyse potential effects of shocks in farm-income risks, sensitivity analyses of the above presented optimization problems are conducted with regard to higher price and yield variability. Based on the above described differences of price variability between Switzerland and other countries, a scenario for higher price variability is integrated in the model by assuming a doubled coefficient of variation of maize prices (CV = 0.26). This sharp increase

**Table 3**
Specification of costs and benefits. *Source*: AGRIDEA and FiBL (2009), Torriani et al. (2007b).

| | |
|---|---|
| *Revenue* | |
| Sale of production | Price (365 CHF/t) ∗ tons of yield per ha |
| Direct payment | 1660 CHF/ha |
| *Fixed costs* | |
| Seeds | 268 CHF/ha |
| Plant protection | 228 CHF/ha |
| Insurance | 134 CHF/ha |
| Machinery costs | 990 CHF/ha |
| Other fertilizer costs | 193 CHF/ha |
| *Variable costs* | |
| Fertilizer | 1.25 CHF/kg N |
| Cleaning and drying | 107 CHF/tons of yield per ha |

represents higher price volatility in a less protected market environment, e.g. due to a free trade agreement with the European Union, and is in the range of maize price variability in the neighboring countries France and Germany. Market liberalization is also likely to decrease output prices, which will further impact nitrogen use (e.g. Weersink et al., 1998), but is beyond the scope of this paper that focuses on the effects of increasing price volatility on fertilizer use.

A second sensitivity analysis assumes higher production risks due to climate change. Finger and Schmid (2008) estimate an increase of maize yield variability of about 15%, while no effect of climate change on the relationship between nitrogen use and maize yield variability has been indicated. Thus, we assume that only the intercept of the yield variation function, $\beta_0$ in Eq. (3), increases by 15% from 0.43 to 0.50. We are aware that climate change might also affect price variability (Battisti and Naylor, 2009). This relationship is, however, beyond the scope of this paper and thus not considered.

## 4. Results from the optimization

Results of the certainty maximization for risk neutral and risk-averse farmers for the initial situation are presented in the upper panel of Table 4. It shows that the results regarding, optimal nitrogen use, profits and maize yields are within the range of currently observed practices (AGRIDEA and FiBL, 2009). In comparison to risk neutral farmers (i.e. the profit maximization problem), risk averse farmers use less nitrogen fertilizer, face smaller but less variable profits and have smaller maize yields. Certainty equivalents for risk-averse farmers are markedly smaller, because income risks reduce utility levels. The risk premium (RP, Eq. (7)) is about 82 CHF, or about 4% in relative terms. Though risk aversion leads to a clear reduction of optimal nitrogen application, the differences for expected profit, profit standard deviation and crop yields are small. A possible explanation is the fact that the production function shows only small yield decreases for reduced nitrogen applications (leading to a flat payoff function) due to the above-average available soil fertility in the here used CropSyst simulations. In particular, the here assumed soil organic matter content, which follows

**Table 4**
Optimization results.

| | *N* (kg/ha) | Expected profit (CHF/ha) | Profit standard deviation (CHF/ha) | CE (CHF/ha) | Yield (t/ha) |
|---|---|---|---|---|---|
| *Scenario 1: Initial conditions* | | | | | |
| Situation w/o tax | | | | | |
| Risk neutral | 79 | 1929.45 | 397.47 | 1929.45 | 8.45 |
| Risk averse | 75 | 1929.20 | 396.25 | 1847.81 | 8.43 |
| *N*-tax of 10% | | | | | |
| Risk neutral | 75 | 1919.86 | 396.26 | 1919.86 | 8.43 |
| Risk averse | 71 | 1919.60 | 394.95 | 1838.34 | 8.41 |
| *N*-tax of 20% | | | | | |
| Risk neutral | 71 | 1910.76 | 395.05 | 1910.76 | 8.41 |
| Risk averse | 67 | 1910.48 | 393.67 | 1829.36 | 8.39 |
| *N*-tax of 30% | | | | | |
| Risk neutral | 68 | 1902.09 | 393.86 | 1902.09 | 8.39 |
| Risk averse | 64 | 1901.80 | 392.41 | 1820.83 | 8.37 |
| *Scenario 2: Higher price risk (assuming a doubling of price variability)* | | | | | |
| Situation w/o tax | | | | | |
| Risk neutral | 79 | 1929.45 | 779.74 | 1929.45 | 8.45 |
| Risk averse | 67 | 1927.11 | 773.61 | 1616.56 | 8.39 |
| *N*-tax of 10% | | | | | |
| Risk neutral | 75 | 1919.86 | 777.89 | 1919.86 | 8.43 |
| Risk averse | 63 | 1917.28 | 771.08 | 1607.17 | 8.36 |
| *N*-tax of 20% | | | | | |
| Risk neutral | 71 | 1910.76 | 776.02 | 1910.76 | 8.41 |
| Risk averse | 59 | 1907.93 | 768.56 | 1598.33 | 8.33 |
| *N*-tax of 30% | | | | | |
| Risk neutral | 68 | 1902.09 | 774.13 | 1902.09 | 8.39 |
| Risk averse | 56 | 1899.03 | 766.06 | 1590.01 | 8.30 |
| *Scenario 3: Higher production risk (assuming a 15% increase of yield variability)* | | | | | |
| Situation w/o tax | | | | | |
| Risk neutral | 79 | 1929.45 | 401.69 | 1929.45 | 8.45 |
| Risk averse | 74 | 1929.17 | 400.34 | 1846.09 | 8.43 |
| *N*-tax of 10% | | | | | |
| Risk neutral | 75 | 1919.86 | 400.43 | 1919.86 | 8.43 |
| Risk averse | 71 | 1919.57 | 398.99 | 1836.64 | 8.40 |
| *N*-tax of 20% | | | | | |
| Risk neutral | 71 | 1910.76 | 399.17 | 1910.76 | 8.41 |
| Risk averse | 67 | 1910.45 | 397.66 | 1827.68 | 8.39 |
| *N*-tax of 30% | | | | | |
| Risk neutral | 68 | 1902.09 | 397.93 | 1902.09 | 8.39 |
| Risk averse | 64 | 1901.77 | 396.34 | 1819.17 | 8.35 |

