Linking bottom-up and top-down models to analyze climate change impacts on Austrian agriculture

Ökonomische Modellierung der österreichischen Landwirtschaft im Klimawandel

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Summary

Agriculture is among the economic sectors most exposed to climate change. The main objective of this article is to present the interface between a sectoral bottom-up and a Computational General Equilibrium top-down model to analyze impacts and adaptation from four climate simulations at sector and macroeconomic level for 2020 and 2040. Agricultural gross margins increase by ±0% to +3% on average indicating moderate gains from climate change in the next decades. However, gains and losses may vary at regional level, which requires targeting of adaptation measures to specific local contexts. While direct effects in agriculture are relative stronger than knock-on effects to the economy, indirect impacts are clearly stronger in absolute terms.
Keywords: climate change impacts, adaptation, bottom-up land use modeling, computable general equilibrium (CGE) modeling

Zusammenfassung

Die Landwirtschaft zählt zu den klimasensitiven Sektoren und ist mit anderen Sektoren eng verflochten. Dieser Artikel präsentiert eine Schnittstelle zwischen einem ökonomischen Landnutzungsmodell (bottom-up) und einem berechenbaren allgemeinen Gleichgewichtsmodell (top-down) für Österreich, um die sektoralen und gesamtwirtschaftlichen Effekte von vier Klimasimulationen und ausgewählten Anpas-

Erschienen 2013 im *Jahrbuch der Österreichischen Gesellschaft für Agrarökonomie*, Band 22(2): 33-42. On-line verfügbar: http://oega.boku.ac.at.

sungsmaßnahmen für 2020 und 2040 darzustellen. Die landwirtschaftlichen Deckungsbeiträge steigen um durchschnittlich ±0% bis +3% und deuten auf moderate positive Klimaeffekte für die nächsten Jahrzehnte hin. Auf regionaler Ebene sind größere Bandbreiten mit positiven und negativen Effekten zu erwarten, sodass Anpassungsmaßnahmen gezielt nach regionalen Kontexten gesetzt werden sollten. Für die gesamte Volkswirtschaft zeigt sich, dass absolut betrachtet die indirekten Effekte überwiegen, während relativ gesehen die direkten Effekte innerhalb der Landwirtschaft selbst bedeutsamer sind.
Schlagwörter: Klimawandelfolgen, Anpassung, bottom-up Landnutzungsmodellierung, allgemeine Gleichgewichtsmodellierung

1. Introduction

Agriculture is among those economic sectors most exposed to climate change. Its vulnerability, however, is determined not only by exposure in terms of directions and magnitudes of change but also by the options of the sector to adapt to a changing climate. Both, climate change impacts and adaptation measures may be transmitted to other economic sectors either at the intermediary input or sector output level. In order to analyze this cross-cutting nature of climate change impacts and adaptation, an integration of climate, biophysical and economic models seems required. Such approach should consider inter-linkages at high spatial resolution to acknowledge local to regional heterogeneity in climate, bio-physical and farm structural conditions (cf. BRINER et al., 2012) and to transmit climate signals via monetary agricultural input requirements, factor demands, and sector output to the economy.
The literature provides several examples for linking bottom-up sectoral and top-down CGE (Computational General Equilibrium) models or bio-physical and economic land use models. For example, BRITZ and HERTEL (2011) link the partial equilibrium model CAPRI with a GTAP CGE model to analyze effects of the EU biofuel directives on global markets and the economy, but do neither consider climate change nor spatially explicit bio-physical input data. In a global assessment, FISCHER et al. (2005) combine bio-physical modeling with an agricultural sector model to analyze climate change impacts from 1990 to 2080 without considering general economic effects. KOLAND et al. (2012) integrate biophysical impacts from climate change in an economic land

use model and a subsequent CGE model to analyze the effectiveness and general economic effects of mitigation and adaptation measures in the Austrian South-East Styria region.

This article is based on experiences from KOLAND et al. (2012). Its main objective is to present an improved interface and results of a combined bottom-up and top-down modeling approach that allows an assessment of the bio-physical impacts of climate change on agriculture and the corresponding inter-sectoral responses of the Austrian economy.

2. Methods and data

The modeling approach consists of the crop rotation model CropRota (SCHÖNHART et al., 2011), the bio-physical process model EPIC (Environmental Policy Integrated Climate; WILLIAMS, 1995), the sectoral bottom-up land use model PASMA (SCHMID and SINABELL, 2007), and a CGE top-down model for Austria.

