Land Use Policy 46 (2015) 75–90

Contents lists available at ScienceDirect

Land Use Policy

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

Spatial modeling of robust crop production portfolios to assess agricultural vulnerability and adaptation to climate change

Hermine Mitter[a,b,*], Christine Heumesser[a], Erwin Schmid[a]

[a] Institute for Sustainable Economic Development, Department of Economics and Social Sciences, University of Natural Resources and Life Sciences Vienna (BOKU), Feistmantelstrasse 4, 1180 Vienna, Austria

[b] Doctoral School of Sustainable Development, University of Natural Resources and Life Sciences Vienna (BOKU), Peter-Jordan-Strasse 82, 1190 Vienna, Austria

ARTICLE INFO

Article history:
Received 14 March 2014
Received in revised form
16 December 2014
Accepted 3 January 2015

Keywords:
Climate change impact
Adaptation
Agricultural vulnerability
Portfolio optimization
Agricultural policy
Agri-environmental payment

ABSTRACT

Agricultural vulnerability to climate change is likely to vary considerably between agro-environmental regions. Exemplified on Austrian cropland, we aim at (i) quantifying climate change impacts on agricultural vulnerability which is approximated by the indicators crop yields and gross margins, (ii) developing robust crop production portfolios for adaptation, and (iii) analyzing the effect of agricultural policies and risk aversion on the choice of crop production portfolios. We have employed a spatially explicit, integrated framework to assess agricultural vulnerability and adaptation. It combines a statistical climate change model for Austria and the period 2010–2040, a crop rotation model, the bio-physical process model EPIC (Environmental Policy Integrated Climate), and a portfolio optimization model. We find that under climate change, crop production portfolios include higher shares of intensive crop management practices, increasing average crop yields by 2–15% and expected gross margins by 3–18%, respectively. The results depend on the choice of adaptation measures and on the level of risk aversion and vary by region. In the semi-arid eastern parts of Austria, average dry matter crop yields are lower but gross margins are higher than in western Austria due to bio-physical and agronomic heterogeneities. An abolishment of decoupled farm payments and a threefold increase in agri-environmental premiums would reduce nitrogen inputs by 23–33%, but also crop yields and gross margins by 18–37%, on average. From a policy perspective, a twofold increase in agri-environmental premiums could effectively reduce the trade-offs between crop production and environmental impacts.

Introduction

Climate variability and change are expected to affect the agricultural sector in many respects (Parry et al., 2007), thus influencing agricultural vulnerability (Fellmann, 2012). In Austria, agricultural vulnerability is likely to vary considerably between agro-environmental regions. Crop production in the alpine region (i.e. the western parts of Austria) could benefit from increasing temperatures and CO_2 fertilization because water supply is sufficient during the growing season. In contrast, crop production in the pannonian region (i.e. the eastern parts of Austria) is likely to suffer from increasing temperatures due to water limitations (Thaler et al., 2012; Strauss et al., 2012; Iglesias et al., 2012b; Eitzinger et al., 2013; Schönhart et al., 2014). However, favorable bio-physical conditions such as topography and soil types may reduce agricultural vulnerability in the pannonian region. Various adaptation measures, i.e. irrigation and soil conservation measures, have been identified of being effective in reducing agricultural vulnerability by decreasing crop yield losses and increasing gross margins or environmental quality under climate change in Austria (e.g. Klik and Eitzinger, 2010; Eitzinger et al., 2013; Mitter et al., 2013; Schönhart et al., 2014). Some of these adaptation measures are supported by Austrian agri-environmental policies, which are thus considered suitable to decrease agricultural vulnerability (Schönhart et al., 2014).

There are alternative definitions, concepts, and methodologies to assess agricultural vulnerability (Hinkel, 2011). Still, there seems to be consensus that vulnerability assessments can be based on bio-physical and socio-economic drivers (Adger and Kelly, 1999; Brooks, 2003; Turner et al., 2003; Wisner et al., 2004; Eakin and

* Corresponding author at: Institute for Sustainable Economic Development, Department of Economics and Social Sciences, University of Natural Resources and Life Sciences Vienna (BOKU), Feistmantelstrasse 4, 1180 Vienna, Austria.
Tel.: +43 1 47654 3664.
E-mail addresses: hermine.mitter@boku.ac.at (H. Mitter), christine.heumesser@boku.ac.at (C. Heumesser), erwin.schmid@boku.ac.at (E. Schmid).

http://dx.doi.org/10.1016/j.landusepol.2015.01.010

Luers, 2006; O'Brien et al., 2004; Füssel, 2007; Soares et al., 2012). Many climate related studies in agriculture focus on bio-physical vulnerability drivers and investigate impacts of climate variability and change on crop yields and agricultural production while accounting for differences in e.g. topography, soil, and atmospheric CO_2 concentrations (e.g. Kersebaum and Nendel, 2014). Most of them also suggest adaptation measures (e.g. Olesen et al., 2011; Teixeira et al., 2013; González-Zeas et al., 2014) and quantify their potential impacts on crop yields (e.g. Jalota et al., 2013; Eitzinger et al., 2013; Nendel et al., 2014). A range of studies focuses more on the effect of climate variability and change on socio-economic vulnerability indicators such as farm income or GDP (e.g. Gbetibouo et al., 2010; Fraser et al., 2013) and analyze the impact of adaptation measures on e.g. gross margins (e.g. Ciscar et al., 2011; Iglesias et al., 2012a; Mitter et al., 2014; Moore and Lobell, 2014; Schönhart et al., 2014). These assessments mostly rely on quantitative, simulation-based approaches which enable to consider a broad range of functional relationships and processes. Compared to indictor-based approaches which rely on observable variables (Hinkel, 2011), simulation-based approaches also allow the inclusion of climate change and policy scenarios but depend on data sources with a high spatial resolution. However, simulation-based approaches often fail to capture the complexity of agricultural vulnerability in spatial context. To our knowledge, socio-economic drivers of agricultural vulnerability such as agricultural policies, farm structure, and farmers' risk aversion are assessed to a lesser extent in quantitative, simulation-based vulnerability assessments. Furthermore, spatially explicit vulnerability assessments are still found to be rare (Lorencová et al., 2013; Frazier et al., 2014). Also for Austria, an integrated agricultural vulnerability and adaptation assessment which combines bio-physical and socio-economic vulnerability drivers at high spatial resolution has not been conducted yet.

