Chapter 1

Modelling the Cost and Benefits of Adaptation. A Targeted Review on Integrated Assessment Models with a Special Focus on Adaptation Modelling

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Abstract This paper gives a targeted review on Integrated Assessment Models (IAMs) with a focus on damage functions and adaptation modelling.

Keywords Adaptation modelling · IAMs

Introduction

Integrated Assessment Models (IAMs) can be roughly distinguished according to their objective as cross-sectoral optimization models (POMs) and economic assessment of climate policies (PEMs) according to Toth (2005). The first are welfare-oriented optimal growth or general equilibrium models; the second are numerical simulation models for the cost minimization of climate policies in a partial or—also—a general equilibrium framework. The most popular models can be grouped according to this structure as in Table 1.1.

An evolutionary “family research” of IAMs helps to identify “generations” of models, where each generation enhanced the scientific understanding of climate change and influenced the economic recommendations for climate policy based on these models.

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Table 1.1 Types of IAMs

IAMs: Integrated Assessment Models						
POMs: Cross-sectoral policy optimization				PEMs: Policy Evaluation		
Welfare optimization		CGE: General Equilibrium		PE: Partial Eq.	Cost minimization	
Optimal Growth			Numerical Simulation			
FUND, ...	DICE, RICE, ENTICE, WITCH, MIND, ...	MERGE, WIAGEM	Mini-CAM, LPJmL, CAPRI	PAGE-2009		M E S S A G E

The first generation of models was developed in the 1990s as “basic models” that integrated climate modules and economic modules in one model. They all went through a period of “learning by doing” than “learning by investment”, in short, they adsorbed endogenous growth theories that improved our understanding of the economic opportunities of a stringent climate policy, and ultimately shifted the ‘optimal’ or ‘cost-efficient’ policy paths towards demanding more and faster action against climate change. It was followed by a phase of learning on adaptation, often blended with geo-engineering which is the focus of this paper.

Effect-wise more important than all earlier are the two most recent generations of IAMs, which introduced climate catastrophes, economically speaking “fat tails” of climate risks, and the trend toward MIMI models, i.e. modularized, open source-based IAMs, which aim to overcome the popular criticism of a lack of transparency and black box-approaches of IAMs.

Figure 1.1 illustrates that not all model families have survived this process of “aging” and “learning”, those that survived, re-acted to the scientific and societal critic by transformation.

Adaptation modelling challenges ahead.

Climate change impacts can be lowered by a variety of sectoral, regional and local adaptation measures. Including those in the damage function is a complex task for the following reasons:

- There are many climate-sensitive sectors each of which has specific adaptation measures, with respective costs and benefits in the short term and the long term. Especially for high temperatures, the benefits of adaption are highly uncertain (Fankhauser 2017).
- The extent and success of adaptation depends on the vulnerabilities and capabilities of regions and societies. Consider the example of the Netherlands and Bangladesh: Both will be highly affected by sea level rise, but the Netherlands is more able to handle such consequences, as the country is richer and has a long tradition of building sophisticated dikes. Damages will rise steeply if the adaptation capabilities of the affected societies are exceeded (Klein et al. 2008).
- The extent and form of adaptation is a choice by individuals and society. These choices may be modelled using a cost–benefit approach. Yet, information on

Fig. 1.1 History of IAMs

adaptation costs is scarce and local damages are uncertain. The literature on the costs and benefits of adaptation mainly considers coastal areas and agriculture.

IAMs dealing with adaptation.

Adaptation is incorporated in IAMs in very different ways (cp. Table 1.2):

- DICE considers adaptation implicitly. That is, the aggregate damage already includes the costs and benefits of adaptation (it is a “net” aggregate damage function). AD-DICE (de Bruin et al. 2009a, b) is an extension to DICE that explicitly considers adaptation. It disaggregates the damage function into adaptation costs and residual damages and selects a preferred combination of mitigation and adaptation.
- FUND introduces adaption for certain sectors explicitly. It includes an explicit cost–benefit analysis of costly coastal protection against sea level rise and assumes that parts of the agricultural damages (associated with the rate of climate change) fade with time at zero costs (autonomous adaptation). For other sectors, adaptation is implicit as in DICE (Diaz and Moore 2017; Estrada et al. 2019).
- PAGE introduces a tolerable temperature that increases with costly adaption measures. Damages are a function of the difference between the real and the tolerable temperature, such that, e.g. a real temperature increase of one degree without adaption causes the same damages as a real temperature increase of three degrees in case adaption has risen the tolerable temperature to two degrees.
- ICAM, MERGE and IMAGE consider geoengineering as an extreme form of adaptation, but at a different degree: some only as the carbon capture and storage (CCS), some also with CO₂ removal (CDR) in different forms. To our knowledge, there is no IAM that would consider solar radiation management or ocean fertilization.

