Chapter 2

Cross-Sectoral Challenges for Adaptation Modelling

Asbjørn Aaheim, Anton Orlov, and Jana Sillmann

Abstract Socioeconomic studies on adaptation based on bottom-up approaches have been focusing mainly on local impacts of weather-related variations, thereby neglecting potential remote impacts. There is little knowledge about challenges that relate to the global and long-term character of climate change. By contrast, impact assessment studies using top-down approaches, such as multi-region, multi-sector computable general equilibrium (CGE) models, provide a consistent framework to capture potential remote impacts, which occur through cross-sectoral and cross-regional interactions. Here we present main findings of our economic impact assessments of climate change and adaption modelling. Furthermore, we discuss the challenges for incorporating adaptation measures and policies into macroeconomic models.

Keywords Adaptation · Impacts of climate change · Macroeconomic modelling · Cross-sectoral interactions

Introduction

Most economic studies on climate adaptation focus primarily on local impacts of climate change on people, companies, and local authorities, whereas potential remote impacts are typically not considered. Attempts to consistently integrate lessons from studies of impacts and adaptation in a model that addresses cross-sectoral impacts indicate how important interdependencies across sectors are, but they also reveal knowledge gaps related to implementing measures to motivate adaptation across levels. Economic theory provides a formal link between descriptions of individual behaviour and economic drivers on the national level. This is the idea behind the macroeconomic model GRACE, which is based on a standard description of relationships between economic activities in countries and describes how they depend on the activities in other countries (Aaheim et al. 2018). The framework of GRACE enables

A. Aaheim · A. Orlov · J. Sillmann (✉)
CICERO Center for International Climate Research, Oslo, Norway
e-mail: jana.sillmann@cicero.oslo.no

to depict cross-sectoral and cross-regional interactions and to integrate lessons from the research on adaptation to project economic development. Moreover, the flexible and consistent modelling framework of GRACE can be used to assess the trade-offs between climate change mitigation and adaptation policies. In the following, we briefly describe the GRACE model as adaptation modelling tool (Sect. “[The Grace Model](#)”) and then give several examples of studies where the GRACE model is applied to different sectors (Sect. “[Implications of National and Global Dependencies in Adaptation](#)”). In Sect. “[Challenges for Adaptation Modelling](#)”, we discuss challenges and opportunities for complementing bottom-up with top-down approaches in adaptation modelling.

The Grace Model

GRACE is a global computable general equilibrium model, which uses data from the national accounts, collected by GTAP (Global Trade Analysis Project) data base (Aguilar et al. 2019). The data give values of deliveries from production sectors to other production sectors and to the final consumption. These are illustrated by the two upper grey boxes in Fig. 2.1. Production of goods and services require input of intermediates, labour, capital, and natural resources. Total input in each production sector as well as the composite of goods for consumption and investments can be read from the columns (red line), while the rows divide total demand for each sector product on other sectors and final deliveries (green line). The demand for each good is divided into domestic demand and demand from the other regions. The regional and sectoral aggregation is flexible depending on the scope and focus of a study. The GTAP database is used to calibrate the demand and production systems in the model. They thereby provide supply and demand functions (curves on the right), and the model finds the combination of prices and quantities under the assumption of market

Fig. 2.1 Structure of GRACE

equilibrium, where supply equals demand. Economic growth is driven by underlying changes in population (labour force), capital (investments and technological change), availability of natural resources and impacts of climate change.

There are two main types of adaptation in GRACE related to i) adaptation in production and ii) adaptation in consumption. The former one refers to the substitutability among production inputs (e.g., labour, capital, and natural resources, including land) to achieve a certain level of production. Furthermore, cross-regional and cross-sectoral mobility of labour and capital are another channel of adaptation in production. The latter one deals with the substitutability between imported and domestically produced goods and services as well as substitutability among different commodities in final consumption.

