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The impact of production and price risk on ecosystem goods and services provision from agriculture and forestry in mountainous regions

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Abstract: Assessing the impact of climate change on Ecosystem Services (ES) requires an understanding of the dynamic link between land cover, ES and economically driven land use decisions. Land use decisions taken by farmers and foresters depend on the yield levels as well as on the prices for outputs and inputs the decision maker expect. However, the variability of yields and prices, i.e. income risk, is also highly relevant for the decision maker. Increasing volatility of climate and more volatile markets for commodities will enhance the relevance of risk for land use decisions in the future.

To assess the impact of increasing production and price risks, we develop an agent-based economic land allocation model. Applying discrete stochastic programming and a safety first approach we integrate the consideration of income variability in the agents' decision making.

We intend to apply our model to the temperature sensitive alpine region of Davos, Switzerland and to compare land use under the consideration of production and price risks as well as using a deterministic (i.e. non-risky) baseline.

Keywords*:* Land use change, Income variability, Agent-based modelling, Production risk

1 INTRODUCTION

In Swiss mountains, very few regions are still truly natural. Land use and the maintenance of Ecosystem Services (ES) provision is determined through a complex interplay between human action and basic ecosystem processes (Lambin et al. 2001). This is particularly the case if ES are provided in ecosystems that are managed to a large extent by humans. In mountainous regions, farmers and foresters are the two main management agents that influence ecosystems. They manage the land to pursue their own goals, such as achieving a sufficient income. Their decisions, however, are not only determined by expectations about average incomes, but also by the impact of their actions on the income variability (e.g. Hardaker et al. 1997).

Income variability in farming can have different causes (e.g. Moschini and Hennessy 2001) such as the uncertainty about product and input prices, or the uncertainty regarding the level of production that will be achieved in each year. Furthermore, crop yields can be influenced by variable weather both positively and negatively (Moschini and Hennessy 2001).

In order to stabilize income, i.e. to mitigate risks, farmers may change their production using different risk-management strategies (Reidsma et al. 2010), for example the storage of grass to smooth the availability of fodder over multiple years (Mosnier et al. 2011). Furthermore, production intensities in fodder and crop production as well as the portfolio of agricultural activities used may change in presence of risks (Finger et al. 2010). Besides direct impacts on land use, risk-management strategies can also indirectly impact land use decisions. For example, the demand for feedstuff will be lower if the farmer mitigates risk by housing fewer animals (Ritten et al. 2010). Since the farmer still will cultivate the available farmland, he is expected to reduce intensity of cultivation or to introduce alternative activities such as crop production. Another risk management option that directly impacts land use is the expansion of forest areas. Since perennial cultures such as energy crops like switchgrass or even forests are less affected by annual volatilities this can reduce income variability (e.g. Bocqueho and Jacquet 2010).

Based on this background, we aim to investigate the role of farmers' income risks on land use and ES provision under current and future climate and market conditions. Our analysis is based on the community of Davos located in the canton of Grison within the Swiss Alps. This example has been chosen because most mountainous ecosystems in Switzerland are managed by farmers and foresters, i.e. the impact of their decisions on ES provision in these regions is significant. In addition the assessment of changes in land use due to increased variability is especially important since these changes may determine ES provision, which are highly important in these regions.

The assessment of driving forces for land use change in mountainous regions, such as the community of Davos, must rely on highly complex and integrative methods since these regions are characterized by a high degree of heterogeneity and complex topography (Briner et al. 2012). For instance, steep slopes that require specialized machinery and manual labor, both significantly increasing the costs of production. In mountain agriculture costs are further increased and potential revenues (e.g. from yields) are further decreased due to poor soils, heterogeneous land suitability and the presence of a harsh climate (Tasser et al. 2011). If land use change is simulated in mountainous regions it is therefore mandatory to consider the high spatial variability.

Current studies on local and regional land use change consider only the impact of climate change and socio-economic changes on mean values. As such they consider the impact of climate change on changes in the average yields of grass- and cropland and not on changes in variability (see for example Henseler et al. 2009, Briner et al. 2012). These models neglect that different decision makers have an unequal ability (and preference) to bear risk (Irwin and Geoghegan 2001). In contrast, farm models that overtly consider variability are not spatially explicit (e.g. Mosnier et al. 2011). We address this deficiency by expanding the agent-based land-allocation model ALUAM-AB (Huber et al. 2012) in a way that the impact of income variability in the goal function of the different agents can be considered. We then apply this model to the region of Davos to answer the following research questions:

- What is the impact of income variability (due to stochasticity in production or prices) on land use?
- How will land use change if agents show different degrees of risk aversion?