Dubois et al. (1999), probably over-estimates average values for the Swiss Plateau region (Torriani et al., 2007a). This will restrict the quantitative results to the specific assumptions underlying this analysis, but the qualitative interpretation will be applicable without loss of generality.

Results for the assumptions that a nitrogen tax would be applied show that an increasing nitrogen tax, ceteris paribus, decreases nitrogen use, maize yields and profits, irrespectively of farmers' risk attitudes. A 10%, 20% and 30% nitrogen tax would reduce the nitrogen use of a risk neutral farmer by about 5.01%, 9.65% and 13.95%, respectively. For a risk-averse farmer, the effect of a nitrogen tax on nitrogen application levels is – though slightly – higher: For instance, a nitrogen tax of 30% reduces the nitrogen use of the risk-averse farmer by about 14.56%. This higher relative reduction of the applied nitrogen amount is reached with lower costs: While for the risk neutral farmer the 30% nitrogen tax induces a reduction of certainty equivalents (or profits) is 27.36 CHF, the risk-averse farmers' reduction of certainty equivalents is slightly lower, 26.98 CHF. Note that also in relative terms (reduction from the initial wealth situation), the utility loss of risk averse decision makers is smaller.

The total financial welfare effects, taking into account farmers utility reduction and the revenue from the nitrogen tax, are negative. These welfare losses are higher (in absolute terms) for increasing level of the nitrogen tax. However, this loss of financial welfare could be outweighed by reductions of external (non-financial) environmental effects of nitrogen application.

In summary, the analysis of farmers' decision making with regard to nitrogen use in Swiss grain maize production shows that (a) risk averse farmer use less nitrogen fertilizer; (b) the relative reduction of nitrogen use due to a nitrogen tax is larger for risk averse farmers; (c) the nitrogen tax and the associated reduction of nitrogen application imply smaller abatement costs for risk-averse farmers. The latter results can be explained with a smaller value of marginal product of nitrogen for risk averse than for risk neutral farmers. This is due to the fact, that the marginal risk premium of nitrogen is positive for risk-averse but is zero for risk neutral decision makers (cp. Ramaswami, 1992). However, under current yield and price risks, these differences between risk neutral and risk-averse decision makers are small.

This contrasts the results for increased price volatility, i.e. assuming an increase of the coefficient of variation of maize prices to increase from 0.13 to 0.26, which are presented in the middle panel Table 4. It shows that an increase of price volatility leads to a sharp increase in the variability of profits, the coefficient of variation of profits for a risk neutral farmer increases from 0.21 in the initial situation to 0.40. This increase in the variability of returns has particular implications for the risk-averse farmers: The risk premium increases to about 313 CHF (or from about 4% to 16% in relative terms), and the differences between risk neutral and risk-averse decision makers with respect to nitrogen use, profits, and crop yields become much more pronounced. In contrast to the initial (current) situation, an increase of price volatility implies that risk considerations become much more relevant. For risk-averse farmers, the increase of price variability, ceteris paribus, leads to a decrease of nitrogen application of about 8 kg/ha (equivalent to 11% of the initially applied nitrogen amount).