Table 1.2 Adaptation modelling approaches properties of IAMs (POMs)

Model	Regions	Damage function	Adaptation / Geoengineering
DICE (DICE- 2013R)	Global	Linear-quadratic	Implicit
RICE (RICE- 2010)	12	Quadratic, region-specific	Implicit
FEEM-RICE 10	10	Quadratic, region-specific	Implicit
ENTICE	Global	Linear-quadratic	Implicit
AD-DICE	Global	Linear-quadratic	Explicit; reactive adaptation
AD-RICE	12	Quadratic, region-specific	Explicit; reactive adaptation
FUND 3.9	16	Complex, different damage functions (8 sectoral DF for each region)	Implicit
WITCH	12	Quadratic, region-specific	Implicit
MERGE-ETL	Flexible	Quadratic, considers catastrophes	Implicit/Geo-Engineering (CCS, CDR)

Note CB-IAM = Cost–Benefit Integrated Assessment Model CB-IAM weighs mitigation costs against the benefits of reducing climate damages within one model. POM = Policy-optimizing models or fully integrated IAMs (Toth 2005)

There are similar differentiations of concepts of adaptation in PEMs.
Properties of IAMs (PEMs).

Model	Regions	Damage function	Adaptation / Geoengineering
ICAM	17	Complex	Implicit/Geo-Engineering (CDR, SRM)
PAGE09	8	Power function with uncertain exponent; considers catastrophes	Explicit; pro-active adaptation
IMAGE 3.0	26	Complex, biophysical feedbacks	Implicit (adaptation potential); soft-linking to GLOFRIS/FAIR / Geo-Engineering (CCS, CDR)

Note CE-IAM only assesses mitigation costs for a predefined mitigation target. More specifically, it calculates the most cost-effective (i.e. least-cost) way. PEM = Policy-evaluation models (Toth 2005).

- Adaptation measures can be further separated into measures that act quickly (e.g. air conditioning) as well as precautionary measures (usually infrastructure with a longlife-span) as in Fankhauser (2017). The latter is aimed at average climate change (better insulation of houses against the increase in summer temperatures) or at protecting against extreme events (e.g. dikes against floods).
- Auffhammer (2018) defines extensive and intensive margin adaptation. The extensive margin response is due to the installation of new equipment (e.g. new air

conditioning systems, irrigation equipment, sea walls, etc.). The intensive margin response means that existing equipment is used more frequently (the more frequent operation of existing air conditioners and irrigation equipment).

- Finally, the IPCC differentiates between adjustment costs (short-term costs of adaptation) and macro-scale adaptation (long-term restructuring of the economy). To correctly model the costs and benefits of adaptation all those different forms of adaptation have to be taken into account.

A special difficulty arises because adaptation costs can be seen as indirect damage costs. IAMs thus often blur the difference between direct damages (e.g. destructions caused by storms) and adaptation costs. In FUND, for example, the increasing energy cost of air conditioning is major damage sector, even though strictly speaking this is an adaptation measure. The corresponding decrease in damages (improved health) is not considered in FUND, even though a health sector exists. This obviously leads to an underestimation of the benefits of adaptation.

Another difficulty arises from the fact that the capacity for adaptation is a main defining element, and thus already explicitly considered for the SSPs. For example, in SSP1 and SSP5 the capacity to adapt is high, as there is a well-educated, rich population and a high development of technologies. In SSP1, there is in addition a good global governance and an intact ecosystem. In SSP3 and SSP4, on the other hand, the capacity is low due to the large, poor population, the lack of global cooperation, a slow technological development and unequal distribution of resources. These features have not yet been included in the damage functions in a harmonized manner.

Conclusions and Recommendation

To summarize, IAMs include adaptation explicitly (i.e. conducting a cost–benefit analysis of adaptation measures), implicitly (i.e. damage function is net of adaptation) or occurring autonomously (impacts fade at zero cost). In any case, these are highly aggregated approaches that do not consider the variety of adaptation possibilities at the local, regional and sectoral level. If at all, IAMs make very rough and ad-hoc assumptions on adaptation costs and benefits and do not include technological details. The understanding of (future) adaptive capacity, particularly in developing countries, through IAMs is still limited (Watkiss 2011). The extent and success of adaptation depends on the vulnerabilities and capabilities of regions and societies. In the face of all these shortcomings our recommendation, however, is not to give up on IAMs but to go through another phase of “aging and learning” of adaptation models that better fit to the heterogeneity of adaptation measures.

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