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Global food security & adaptation under crop yield volatility

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ABSTRACT

Climate change projections raise concerns about future food security and needs for adaptation. While a variety of studies quantify and analyze climate change impacts at the level of crop yields, it has been recognized that changes in yield variability may have even more important effects on food security. In addition, large-scale analysis is typically based on different scenarios rather than providing aid to determine decisions that are robust across these scenarios. We develop a stochastic version of a global recursive dynamic partial equilibrium model integrating the agricultural, bio-energy and forestry sectors in order to examine food security under crop yield variability. The results indicate that food security requires overproduction to meet minimum food supply constraints. This does not only lead to higher prices, but also to larger cropped areas associated with an increase in GHG emissions and pressure on biodiversity, as more natural areas are converted to agriculture. Trade liberalization and enhanced irrigation are both found to be promising adaptation channels for food supply stabilization.

1. Introduction

The volatility of food markets mainly stems from relatively inelastic demand and fluctuating supply due to stochastic weather events, uncoordinated policy interventions, and discontinous technological developments. The impact of speculation and increased demand for biofuel feedstock have been a prime research topic for years after the 2008 food price hike (Abbot et al., 2008; Wright, 2010; Gilbert and Morgan, 2010). It is expected that food market volatility will further increase in the medium- to long-run due to adverse climate change impacts on crop production. This has spurred efforts in adaptation research over the past years. A study by Lobell et al. (2008), for example, prioritizes specific crops in particular regions for adaptation. Those crops are assessed by their importance for a region's food-insecure population and their vulnerability to shocks without adaptation. Among other results, they also find that there are many cases exhibiting high uncertainty, i.e. impacts range from highly negative to positive. They explain the finding by those crops' strong dependence on historical rainfalls and the large uncertainty in future changes in precipitation patterns. As the uncertainty differs among crops, this also indicates that different actors might have different priorities depending on their risk preferences. Note that this is in line with findings from ongoing model intercomparison exercises in the agricultural modeling community (Rosenzweig et al., 2013). Other literature on climate change impacts in agriculture includes Lobell et al. (2011), Deryng et al. (2011), Tubiello et al. (2002), Luo (2011), White et al. (2011), Gornall et al. (2010) and Parry et al. (2004), where the focus has so far been on crops while neglecting other sectors such as livestock, which

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are thus surrounded by large uncertainties (Thornton et al., 2009; Vermeulen et al., 2012).

Adaptation mechanisms that have long been deemed promising include the development of new crop varieties that are more robust to drought (e.g. Mutekwa, 2009; Naylor et al., 2007), and irrigation expansion (e.g. Falloon and Betts, 2010; Piao et al., 2010; Verchot et al., 2007). Other adaptation measures discussed in the literature are related to storage or diversification (Thornton et al., 2010). Of course, these measures are rather costly for the producer (Lobell et al., 2008) and, in the absence of higher storage capacity, the focus in the adaptation debate has gradually shifted to trade liberalization, where production shocks in one region would be cushioned by output and trade adjustments in other parts of the world (see e.g. Foresight Report, 2011). While acknowledging that the development of new crop varieties and similar adaptation options are promising strategies, we also realize that they will require substantial time and investment into research and development. These are important areas for future research. However, it would go beyond the aims of this study, which seeks to investigate the impact of crop yield variability on production decisions when food security is prioritized. As our focus is therefore more methodological and we only intend to give an outlook on the possible influence of adaptation, we restrict the analysis to the potential that could be realized through the expansion of irrigation and the removal of trade barriers; we mimick the former by increasing the elasticity of the water supply and the latter by changing trade costs.