Implications of National and Global Dependencies in Adaptation

GRACE provides an opportunity to utilize knowledge on mitigation options and physical impacts of climate change to assess the global consequences on standardized, economic indicators for evaluation of the economic development in countries and regions. The GRACE model confirms that without mitigation policies, the impacts of climate change on economies can be large, which implies high costs of adaptation. For instance, Aaheim et al. (2017b) addressed the economic consequences of mitigating climate change by reducing emissions from a high-emission pathway that leads to an increase in global mean temperature between 5.0 and 6.0 °C (RCP8.5) to approximately 3.0 °C in a moderate emission pathway (RCP4.5) in 2100. The mitigation alternative (i.e., RCP4.5) gives moderate costs in some regions and small benefits in others. A high-emission pathway (i.e., RCP8.5), on the other hand, implies huge costs in all regions, occurring mainly after 2070. The explanation to the moderate impacts in both alternatives in the coming decades is adaptation among economic agents with resulting price effects with impacts on sector composites and trade. The potential for this adaptation is limited, however, as becomes apparent under stronger impacts associated with high emissions.

The study shows that RCP4.5 may represent an optimal, global strategy, as it leads to a stabilization of climate change impacts in the long term. At the same time, it illustrates the challenges in achieving the “best solution for future generations”, as the policy needed to achieve a 3.0 °C target implies an increase in the cost of emitting a ton of CO₂ at 12—15 percent per year from 2010 to 2075, according to this study. This is far beyond the shadow costs of cutting emission today, despite the ambitions in the Paris Agreement. The model is further developed with the aim of specifying economic activities that will be affected directly by climate measures or impacts of climate change. Some examples are given below.

Table 2.1 Impacts of climate change (in Bill US\$) expected in 2100 on the value added from forests world-wide with and without adaptation in three emission scenarios (RCPs, van Vuuren et al. 2011) and three adaptation scenarios

	RCP2.6	RCP4.5	RCP8.5
No adaption	−1.8	−1.5	−2.5
Adaption in forest management	7.5	5.2	8.0
Adaption in management and harvesting	28.7	17.4	26.4

Adaptation in the Forestry Sector and the Global Impacts

Aaheim and Wei (2020) estimate the economic consequences of climate change on the biomass in forests in 27 countries in the world under different emission scenarios based on the physical estimates, which included adaptation in the utilization of forests and resulting market effects. They use the GRACE model with a modified module for forest management, where the standing biomass is interpreted as wealth, similar to the stock of capital, and the harvesting is interpreted as the return of this wealth. The estimates were further presented with three alternative scenarios of “economic impacts” (see Table 2.1). The first scenario reveals the economic cost of the impact on the growth of the biomass, if there are no price effects or any adaptation. The second scenario shows the impact on the value of harvested wood after adaptation to the new relationship between the growth and stock of biomass and to the market effects of the impacts in world markets. The third scenario shows the impact on the value added in the forestry sectors, where adaptation takes place also in the harvesting of forests, reflected by the production functions in the model. Examples are to leave less wood for waste, to improve the transport network or to harvest less accessible parts within an area.

If based on the physical assessment alone, climate change leads to a reduction in the value added from forests world-wide. This is partly due to the variations in value added across regions, where the growth of forests is negatively affected in regions with a high value added. Under the ‘No adaptation’ scenario, the physical effects on forests are negative in all RCPs. Price effects and resulting adaptation related to the management turns the impacts on the value of forests positive, however. In addition, adaptation related to the harvesting implies that the forestry sectors will benefit from getting more out of each m³ harvested. This further increases the positive economic impacts. It must be noted that the impacts vary a lot across regions and in the different RCPs. In some regions, the value of forests decreases under RCP2.6 and RCP4.5.

Adaptation from a Local Perspective and the National Impacts

In general, there are two approaches to assess the impacts of climate change, such as bottom-up and top-down. The former one addresses local impacts on

households, farmers, companies, and local authorities. The latter one deals with a broader (macroeconomic) implications of climate impacts. Both approaches have their strengths and weaknesses. Aaheim et al. (2018) provided a consistency check in assessments of economic impacts of climate change on aggregated levels with local studies of impacts and adaptation among smallholders in Nepal up to 2050 under a high emission pathway (RCP8.5). The impact to the Nepalese economy is assessed with the basic version of GRACE, where the impacts to agriculture are quantified based on a meta study of estimates from different integrated assessment models. It is assumed that the productivity of land will be reduced by 2.7 percent in 2050 on average for Nepal.