To answer these questions this article proceeds as following. First the agent based model is described with an especial focus on the risk assessment part. Then expected results are described. In the end possible impact of land use change on ES provision will be discussed.

2 METHODS

For the assessment of the impact of uncertainty in weather and prices we expand earlier work (Huber et al. 2012). More specifically, we use a recursive dynamic agent based model to increase the understanding of agricultural land use changes triggered by market and policy changes considering individual preferences of the farmers.

2.1 Land use activities

The land use activities considered follow Briner et al. (2012). We consider 9 different grassland activities, 3 cropping activities and one forest activity. Grassland activities differ in the way the grass is harvested (grazed or mown), by the decision if grassland activities are integrated in a crop rotation and in the intensity of cultivation of the grassland. Available cropping activities are wheat, barley and potato, each at one intensity level. In addition agents have the possibility to use the land as forests. Weather does not have an immediate impact on the yield of forests, since forest yields are climate but not weather dependent. This means that yearly favourable and unfavourable weather is compensated during the long growing period. In contrast to agricultural land uses forest is therefore assumed to be a risk free alternative with constant yields. Note that this assumption is also based on the employed discounting. Thus, the occurrence of risks (losses) in forest production in 50 years may not be as relevant for the decision maker as those in agricultural production occurring today, while agricultural production, however, is assumed to differ between years.

2.2 Livestock activities

The farmers represented in the model have the possibility to house different ruminants limited to the production systems currently relevant in the region. Available are dairy cows, suckler cows, heifers, sheep for milk production, sheep for meat production. One housing system is available per animal species except for dairy cows, which can either be housed in a stanchion barn or in a loose barn. To minimize aggregation bias, the housing systems were modeled in different sizes allowing different levels of labor productivity and investment costs per animal.

2.3 Balances

2.3.1 Fodder balance

The demanded fodder can either be produced on farm or – in certain scenarios – can be purchased on a roughage market at common prices. If additional fodder is produced, but not needed for feeding livestock, it can be sold on the market. Prices for purchased fodder are much higher than for sold fodder. For each farm (i.e. each agent) and year, an equal fodder balance is required. Note that concentrate feedstuff cannot be produced in the region due to unfavorable climatic conditions and therefore needs to be bought by the farmer.

2.3.2 Nutrient balance

To receive direct payments farmers have to fulfill certain cross-compliance restrictions (Proof of Ecological Performance PEP, see El Benni and Lehmann 2010 for details). One of these restrictions is limiting the available nutrients from livestock activities and artificial fertilizer. This nutrient balance is calculated based on the official Swiss methodology (Suisse Bilanz; see Amaudruz et al. 2003 for details). The amount of available plant nutrients in the model therefore is not allowed to exceed demand by land use activities by more than 10%. To maintain adequate yields and soil fertility minimum available plant nutrients must meet demand calculated for each land use activity on each parcel. If there are not enough nutrients available from livestock activities agents have the possibility to purchase additional artificial fertilizer.

2.3.3 Labor balance

The available amount of labor needs to be enough to accomplish all farm-work, including farm management. To ensure a sufficient amount of labor available during the whole year, two different balances are calculated. First labor balance is spanning over the whole simulation period of one year. Since in mountain regions the time that can be used for conservation of fodder for the winter season is only very short this results in a distinct peak in work load during summer season. To ensure that there is enough labor available during the vegetation period there is a second labor balance calculated for this specific period.

The available labor is mainly the farmer and his family, for whom different opportunity costs for labor are assumed. In addition to family labor, there is also a possibility to hire additional labor on an hourly rate.

2.4 Calculation of the land-rent

Calculation of the current costs for inputs is based on price statistics as provided by Blum et al. (2010). Since we focus on output price uncertainty, inputs' prices are expected to remain at a constant level. In contrast, yearly prices for outputs are drawn randomly from a normal distribution. This distribution is estimated using past price data.

2.5 Design of the agents in the model

The design of the agents is based on information from agricultural census data. All running farms in the region are divided into 10 different clusters based on their production structure, which is formed by the production system and number of livestock housed on the farm, the size of the land cultivated and land use. All farms falling inside one of these 10 clusters are then aggregated to one agent. For the calculation of the available workforce the number of farmers is also aggregated. However we explicitly account for the age of all farmers in the model, to calculate the number of farmers that retire after each decision period.

Further agent characteristics are based on a survey made with farmers in another mountainous region of Switzerland, on literature (Rossier and Wyss 2006) and on expert knowledge. Agents were characterized with respect to their available time to work on the farm, for their expected minimum income they need to achieve to keep the farm running and for their risk preferences.