EPIC has been applied on homogeneous response units (HRU) and regional climate data (cf. 3. Scenario description) utilizing a rich set of crop management variants including typical crop rotations provided by CropRota and alternative fertilization and irrigation systems. Each HRU is assumed to be homogeneous with respect to soil type, slope, and altitude at a spatial resolution of one to several km². Crop yields from EPIC are averaged over two 20-yrs periods (2011-2030 and 2031-2050) and aggregated to the NUTS-3 level to serve as input to PASMA, an economic land use optimization model for Austrian agriculture. PASMA maximizes total gross margin from land use and livestock activities for all Austrian NUTS-3 regions by applying positive mathematical programming methods. PASMA has its strength in the detailed description of the socio-economic, political and bio-physical systems. It builds on major land use data and statistical sources such as the Integrated Administration and Control System (IACS) and farm survey data. Furthermore, PASMA is made widely consistent with the Economic Accounts of Agriculture (LGR).

PASMA is upward-linked to the CGE model (see Fig. 1), which is a static multi-sectoral (25 sectors) small open economy model based on the GTAP 7 database (GTAP, 2007) and calibrated for 2004. For all types of domestic production activities, nested constant elasticity of substitution (CES) production functions are employed to specify the substitution between primary inputs as well as intermediate energy and material inputs. For major land demanding sectors such as plant production sectors, output results from a low elasticity of substitution (s: 0.1) between land and a non-land composite to acknowledge the fixed factor land. The main advantage of the GTAP database is its broad representation of 12 agricultural sectors and its consistent bilateral trade flows for 113 regions/countries and 57 commodities.

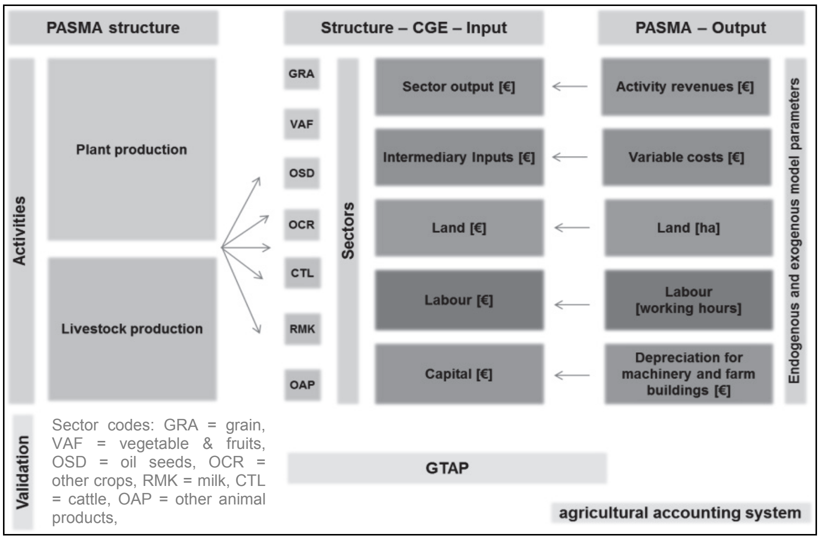

Fig. 1: Interface between the bottom-up land use model PASMA and the top-down CGE model for the Austrian economy
Source: BEDNAR-FRIEDL et al. (2012)

The sectoral concordance between PASMA and the CGE model is established by mapping detailed PASMA model outputs to three livestock and four plant production sectors in the CGE model (see Fig. 1). Moreover, each intermediate input, expressed in variable production costs in PASMA, is matched with one (non-)agricultural sector in the CGE model.

A consistent baseline is built with the CGE model for 2020 and 2040 (targeting the applied 20-yrs periods, see above) with respect to agricultural output levels (including price level adjustments), intermediary input shares in agriculture, land development (resource endowment), and agricultural subsidies (with land-based subsidies in crop sectors and capital-based subsidies in livestock sectors). In the CGE model, three key drivers trigger economic development, namely factor development, multi factor productivity (MFP) growth and autonomous energy efficiency improvements (AEEI) (for details on baseline calibration see BEDNAR-FRIEDL et al., 2012). Consistency in linking variables is also ensured throughout the simulation of scenarios.

3. Scenario Description

Regional climate change is considered with data from four contrasting regional climate models (RCMs; based on ENSEMBLES project, www.ensembles-eu.org) along a precipitation as well as temperature gradient. RCMs are driven by different general circulation models based on the global CO_2 emission scenario SRES A1B (high global economic growth, balanced energy technologies). In the period 2031-2050 and compared to 1991-2010, two RCMs model above median warming for Austria with annual precipitation changes either slightly below (ETHZ_CLM) or above (CNRM_R4.5) the median of all available RCMs. ICTP_RegCM was selected as it meets the median for both criteria, and SMHI_RCA was chosen for resulting in slightly less warming and nearly meeting median precipitation patterns. EPIC simulates climate impacts on crop yields, which are input to PASMA. Consequently, climate change signals are embedded in the PASMA scenario results and passed on to the CGE model.

