Stochastic modelling for robust decision-making: The Common Agricultural Policy

Key Messages

- The performance of adaptation options is typically assessed against specific potential outcomes of climate change impacts and not across a range of possible outcomes. In case the specific outcome tested is different from the realized outcome, considerable maladaptation of measures may occur.
- Stochastic modelling can be employed by policymakers to take into account the possibility of adjusting measures over time and thus identify robust measures that perform well across scenarios of future change.
- Stochastic modelling can be employed by policymakers to come up with policy recommendations that ensure food-water-energy-environmental security and stability (sustainability) of systems making them better-off independently of what uncertainty scenario or catastrophic shock materializes.
- In the face of climate change uncertainty and risk, robust adaptation includes two main conceptual types of interdependent decisions: the ex-ante decisions taken before uncertainty is resolved and the ex-post decisions taken when additional information about uncertainty becomes available.
- A stochastic version of the Global Biosphere Management model was developed to examine climate change adaptation measures in the framework of the Common Agricultural Policy.
- It is concluded that robust recommendations enable a more efficient (re)distribution of CAP funds that require less natural resources as compared with scenario-dependent adaptation under the assumption of a shock.
- Agricultural policies are characterized by strong synergies, depend on the location, the agricultural activity, risk exposure, etc. Implementation of agricultural reforms in one region can affect other regions. Thus, introduction of CAP measures, in particular, changing structure of CAP subsidies (i.e., from coupled to direct payments; from historical to flat) can cause changes in production and trade structure, e.g., make EU more import dependent, lead to an increase in terms of demand and cropping area for some regions and crops, whereas they lead to a decrease for other regions and crops.

Context

Traditional economic assessment approaches (e.g. cost-benefit analysis, cost-effectiveness analysis) do not integrate the different kinds of uncertainty and risks related to socio-economic and biophysical development, as well as the effectiveness of implemented adaption options, and do not take the complex interdependencies of different sectors and biophysical processes into account.

More sophisticated assessment methods of costs and benefits of adaptation commonly used for policy impact assessments are Integrated Assessment Models (IAMs). However, most IAMs have so far analysed adaptation as an idealised response to an individual future climate change simulation (even if they repeat these simulations for several times). Thus, deterministic models produce scenario-dependent decisions, which can lead to maladaptation and irreversibilities if other than planned scenario occurs. In contrast, stochastic modeling can help to identify more robust measures which perform well under multiple potential futures.

This Insight presents the application of stochastic modeling to the analysis of robust trade-offs for climate change adaptation in land use systems. The framework can be used by policy makers to derive conclusions regarding aggregate (region and country-specific) implications of climate change and relevant adaptation policies as well as at resolutions specified by case study projects. An illustration is provided using adaptation to climate change in the framework of the EU Common Agricultural Policy.

As a simple example, to highlight the advantages of stochastic modelling and robust decisions compared with the deterministic model solution, consider two crops, A and B, and two scenarios of nature (climate), e.g., a wet and dry season. Crop A is better than crop B in a wet season, and B is better than A in a dry season. At the time planting decisions have to be made, we do not know whether there will be a wet or dry season. In a deterministic scenario-specific model, we would either assume a wet or a dry season, and based on this crop A or crop B is chosen as the optimal production strategy. Therefore, the deterministic approach may result in maladaptation if crop A is planted and dry season occurs (or crop B in case of a wet season). A robust solution may be crop C (or a combination of A and B), which is neither better than crop A in wet or crop B in dry season; however, it is better when faced with uncertainties about the season. Robust solutions may also involve a proper balance between domestic production and imports of shortfalls. Therefore, the set of feasible solutions of the stochastic model is larger and qualitatively different than of the deterministic counterpart.

Robust solutions minimize the costs associated with decisions taken in light of uncertainties as well as the costs of correcting these decisions after information on uncertainties becomes available.

Policy and methodological developments

Land use systems are characterized by complex dependencies at national and international levels. In combination with climate change risks, e.g. shocks to crop yields, they can be easily disrupted, leading to systemic risks, unsustainable development and raising issues for food-water-energy-environmental security. Without properly accounting for these interdependencies, uncertainties, and systemic risks, policy measures might not lead to the most efficient way of supporting adaptation of farmers to climate change.

Several IAMs have already been used to evaluate the impacts of climate change on land use systems, e.g. IMPACT, ENVISAGE, GCAM, GLOBIOM, GTEM, MAGNET, MAgPIE, AIM, etc. The Global Biosphere Management (GLOBIOM) in particular is a well-established global recursive-dynamic, partial-equilibrium model running at the level of major countries and world regions. The model integrates the agricultural, bioenergy, and forestry sectors allowing for policy analysis on global and regional issues concerning land use competition and land use transformations driven by increasing demands for food, feed, water, and biofuels. The main land uses distinguished are crop land, grass land, forest (managed and non-managed) land, short-rotation forest plantations, and other natural land.

The standard version of GLOBIOM (as well as other IAMs) uses a scenario-by-scenario analysis of potential climatic shocks to derive scenario-dependent policy advice regarding adaptation measures, which may lead to maladaptation and irreversibilities.

A stochastic version of GLOBIOM is based on the principles of a two-stage (two types of decisions) stochastic optimisation framework. It allows to take a multitude of scenarios and uncertainties into account. Stochastic GLOBIOM enables coherent analysis of trade-offs between ex-ante measures (taken in front of uncertainties) and ex-post measures (helping to adjust initial decisions after learning additional information).