Furthermore, the increased price variability leads to larger differences in the effects of the nitrogen tax between risk averse and risk neutral farmers. In particular, the relative reductions of nitrogen use for the risk-averse decision makers are getting larger, while the utility losses associated with the tax are getting smaller. For instance, the 30% nitrogen tax would reduce the nitrogen use by 16.70%, reducing the CE by 26.55 CHF, compared to a reduction of nitrogen use of 14.56% and a CE reduction of 26.98 CHF in the initial, current-risk situation.

For the case of increased yield variability (lower panel of Table 4), the results are, in general, similar to those for the increased price volatility. However, the effects of an expected 15% increase in yield variability due to climate change seem to be negligible compared to a sharp increase in price risks. Thus, agricultural policy in Switzerland towards reductions of nitrogen applications should – in the medium-term perspective – especially take changes in price risks into account.

In summary, endogenous shocks in income risks (either due to increases yield or increases price variability) emphasize the findings for the initial situation: risk-averse farmers further reduce their nitrogen applications; a nitrogen tax leads to higher relative reductions of nitrogen application. Furthermore, endogenous shocks in income risks further reduce the abatement costs for risk-averse farmers. These effects can be explained by the fact that the higher price or yield volatility further reduces the value of marginal product (i.e. further increases the marginal risk premium) of nitrogen for risk-averse farmers.

## 5. Discussion

We find risk-averse farmers to use less nitrogen than their risk neutral counterparts, which is in agreement with other studies (e.g. Chowdhury and Lacewell, 1996; Isik, 2002). This result is based on the findings that nitrogen increases the yield variability, which is in agreement with other studies (e.g. Moschini and Hennessy, 2001; Rajsic et al., 2009). A different argumentation is used by Babcock (1992) and Babcock and Blackmer (1992), who show that in particular if soil available nutrients are unknown, applying more nitrogen than necessary can be a risk reducing strategy (following the decision rule "apply extra fertilizer just in case it is needed", Babcock and Blackmer, 1992). Due to the availability of extension services, technologies and high levels of education, we think that farmers in western countries have a good awareness of soil conditions and available nutrients in the soil (Babcock and Blackmer, 1992). Accordingly, we assume in our model that soil organic matter content (i.e. available nutrients in the soil) are known by the farmer. Thus, our finding that risk-averse farmers use less nitrogen is not in contrast to the results of Babcock (1992) and Babcock and Blackmer (1992).

More general, we assumed in our analysis that farmers are aware of expected levels of maize yield and yield variability as well as of the effect of nitrogen application on these variables. In order to validate these assumptions, further research should investigate farmers' decision making processes with regard to fertilizer use (cp. e.g. Kienzler et al., 2011). The here presented analysis of relationships between maize yield and the amount of nitrogen application is based on generated data with the crop simulation model CropSyst and is thus restricted on the employed model- and soil-specifications. We are aware that more site specific modelling approaches are needed to account for the spatial heterogeneity of soil conditions in Switzerland, especially regarding soil fertility (BLW, 2000). Thus, further bio-economic assessment of nitrogen response functions and nitrogen taxation should be considered in a spatially explicit modelling approach.

The elasticities of optimal nitrogen use to changes in nitrogen costs indicated in our analysis are about −0.5, i.e. a 1% increase in nitrogen costs (e.g. due to a tax) decreases nitrogen use by about 0.5%. Though this estimate is in the range of elasticities reported in other studies (cp. Burrell, 1989, for an overview), we expect that the presented estimates likely overestimate real-world elasticities. This is, for instance, due to the fact that also non-economic drivers (e.g. habits, preferences for good looking crops) can be very important for input use decisions (Rajsic et al., 2009). Observed reactions of nitrogen use of farmers to changes in nitrogen prices over time could be used to analyse potential mismatches between model assumptions and real behavior. For our analysis this is, however, not possible due to the lack of data available.

Furthermore, our analysis may overestimate nitrogen use elasticities because inter-seasonal adjustments of input applications are not considered directly. Hyytiäinen et al. (2011) show that nitrogen taxes may also induce an adjustment in the amount of fertilizer application within the season. In contrast to the analysis of Hyytiäinen et al. (2011), where the starting point was a single nitrogen application per season, our analysis assumes 3–4 fertilizer application events per season, which reflects current practises in Swiss crop production. Thus, the potential for adjustment in this respect may be limited in our application. Along these lines, Lehmann et al. (2011) showed that even the optimal timing of fertilizer application within the growing season may change under changing (climatic and economic) boundary conditions.