Business as usual scenarios (BAU) for 2020 and 2040 neglect climate change. The 2020 BAU accounts for expected reforms of the Common Agricultural Policy (CAP) such as the abolition of milk quotas, the transition towards a regional system of decoupled direct payments, greening of the 1st pillar and premium reductions in the 2nd pillar of the CAP. Furthermore, we take declines in agricultural land due to infrastructural development into account. Data on productivity and price developments are drawn from OECD-FAO (2011) forecasts and other literature. For 2040, we assume no changes in CAP, productivity, and prices due to considerable data uncertainties. Regarding adaptation to climate change, two scenarios are distinguished. A first “impact” scenario SZEN1 reproduces BAU with respect to land use and limits adaptation to choices on plant sowing and harvesting dates as well as adjustments of livestock numbers. This mirrors adaptation to annual weather conditions and approximates the economic impacts of climate change on agriculture and its vulnerability. The "autonomous adaptation" scenario (SZEN2) builds on SZEN1. It also allows for shifts in cropping systems (i.e. crop rotation, fertilization, irrigation, and tillage).

4. Results

Figure 2 shows relative changes in the aggregated plant and livestock sector outputs from PASMA. These results are input to the CGE model. Depending on the climate simulation, changes in aggregated agricultural output range from ±0% to +3% in 2020 and from +2% to +5% in 2040 compared to BAU. Disaggregated outputs of individual agricultural sectors in SZEN1 are between -1% and +5% in 2020 and -2% and +8% in 2040. Total agricultural gross margin increases between ±0% and +2% in SZEN1 for the year 2020. Higher grassland yields in the ETHZ_CLM and ICTP_RegCM simulations allow for larger livestock herds and, consequently, increasing livestock production values.

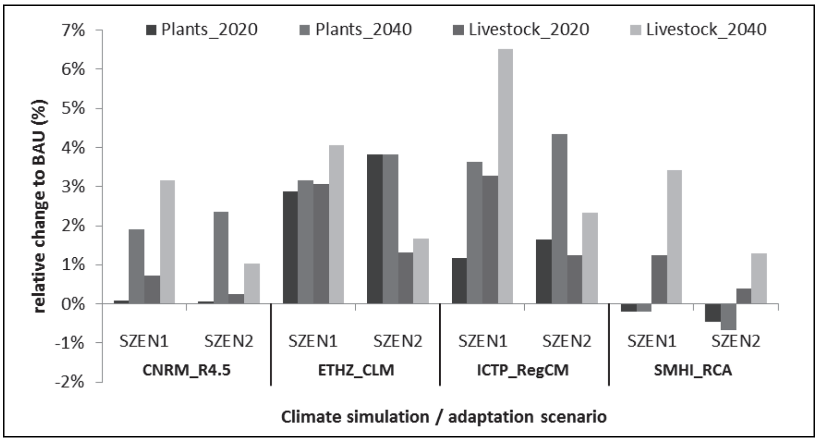

Fig. 2: Changes in agricultural plant and livestock sector outputs between adaptation scenarios (SZEN1 and SZEN2) and BAU for four climate simulations in the years 2020 and 2040 (results from the PASMA model)
Source: Own drawing, 2013

Climate change impacts slightly increase over time such that total gross margins are positive for all four climate simulations ranging from 0% to +3% in the year 2040 on average. Due to income stabilizing effects of subsidies, changes in gross margins including subsidies are about 1%-point higher than those without subsidies.

Increases in production values in SZEN2 are slightly lower and range between ±0% and +2% in 2020 and ±0% and +3% in 2040 depending on the climate simulation. Corresponding outputs among individual agricultural sectors in SZEN2 range between -1% and +6% in 2020 and -2% and +6% in 2040. However, total gross margin increases only marginally compared to SZEN1. In 2040, it is about 1%-point above SZEN1 results at the aggregated national level, indicating only small net-gains from those adaptation measures considered in this study.

Economy-wide and cross-sector effects of climate change impacts are subject to inter-industry dependencies and relative prices on factor and product markets. They are captured by the CGE model. Relative factor prices allocate the use of the production factors land, capital and labor. In BAU, real land prices decline as a consequence of reduced demand for land. Agricultural prices decrease strongest in the sectors vegetable & fruits (VAF) and other crops (OCR) and least in grain (GRA). Foreign trade is depicted by the Armington assumption, according to which price differentials between foreign and domestic products as well as elasticities determine the extent to which goods are traded. Due to the small open economy assumption, foreign prices cannot be influenced by domestic decisions. As a consequence, domestic agricultural prices respond to changed productivity and agricultural policy, leading to shifts in domestic output and imports. Productivity gains in agriculture as experienced through climate change in SZEN1, however, lead to a slight increase in land prices relative to BAU.