In stochastic GLOBIOM systemic risks are characterized by the entire structure of the systems including distributions of risks shaped exogenously and endogenously by decisions of agents, costs structure, market prices, technologies, security constraints characterized by critical quantiles, Value-at-Risk (VaR) and Conditional Value-at-Risk (CVaR) risk measures, and feasible decisions of agents. The model incorporates stochastic representation of crop yields facilitating analysis of induced systemic risks on crop production and food, energy, and water provision. Stochastic GLOBIOM is capable of treating cascading events in interdependent climate-agriculture-energy systems, e.g. a shock to corn production possibly leading to a deficit of important feedstocks for biofuels. To meet the biofuel targets, corn may be substituted by a costlier feedstock, for example, wheat, that would divert wheat from direct food and feed consumption, raising the prices both for biofuels and crops (for food and feed). That may, in turn, intensify production, destabilize market flows, and require additional storage capacities and trading possibilities. Stochastic GLOBIOM can be applied to designing robust land allocation, trade and storage decisions ensuring food, energy, water, environment security (FEWES) under systemic risks. Many countries and regions often implement strict market strategies, e.g. bans, which in the presence of climate change risks will stimulate price increase, food insecurity, and instability in other systems. Stochastic GLOBIOM may serve as a tool for revealing and relaxing such “bottle necks” (tight dependencies) causing systemic risks in land use systems.

Exposure to production and market risks motivates the reliance on domestic grain storages to smooth consumption and lower prices. This happens especially in the presence of systemic risks when production shocks may be correlated across trade partners or/and if some markets are isolated or tightened by constraints and regulations, i.e., bans, subsidies, biofuel mandates, etc. Storages may prevent from undertaking costly investments, e.g., in irrigation capacities.

The stochastic GLOBIOM permits designing robust combination of strategic (e.g. land management) and operational (e.g. trades and storages) decisions within one common modeling framework. Endogenous demand, price, trade, storage decisions are computed at the country level and/or aggregated world regions, while decisions on production and land use allocation among management systems are taken at the level of simulation units of about 50 km2 resolution.

At the level of EU, stochastic GLOBIOM allows for investigation of the effects of different CAP measures, both individually and combined (see Illustration below). In particular, in Deliverable 7.3 it was used to investigate the effects of different Pillar 1 payment schemes and derive a robust one based on the combination of economic, social, agricultural and risk (security) principles. Using calculations of geographically-detailed “profiles” of risk-adjusted production and prices derived from stochastic GLOBIOM, we defined the so-called robust CAP policy mixes based on the estimated demand for storages in different locations and analyze the effects of storages on demand, price, land conversion, water consumption, etc.

Illustration: Using stochastic modelling for increasing the robustness of the EU Common Agricultural Policy (CAP)

The stochastic GLOBIOM was applied to compare synergies and trade-offs between structural policy measures (costly, often irreversible, that can imply high sunk costs and lock-in situations, e.g. investments in irrigation systems, food/feed storage capacities) and non-structural measures (measures that can be reversed or adjusted for on short notice, such as payments per hectare) in the CAP.

Results indicate that robust policy making can save a considerable amount of maladaptation compared with investments into adaptation projects appraised using scenario-by-scenario deterministic analysis. For example, under a deterministic scenario, an extreme shock may lead to a large uptake in cropland, which may imply large irreversible costs. By taking into account years with good and bad yields, the stochastic model provides a middle way in terms of uptake of cropland between an average yield deterministic model and an extreme shock deterministic model.

Strong synergies and trade-offs between non-structural and structural measures were found. In some regions, the introduction of rather moderate grain storages can not only increase adaptive capacity towards climatic shocks, but also decrease water demand, save investments into irrigation expansion, stabilize profits and thereby decrease the demand for income support.

The study also indicates that policy measures may substitute each other; hence, the adoption of one policy reduces the need for other policies. Under a scenario of robust subsidies combined with storage facilities, irrigated area decreases by about 6% compared to the case without storages.

Furthermore, the effects of agricultural policies are interdependent and depend on the location, the agricultural activity, risk exposure, etc. Direct payments lead to an increase in terms of demand and cropping area for some regions and crops, whereas they lead to a decrease for other regions and crops. Moreover, effects differ when analyzing direct payments alone or together with other policy measures such as storage capacities. The clearest example here is the demand for irrigated land. The demand for irrigated land reduces when direct payments and storage facilities are provided. Hence, different policy measures may act as substitutes in different regions.

Main implications and recommendations

Decision making in front of uncertainties requires two types of interdependent measures – long-term strategic, taken ex-ante in front of uncertainties without knowing real state of nature, and operational ex-post measures, taken to adjust initial decisions when additional information on uncertainties becomes available. While traditional approaches are able to evaluate either ex-ante or ex-post decisions, stochastic modeling allows for the evaluation of these interdependent decisions simultaneously.

The modeling framework presented in this Insight (stochastic GLOBIOM as an example of a stochastic IAM) allows for the spatio-temporal assessment of impacts and adaptation policies at both national and regional levels, in both the medium and long term. The model can help derive robust policy recommendations to increase the stability of land use systems and reduce the cost of adaptation

There are, however, some limitations to the framework presented. The model outlined focuses only on land use systems, though this could be remedied through effective linkage with other sectoral models, but this would require additionally methodologies and algorithms. The model only incorporates yield stochastically, though could be extended to include more generators of uncertainty scenarios, such as costs, resource availability. Additionally, further improvement on the representation of and agricultural policies can be made. Lastly, sensitivity analysis on the assumptions made could provide additional insights on the results obtained.

Further Information
Report on major uncertainties related to climate impacts and socio-economic costs, and policy recommendations related to the eff
Integrated management of land use systems under systemic risks and security targets

Contact
Tatiana Ermolieva
Esther Boere

Partner
International Institute of Applied Systems Analysis (IIASA)
Agricultural University of Athens
Potsdam Institute for Climate Impact Research (PIK)
Wageningen University