To address the vulnerability of smallholders, the study also includes an assessment of the impacts to farmers in a local community. Descriptions of the sources of livelihood among smallholders (e.g., consumption of own produced goods, products bought in market and work time spent on own farm and outside the farm) were collected from interviews of 60 households in Bamrang Khola village in Khotang district of Nepal (Aaheim et al. 2017a). The data were used to analyse how the economic behaviour described on the macro level depends on constraints that are ignored in GRACE. First, the output is constrained by the size of the farm. Second, there is a division between food products sold in markets and food for the farmers' own consumption. Third, farmers can work outside the farm to gain monetary income. Hence, their consumption is partly based on market transactions.

The impacts of climate change refer to the projection for Bamrang Khola in the climate projection for Nepal used in the macroeconomic analysis indicating a reduction in the productivity of land at two percent and health effects, which reduces the productivity of work by 2.4 percent. Because of the inability to take full advantage of the price effects indicated by the macroeconomic analysis, the study of the impacts to the local households gives a very different picture of the vulnerability of people in the agricultural sector in Nepal than what comes out of the macroeconomic analysis. The impacts differ also depending on the size of the farms disposed by the different households.

The message from this study is, firstly, that the constraints related to the farm size puts strong limitations to adaptation in most of the farms. Most of the households are subject to constraints that enforce a notable reduction in work on the farm, which can be compensated only by a slight increase in monetary income needed to compensate losses in the production of food from farm with food and other goods from the market. These impacts are disregarded in the macroeconomic assessment. The second message is the difference between the estimated impacts on the Nepalese economy in the macroeconomic assessment and the impacts to households in the micro-based assessment, despite the attempt to base both on the same description of the future. While GDP and consumption are reduced by approximately 0.25 percent in Nepal according to the macroeconomic analysis, sources of livelihood for most of the smallholders are reduced by more than two percent, depending on the size of the farm, according to the household study. There are possible explanations to this, which need to be confirmed by further studies. This points to the need for a

better understanding of how climate change affect parts of societies, and the most vulnerable, to coordinate targeted adaptation strategies across levels.

Adaptation to Heat Stress

Orlov et al. (2020) conducted an economic impact assessment of heat-induced impacts on worker productivity under RCP2.6 and RCP8.5. The authors implement autonomous adaptation in the GRACE model, such as penetration of air conditioners and mechanization of outdoor work in agriculture and construction, which were linked to different SSPs. Projections of mechanization for different SSPs were extrapolated based on a regression analysis, where the number of tractors per hectare was used as a proxy for mechanization and GDP per capita as an explanatory variable. Results from model simulations showed that under RCP8.5 by 2100, heat-induced reductions in worker productivity lead to an average decline of 1.4% in GDP relative to the reference scenario with no climate change (see Fig. 2.2). This is approximately 0.4 percentage points less than when no autonomous mechanization is assumed.

Fig. 2.2 Changes in global GDP under RCP2.6 and RCP8.5 compared to the reference scenario with no climate change. The solid and dashed lines show the mean values and the shaded areas indicate uncertainties in the estimated impacts. In the plot legend, “mechanization” (solid lines) stands for decreasing work intensity due to mechanization driven by an economic growth, while “no mechanization” (dashed lines) implies a constant work intensity. “Hothaps” stands for the epidemiological exposure–response function, while “ISO” implies that ISO: 7243:1989 standards are used to assess heat stress impacts on worker productivity