The agricultural sectors show strong inter-dependencies as well as upward and downward linkages across the value chain (see Fig. 3). The food sector responds most strongly to impacts in agriculture. It produces intensively with agricultural goods (20% of its production inputs; this amount corresponds to some 68% of total inputs supplied by agriculture within the economy), and is also an important supplier to agriculture (animal feed from residues). In SZEN1, production value in FOOD rises between ±0% (SMHI_RCA) and +1% (ETHZ_CLM and ICTP_RegCM) in 2020 and between +1% (CNRM_R4.5) and +2%

(ICTP_RegCM) in 2040. There are weaker linkages to other yet important sectors in the economy. Positive effects arise for trade (TRD) and services (SEV), while negative effects arise in other industry (NEIS) and energy intensive industry (REIS) due to substitution of demand. Regarding the two periods, cross-sectoral effects (absolute changes to BAU) are generally stronger in 2040 than 2020.

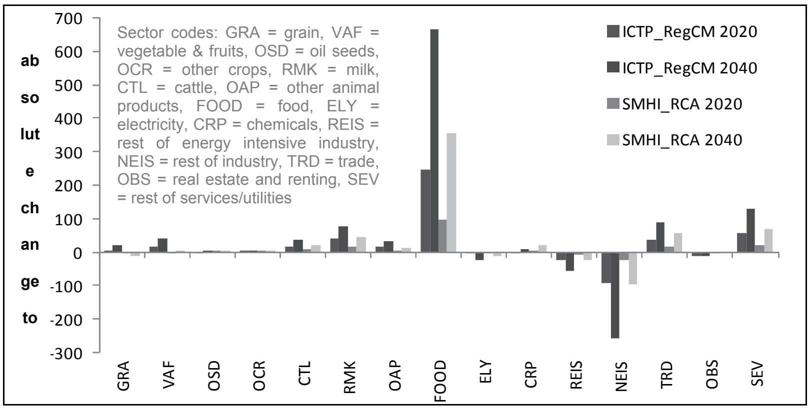

Fig. 3: Climate change impacts (SZEN1) of production quantities for selected sectors and two climate simulations (ICTP_RegCM and SMHI_RCA) for 2020 and 2040 (change to BAU 2020 and 2040, respectively) (results from CGE model)
Source: Own drawing, 2013

5. Discussion and Conclusions

Results of the bottom-up and top-down modeling approach indicate moderate positive impacts from climate change on Austrian agriculture and the economy until 2040, on average. This appears reasonable considering moderate average temperature increases with minor changes in precipitation patterns until 2040. A meta-analysis by IPCC (2007, 286) on crop model results for maize and wheat yields reveals similar impacts for mid to high latitudes. However, several issues must be acknowledged when interpreting our results. The aggregated results conceal that climate change impacts are much more diverse at NUTS-3 level. Further research should focus more on these disaggregated bidirectional effects in order to facilitate farm and policy decisions towards climate change adaptation. However, adaptation in PASMA, as

in any optimization model, builds on predefined activities and therefore may underestimate net-gains from adaptation, e.g. by introducing new crop species. Climate change affects agriculture in multiple ways and only one, i.e. impacts on crop production, has been considered in this study. EPIC data inputs on weather are on a daily basis. It accounts for certain extreme weather events such as early and late frost or dry periods in the growing season, but does not consider hail or extreme precipitation events within a single day. Further issues to be assessed in future studies are impacts of new livestock and plant diseases, climate stress on livestock or changes in market volatility.
Measured in relative changes of sector outputs, directs effects for agriculture are stronger than knock-on effects in the economy. This is evidently due to the fact that agricultural output contributes less than 0.5% to Austrian GDP at production cost in 2004. Yet, in terms of absolute changes, indirect impacts (i.e. knock-on impacts to other sectors) are clearly stronger than direct effects. Among cross-sectoral impacts, the main industry affected from climate change is food. Overall, direct impacts 2020 and 2040 are positive for the agricultural sector. The sum of direct and indirect effects for these time periods remains positive because of favourable spill-over effects into other sectors. Impacts of global change phenomena on international market prices and foreign trade elasticities, however, remain major sources of uncertainty in the results. Assessing the sectoral and macroeconomic effects along the presented modeling chain is helpful in understanding the key triggers for production shifts in agriculture. Compared to e.g. the CAP reform proposals, the consequences from a changing climate appear modest until 2040. Yet the output response is important for food supply and the environment and becomes more pronounced and uncertain in the future.

Acknowledgement

This article results from the research project ADAPT.AT financed by the Climate and Energy Fund within the Austrian "ACRP" Program. We further thank the ReLoClim Research Group at Wegener Center, University of Graz, for providing climate scenarios and anonymous reviewers for their comments on an earlier version of this article.

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