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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:

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

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:

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

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 $\hat{w} = Y - \hat{Y}$, are used to estimate the yield variation function using the following specification (Finger and Schmid, 2008):

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

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.