Challenges for Adaptation Modelling

Drawing from the results of above presented studies, we emphasise the importance of adaption measures and policies to deal with adverse climate-induced impacts. We find that adaptation plays a key role in diminishing adverse impacts of climate change. Furthermore, we identify several challenges for incorporating adaptation into global macroeconomic models. While most of local studies on adaptation using bottom-up modelling approaches neglect potential remote impacts, top-down economic models, such as CGE models, feature great macroeconomic consistency and can capture cross-sectoral and cross-regional interactions. However, due to modelling complexity, multi-region multi-sector macroeconomic models are very aggregated and underly simplified assumptions. Often, market-related barriers and inertia are not implemented in those models, which might lead to an underestimation of economic costs arising from climate change. The studies presented above indicate that the impacts to countries and to national economies may differ substantially from the conclusions drawn from bottom-up approaches. On the other hand, the generalizations used to address impacts and adaptation on a national level in top-down approaches have a weak empirical foundation in most cases. The examples above show the potential for improving the linkages, for instance, by informing the top-down modelling by refining the modelling assumptions or damage functions with local insights from interviews or field experiments. There is a need for a better integration of results and methodology from local studies on climate impacts and adaptation into a broader framework of macroeconomic models to provide more consistent and accurate impact assessments. And vice versa, local studies based on bottom-up methods might greatly benefit from insights obtained from top-down analyses, which can set some boundary conditions including indirect cross-sectoral and cross-regional economic responses. Therefore, there is a big potential in the complementarity of top-down and bottom-up approaches, which is not yet fully realised. To bridge the top-down/bottom-up divide in adaptation modelling, more interdisciplinary studies involving the combination of two approaches are needed. Also, the involvement of stakeholders and decision-makers is vital to better understand challenges for adaptation planning in practice.

Moreover, many adaptation measures are implemented autonomously in CGE models, which means that the implementation of adaptation measures depends on the assumed socioeconomic scenarios (e.g., SSPs), and these are not a part of optimisation in the model (i.e., no proactive adaptation). Adequate representation of extreme events in models based on national aggregates with annual data, and the sensitivity to the variability of impacts within countries in the national aggregates can further improve CGE modelling. Finally, most of the large-scale CGE models applied for impact assessments of climate change are either static or recursive-dynamic, which implies that consumers and producers make their decisions based on current prices, whereas anticipatory adaptation might play a big role in reducing the future economic cost of climate change. Therefore, a better integration of proactive adaptation under uncertainties into macroeconomic models is needed.

Acknowledgements The authors are supported by the European Union's Horizon 2020 research and innovation programme under grant agreement No 820655 (EXHAUSTION) and No 820712 (RECEIPT).

References

- Aaheim A, Orlov A, Dhakal K (2017a) Socio-economic impacts of climate change in Hindu-Kush Himalaya, CICERO Report 2017:07. CICERO Oslo
- Aaheim A, Wei T, Romstad B (2017b) Conflicts of economic interests by limiting global warming to +3 °C. *Mitig Adapt Strat Glob Change* 22(8):1131–1148. <https://doi.org/10.1007/s11027-016-9718-8>
- Aaheim A, Orlov A, Wei T, Glomsrød S (2018) GRACE model and application, CICERO Report 2018:1. CICERO, Oslo
- Aaheim A, Wei T (2020) Relationships between physical effects of climate change on forests and economic impacts by world region, CICERO Report 2020:02. CICERO, Oslo
- Aguiar A, Chepeliev M, Corong EL, McDougall R, van der Mensbrugghe D (2019) The GTAP data base: Versions 10, *J Glob Econ Anal* 4(1):1–27. <https://doi.org/10.21642/JGEA.040101AF>
- Orlov A, Sillmann J, Aunan K, Kjellstrom T, Aaheim A (2020) Economic costs of heat-induced reductions in worker productivity due to global warming. *Glob Environ Chang* 63. <https://doi.org/10.1016/j.gloenvcha.2020.102087>
- van Vuuren DP, Edmonds J, Kainuma M et al (2011) The representative concentration pathways: an overview. *Clim Change* 109:5. <https://doi.org/10.1007/s10584-011-0148-z>

Open Access This chapter is licensed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.