Thus, the aim of our analysis is to assess the impact of selected bio-physical (i.e. climate variability and change, soil, topographic, and agronomic conditions), and socio-economic drivers (i.e. agricultural policies and farmers' risk aversion levels) on agricultural vulnerability in Austria. Additionally, a set of adaptation measures is identified to reduce vulnerability. Hence, we firstly assess the impacts of climate change scenarios on agricultural vulnerability. Agricultural vulnerability is indicated by level and variability of crop yields and gross margins. Secondly, we identify optimal combinations of viable adaptation measures. These crop production portfolios help to evaluate the trade-offs between expected average and climate-induced variability of crop yields and gross margins. We consider a spectrum of climate change scenarios for the future period to identify those combinations of adaptation measures which are the most robust to a range of plausible futures (as suggested by Adger et al, 2008). Robust strategies are typically low-regret, i.e. beneficial even without significant changes in climatic conditions and reversible by having low costs of maladaptation (Hallegatte, 2009). Thirdly, we assess the effect of agricultural policy scenarios on the choice of robust crop production portfolios and vulnerability indicators under climate change. Fourthly, in all above aspects of our analysis, we consider the effect of different risk aversion levels on the choice of crop production portfolios and vulnerability indicators. Considering a number of agricultural policies and different risk aversion levels allow us to quantify potential effects of changes in adaptive capacity and socio-economic drivers on agricultural vulnerability.

Therefore, we have employed a spatially explicit integrated agricultural vulnerability and adaptation assessment framework, covering Austrian cropland at 1 km grid resolution. This enables us to consider bio-physical heterogeneities in topography and soil. The framework encompasses climate change, crop rotation, bio-physical process, and economic portfolio optimization models that allow developing optimal crop production portfolios, which consist of alternative crop management practices for the historical period 1975–2005 and the future period 2010–2040. Our assessment of agricultural vulnerability and adaptation is appropriate to quantify the effect of bio-physical and socio-economic vulnerability drivers on selected agricultural vulnerability indicators. Investigating six contrasting agricultural policy scenarios shows potential impacts of policy changes and induced changes in adaptive capacity on crop yields, gross margins, and environmental outcomes. Quantifying the interactions between policies, crop yields, environmental impacts, and climate change are deemed crucial in order to improve policy development (Paloma et al., 2013). Similar integrated modeling frameworks have already been applied to assess the cost-effectiveness of agri-environmental program measures at farm and landscape level (Schönhart et al., 2011a), analyze environmental effects of agricultural trade policies in a case study region (Kirchner and Schmid, 2013), investigate investment decisions under climate-induced uncertainty (Heumesser et al., 2012), quantify climate change impacts in the agricultural sector (Schönhart et al., 2014), and on crop productivity (Strauss et al., 2012).

Our study adds to the scientific literature in several ways. Firstly, we address bio-physical and socio-economic drivers to study agricultural vulnerability to climate change. Such integrated, vulnerability and adaptation assessments are seldom undertaken (Gbetibouo et al., 2010). We also integrate risk aversion into the assessment framework and quantify its effect on crop production choices, contributing to the limited knowledge on the socio-economic dimension of climate change (Di Falco, 2014). Secondly, we combine five regional climate change scenarios to ensure the robustness in choices of crop management portfolios and adaption measures (as suggested by Adger et al, 2008). Thirdly, we provide spatially explicit results that reveal regional differences in agricultural vulnerability at 1 km grid level. Policy and adaptation planning require results at high spatial resolution which are still found to be rare (Lorencová et al., 2013). Furthermore, such results allow us to map the suitability of robust adaptation measures which is a particularly useful communication tool (Dransch et al., 2010). Thus, our investigation may inform policy planning processes to identify priorities for resource allocation.

The article is structured as follows. In section "Vulnerability concepts, drivers, and indicators" we synthesize the conceptual background of agricultural vulnerability and adaptation and provide a conceptual structure for our assessment. In section "Integrated agricultural vulnerability and adaptation assessment framework", we describe the integrated assessment framework which is exemplified on Austrian cropland. In the "Results" section, we present optimal crop production portfolios under climate and policy change as well as the effect of risk aversion levels on portfolio choices. In the "Discussion" we discuss the obtained results and the applied integrated assessment framework and draw conclusions in section "Summary and conclusions".

Vulnerability concepts, drivers, and indicators

There are distinct definitions, concepts, and methodologies to assess agricultural vulnerability to climate change (Hinkel, 2011). They typically differ by discipline, context and purpose of the assessment (O'Brien et al., 2004; Brooks et al., 2005; Adger, 2006; Smit and Wandel, 2006; Ionescu et al., 2009). A broadly cited definition by the Intergovernmental Panel on Climate Change (IPCC) states that vulnerability is "*a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity*" (McCarthy et al., 2001, 995; Parry et al., 2007, 883). There seems to be a general notion that vulnerability to climate change can be assessed in terms of bio-physical