Since there are no spatially explicit data about the land ownership, available parcels are randomly distributed among agents. The implementation of several restrictions guarantees that the share of land of each quality, represented by the slope, is consistent with reality.

2.6 Optimization procedure

The particular focus of our contribution is that the decision making of the farmers takes into account expected income as well as income variability. We thus apply a combined discrete stochastic programming (DSP) and safety first-approach (e.g. Cocks 1968). The strength of DSP is that it makes possible solving multi-stage decision problems with uncertain outcomes. It is possible to introduce uncertainty into the coefficients of the objective function as well as into input-output coefficients or resource endowments. It is only necessary to know the probability of realization of different discrete states of nature, which makes it possible to directly use yield data generated with a crop-yield model as used in this modeling framework.

We use a two stage decision model. In the first stage, the land use activities are chosen for all different years. Based on the results of this decision in the second stage livestock activities are optimized, i.e. the number of different animals is adapted in order to reach maximum income. In addition, in stage two decisions about trade of fodder as well as the hire of additional labor are made. In this framework, it is assumed that there is complete information about the outcome of the first stage decision (Appland and Hauer 1993).This means that the farmer already knows the outcome of this land use decision, i.e. the amount of grass harvested, when he decides how many animals he wants to house etc.

The optimization procedure is described in equations 1-4. Equation 1 shows the goal function that is optimized to maximize aggregated land rent *Z*. *X* represents the decision vector of the decision of stage 1, i.e. the decision of the choice of the land use activities. These decisions are made on an annual basis. The decision vector *Y* is the same for all different states of nature *k*. These states of nature *k* differ in weather and subsequently in the yields that can be harvested on crop- and grassland. *g* represents the profit margin (i.e. win or loss) attributed to each land use activity. *Y* is the decision vector of decisions made in stage 2. This is the choice of the livestock system, the number of animals housed as well as decisions about the trade of fodder. Since farmers are assumed to know the outcome of their land use decisions, they can adapt to changes in yield and prices. Decision vector *Y* is therefore dependent on the state of nature *k*.

$$\max Z_t = \frac{1}{k}\sum_{k=1}^{10} gX_t + m_{k,t}Y_{k,t} \tag{1}$$

s.t.

$$aX_t + bY_{k,t} < r \tag{2}$$

$$c_k X_t - dY_{k,t} > 0 \tag{3}$$

$$X_t => 0, Y_{k,t} => 0 \tag{4}$$

Optimization is subject to different restrictions described in section 2.3. These are represented by Equations 2 to 4. Constants *a* and *b* represent demand for resources of the different activities. *r* is the amount of resources available. *c* and *d* are supply and demand of fodder or nutrients that are transferred between land use activities and livestock activities. For details about the applied restrictions see section 2.3.

In a subsequent step a time dimension *t* is introduced into the model, i.e. the model is made recursive dynamic. Temporal dynamics are driven through changes in economic parameters that differ between years. Recursive dynamic elements are the number of stable houses, the number of farmers represented by one agent in the model, and the land distribution.

Since we assume that farmers do not only optimize expected income but also take into account income variability in a next step a safety-first approach is implemented in the modelling approach. This approach is based on Roy (1952) and since then was used in several studies (e.g. Haley 2012). In its original version the safety-first approach means that farmers intend to optimize their product portfolio in a way that the probability that income is lower than a certain threshold is minimized. In this study we apply a more restrictive version of the safety first approach in that we assume that a certain threshold depending on the agent’s risk aversion is not allowed to be undercut since the farm goes bankruptcy otherwise.

2.7 Land-market

Different agents are linked over a market for land as suggested by Lauber (2006). Land enters the market only if it is not cultivated by the agent anymore. This can be the case because cultivation is not profitable anymore, i.e. an agent lets a parcel fall fallow. Furthermore, the retirement of a farmer without successor and giving up of a farm because income falls beyond a certain threshold can induce land to enter the market. Since the agents in the model represent an aggregation of several farms with a similar production structure they can retire partly each year. If a real farmer, who is part of an agent, becomes retired only the share of the agent's land corresponding to this farmer enters the market if there is no successor. All the other farms that are part of the agent stay with the agent. The probability that the single farmer has a successor is thereby dependent on the income that is possible to achieve on the farm as well as on the size of the farm (Rossier and Wyss 2006). The distribution of the land that enters the market is divided into two steps: 1) It is assessed which agents are interested in the land. This is assumed to be the case if the shadow price for the use of a certain parcel is positive, i.e. if the additional parcel would increase the income of the agent. 2) The available parcels are assigned randomly to the agents that are interested in these parcels.