We are aware that even though risk preferences are important for farmers' utility (risk premiums indicated in our analysis range from 4% to 16%), the sensitivity of optimal input use, reflecting the extent of risk avoidance, to changing risk preferences may be smaller (e.g. Pannell et al., 2000). In addition, some assumptions of our modelling approach may cause an overestimation of the effects of risk preferences on nitrogen use decisions. For instance, we restricted the here presented analysis on a single agricultural activity, grain maize production, in order to clearly illustrate the effects of risk aversion and nitrogen taxes on nitrogen use. However, if more on- and off-farm activities would be taken into account, the introduction of risk aversion might also imply shifts towards less risky activities (e.g. Weersink et al., 1998). Thus, the optimal farm program response to increasing price or production risks may not only be the reduction of input use but also the switch to less risky production programs (e.g. less risky crops) or an increased share of off-farm activities. Moreover, also the introduction of a nitrogen tax can imply, besides reductions of fertilizer use for specific crops, adjustments in the optimal whole farm program.

To overcome this drawback, multi-output production systems can be estimated that represent farmers explicitly as portfolio managers and directly consider interactions between different activities (e.g. Tveteras et al., 2011). Furthermore, bio-economic models could be developed further to address these points. More specifically, the biophysical spatial explicit modelling of whole farm programs, taking risk considerations and other adjustment strategies towards increasing risks and fertilizer prices (e.g. tillage intensities, fertilizer application techniques and site specific farming practices) into account, is necessary for scientifically based policy recommendations on optimal taxation of nitrogen fertilizer.

Analysing the effects of nitrogen taxes, we find that a smaller tax is required to reach desired reductions of nitrogen applications for risk-averse farmers than for risk neutral agents. Moreover, the abatement costs of nitrogen reduction are smaller for risk-averse farmers. Because a high heterogeneity with regard to risk preferences among farmers within a country can be expected (e.g. Rosenzweig and Binswanger, 1993), nitrogen taxes will thus have heterogeneous effects. Moreover, spatial heterogeneity of soil fertility will further increase the heterogeneity of nitrogen tax effects. Sheriff (2005) shows that these heterogeneities can be a particular positive argument for nitrogen taxation, because the reductions of nitrogen use due to the tax will be allocated across farms in a cost efficient way: For instance, those farmers that have the smallest abatement costs (e.g. due to high risk-aversion) will reduce their nitrogen applications more than those farmers that face high abatement costs. This 'sorting effect' of nitrogen reductions according to marginal costs based on heterogeneous risk preferences is furthermore an argument against a uniform nitrogen use restriction, which is currently applied in Switzerland via cross-compliance obligations (El Benni and Lehmann, 2010). Given a heterogeneous distribution of marginal nitrogen abatement costs, input use restrictions might imply higher costs to reach a specific nitrogen reduction goal (Sheriff, 2005).

In summary, a tax solution to internalize external effects of nitrogen application and to reduce nitrogen application seems to be superior to uniform nitrogen use restrictions, in particular if risk considerations are taken into account. However, different interest groups may have low incentives for changes towards a tax-based system (O'Shea, 2002), which may hamper its implementation. An additional problem is that, if price elasticities of input use are small, a tax may not necessarily lead to the desired changes in nitrogen use (Falconer and Hodge, 2000). If a tax does not imply environmental benefits, however, it can induce welfare reductions. To overcome problems of acceptance and impacts, such policy measure should be accompanied by a set of measures. In particular, education, training and awareness creation may contribute to higher efficacy of agri-environmental policy intervention (Falconer and Hodge, 2000). Furthermore, a tax system may be combined with specific standards designed to prevent environmental damages above very critical thresholds (O'Shea, 2002).

## 6. Summary and conclusion

Using the example of Swiss grain maize production, we show that risk-averse farmers use less nitrogen fertilizer than risk neutral decision makers. This result is based on the empirical finding that nitrogen increases yield variability and thus the marginal risk premium of nitrogen is positive for risk-averse but zero for risk neutral decision makers. Due to this relationship, a smaller nitrogen tax is required to reach desired reductions of nitrogen applications for risk-averse farmers than for risk neutral agents. Moreover, these nitrogen reductions imply lower abatement costs for risk-averse farmers. These results imply that ex-ante assessments of the effects of a nitrogen tax that are based on profit-maximizing behavior might under-estimate the nitrogen reduction and over-estimate the total abatement costs due to a tax on the national level.

The analysis of endogenous shocks in income risks due to increasing yield and price variability shows that the above described effects become more pronounced because differences in optimal input allocation between risk neutral and risk-averse farmers increase. Thus, agri-environmental policy should take into account effects of further market liberalization on price volatility and its implications on nitrogen use and the effects of nitrogen taxation in crop production. Because this effect of more liberalized markets may be also evident in other countries, this finding is also relevant at a larger scale. In the long run, also effects of climate change on yield variability have to be taken into account if effective nitrogen reduction policies are designed.

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