While uncertainty analysis in itself is not a new topic in agricultural economics (see e.g. OECD (2009) for a review), there are relatively few attempts to implement such analysis in large-scale models, even though the spread of yields over crop models and climate scenarios is immense (Rosenzweig et al., 2013). In addition, there is currently a lack of analysis of impacts of climate change on socio-economic factors (see e.g. the IFPRI study by Nelson et al. (2009) and the more recent Nelson et al. (2013) for exceptions, where the latter also looks into economic responses to those impacts, and with focus on the livestock sector Havlík et al. (in press)), which this analysis also addresses. Typically, uncertainty is examined through scenarios or sensitivity analysis: Nelson et al. (2010) use the IMPACT partial equilibrium model to investigate drought in South Asia between 2030 and 2035 by letting rain-fed crop areas in Bangladesh, India and Pakistan fall by 2% annually and then return to the baseline. They find a sharp increase in world prices during the drought, e.g. 32% for wheat, leading to an increase in malnutrition. The authors also find that during the drought, the region becomes a net importer for crops that it had previously been exporting, pointing again to the importance of international trade. Similarly, Robinson and Willenbockel (2010) examine a drought in the NAFTA area, China and India using the GLOBE static computable general equilibrium model by simulating a 20% yield drop in the USA, Canada, Mexico, China and India. Again, crop prices rise by up to 40%. Trade can cushion some of this impact, but if an export tax is introduced, crop prices are significantly higher in all regions including those not directly affected by the drought.

While this and other research give a very good impression of the magnitudes involved in impacts, the associated uncertainty and the potential importance of adaptation mechanisms, the aim of this study is to assess the effects of uncertain impacts on production choices. More specifically, rather than optimizing for given scenarios or introducing shocks to a deterministic model in order to observe the response over time, we want to optimize production choices under crop yield volatility. Therefore, our study is better placed with the work by e.g. Beach et al. (2010), Chen and McCarl (2009) and Butt et al. (2004), who extend the objective function of the US forestry and agricultural sector model (FASOM) to include a function of the yield variance. Applying their extended model to the case of Mali, they find that the model incorporating risk outperforms the model without risk consideration when comparing predicted to observed crop area. In this study, we have to restrict ourselves to a relatively stylized approach due to the difficulty that model results become more cumbersome to interpret, if not less meaningful, if we add the variance to the objective function. Therefore, we prefer to examine the impact of risk aversion by observing the differences in choices for different prioritizations of food security. In the first step, we optimize production choices under uncertainty, i.e. maximize the expected value of welfare under different scenarios of yield developments. Subsequently, we observe the implications of the optimal production choice depending on the yield scenario realized, i.e. the outcomes in terms of prices and allocations and the realization of trade for each possible scenario.

The analysis is carried out using the Global Biosphere Management Model (GLOBIOM)[1] (Havlík et al., 2011). GLOBIOM is a global recursive dynamic partial equilibrium bottom-up model aiming to give policy advice on global issues concerning land use competition between the major land-based production sectors. Concept and structure of GLOBIOM are similar to the US Agricultural Sector and Mitigation of Greenhouse Gas (ASMGHG) model (Schneider et al., 2007).

For this study, the world in GLOBIOM is divided into 27 economic regions representing either individual large countries or aggregates of countries. Demand and international trade are represented at the level of these regions. The supply side of the model is based on a detailed disaggregation of land into Simulation Units — clusters of 5 arcmin pixels belonging to the same country, altitude, slope and soil class, and to the same 30 arcmin pixels for climate (Skalský et al., 2008). Crop, forest and short rotation coppice productivity are estimated together with related environmental parameters like greenhouse gas (GHG) budgets or nitrogen leaching, at the level of Simulation Units, either by means of process-based biophysical models, e.g. the Environmental Policy Integrated Climate Model EPIC (Williams, 1995), or by means of downscaling (Kindermann et al., 2008). Changes in the demand on the one hand, and profitability of the different land-based production activities on the other hand, are the major forces of land use change in GLOBIOM.

In this study, we extend the model to investigate the impact of stochasticity on production choices when ensuring food security is an explicit model constraint. The source of stochasticity stems from weather variability and climate change, making it more risky to rely on average yields and thus requiring stochastic optimization techniques. In particular, stochastic crop yields pose a threat to achieving a pre-specified safety level of nutrition.

[1] www.globiom.org.