2.8 Crop-yield model

Sets of ten years of projected future yields of relevant crops are calculated using data on optimal and absolute crop growing conditions (FAO 2007) for every parcel of 100m by 100m. The minimum and maximum temperature and precipitation values and the values that define the crops temperature and precipitation extremes, are extracted from the FAO crop data base EcoCrop (FAO 2007). Applying these values, we fit a relative crop yield curve for temperature and precipitation values using an incomplete beta distribution (Briner et al. 2012). These species specific crop yield curves are then used to calculate the relative yield for six crops based on monthly precipitation and temperature values. The projected realized yield is taken as the minimum yield value from the temperature and precipitation responses. The absolute yield of crops is calculated by standardizing the values against observed yield of crops in 2000.

2.9 Forest landscape model

The spatially explicit forest-landscape model TreeMig (Lischke et al. 2006) allows a grid-based simulation of forest dynamics over several centuries with different climate change scenarios. Each 100 m by 100 m cell simulates forest dynamics based on species specific germination, establishment, growth, competition, reproduction and mortality. Spatial interaction between the cells is given by explicit seed dispersal simulation. As an input to the land-allocation model, TreeMig provides information on potential changes in tree species diversity and forest yields, driven by climate change.

3 EXPECTED RESULTS

Based on the results of other studies that accounted for uncertainty in farmers' decision making, we expect that land use will be less intensive if income risks are considered. This response is also expected if certain risks (e.g. price and yield volatility) or farmers' risk aversion increase. In addition, the number of animals will be reduced in order to ensure the availability of fodder to feed all livestock. Since extensive use of meadows is rewarded by the government by paying subsidies, this extensification leads to an increasing share of subsidies in the total income of farmers. Subsidies are paid irrespective of the realized yield of grasslands and therefore these extensive meadows provide a safe income. Thus, direct payments can replace other risk management instruments (Finger and Lehmann, 2012).

4 DISCUSSION

The consideration of yield uncertainty leads to a change in agricultural production and subsequent changes in land use compared to solutions with no risk aversion. In this case farmers rely more on the continuous payment of subsidies than on uncertain yields. Furthermore Bocqueho and Jacquet (2010) show that perennial energy crops can be a land use option if instead of the Net Present Value (NPV) the expected utility is maximized. In this case energy crops provide an option to diversify income and therefore lower the variability of income. This is the case even if expected NPV of energy crops is lower than that of traditional crops. Since the gap between the expected NPV of agricultural and forest land use, that can be expected to have same impact on income than the cultivation of perennial energy crops, under today’s economic conditions still is significant, the transformation into forests is not yet a considerable risk-management strategy. Under a future open market scenario this could be changing and forests could, at least on less suitable parcels, be a strategy to reduce income variability.

With respect to the provision of ES, the expected decrease in the number of animals will lead to a decrease in food provision but an improvement in the carbon balance. Briner et al. (2012) showed a clear trade-off between food provision and carbon sequestration. It can therefore be expected that higher risk aversion of farmers will have a positive impact on carbon sequestration. In addition the risk aversion and the subsequent increase in extensively used meadows can be assumed to have a positive impact on biodiversity in this region. Knop et al. (2006) showed that extensively used meadows are especially rich in species. In addition under future scenarios the reforestation of certain parcels will increase landscape diversity, which is also considered positive for biodiversity. Graveline et al. (2012) also show that the consideration of uncertainty in prices and yields leads to decisions that reduce the emission of nitrate in two French regions, a trend that could also be visible in Davos. With respect to the applied agents the impact of uncertainty on ES provision is expected to be higher if the agents work fulltime on the farm since then they do not have an additional income that could allow them to endure years with unfavourable weather or market conditions. For these agents higher uncertainty is expected to lead to less intensive land use and subsequently to higher provision of biodiversity and improved carbon balance but less provision of food.

The expected impact of uncertainty however might be slightly overestimated in our model. The only available risk management options are a change in land use as well as in the number of animals. For example Mosnier et al. (2011) or Briner and Finger (2012) show that there are additional risk management options available to reduce the exposure of farmers to income risk, such as the storage of fodder or an adaptation of the animals’ diet. Our model also does not take costs associated with variability in the herd size into account. If the size of the herd has to be reduced, animals can normally only be sold at a lower price than if these animals would be purchased on the market, causing a net loss. The consideration of these costs in the model would increase costs associated with risk management. It would however also be necessary to introduce more but shorter decision periods since the consideration of these details only makes sense if the agents have the possibility to adapt their herds during the year, i.e. that they have more flexibility to adapt to new circumstances

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