THE FISCAL IMPLICATIONS OF CLIMATE CHANGE ADAPTATION

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PART I

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Contents

List of abbreviations

A	Adaptation (in mathematical formulas)
ADAM	Adaptation and Mitigation Strategies: Supporting European Climate Policy (a research project under the 6th Framework Programme)
AT	Austria
AWG	Working Group on Ageing Population and Sustainability
B	Benefits (the mathematical function)
BE	Belgium
BG	Bulgaria
AD-DICE model	A modification of the DICE model (see below) that takes into account adaptation to climate change
BAU	Business as usual
BLOC	Backing, loss sharing, open and central & uniform
C	Costs (the mathematical function)
CAP	Common agricultural policy
CBS	Cost-benefit analysis
CCS	Carbon capture and storage/sequestration
CGE	Computable general equilibrium
CO_2	Carbon dioxide
CY	Cyprus
CZ	Czech Republic
D	Damages from climate change (in mathematical formulas)
DE	Germany
DG	Directorate-General of the European Commission
DICE model	Dynamic Integrated model of Climate and the Economy
DK	Denmark
E	A negative externality – a cost that must be borne by others (in mathematical formulas)
EE	Estonia
EEA	European Environment Agency
EL	Greece
ES	Spain
EPC	Economic Policy Committee
ESV	*Elementarschadensversicherung* [supplementary natural hazard insurance]
EU	European Union
EU25	The EU member states until the end of 2006 (excluding the current members Bulgaria and Romania)
EU ETS	EU Emissions Trading Scheme
EUSF	EU Solidarity Fund
FOC	First order condition
FI	Finland
FINSKEN	A regional climate model for Finland

FR	France
G8	Group of eight (France, Germany, Italy, Japan, the United Kingdom, and the United States, Canada and Russia)
G5	A group of emerging countries consisting of Brazil, China, India, Mexico and South Africa
GDP	Gross domestic product
GDV	German Insurance Association
GHG	Greenhouse gas
GRACE	A general equilibrium model used in ADAM
HU	Hungary
IE	Ireland
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IT	Italy
JRC	Joint Research Centre of the European Commission
LV	Latvia
LT	Lithuania
LU	Luxembourg
M	Maintenance costs (in mathematical formulas)
MC	Marginal costs (in mathematical formulas)
MB	Marginal benefit (in mathematical formulas)
MNP (currently PBL)	The Netherlands Environmental Assessment Agency
MPI	Max Planck Institute
MT	Malta
NL	The Netherlands
NO_x	Nitrogen oxides
NPV	Net present value
OECD	Organisation for Economic Cooperation and Development
PESETA	Projection of Economic Impacts of Climate Change in Sectors of Europe based on Bottom-up Analyses (a research project funded by the European Commission)
PL	Poland
PPP	Public–private partnership
ppp	Purchasing power parity
PT	Portugal
R	Emissions reduction = mitigation (in mathematical formulas)
R&D	Research and development
REMO	Regional Climate Model (Regionales Klimamodell)
RO	Romania
SCC	Marginal social costs of carbon
SE	Sweden
SI	Slovenia
SK	Slovakia

SLR	Sea-level rise
SRES	Special Report on Emissions Scenarios (by the IPCC)
TC	Total costs of climate change (in mathematical formulas)
tCO_2	Metric tonnes of carbon dioxide
TSO	Transmission system operator
UBA	The Federal Environment Agency of Germany (Umweltbundesamt)
UK	United Kingdom
UKCIP	United Kingdom Climate Impacts Programme
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
WETTREG	Weather-based Regionalisation Method (Wetterlagen-basierte Regionalisierungsmethode, a regional climate projection model)
WHO	World Health Organisation
WIAGEM	World Integrated Assessment General Equilibrium Model
WRI	World Resource Institute (a Washington-based think tank)
WRMA	Weather Risk Management Association
ZÜRS	Zonierungssystem für Überschwemmung, Rückstau und Starkregen – an electronic database system developed by GDV
a_i	Amount of adaptation committed by individual *i* (in mathematical formulas)
f, *g*	Symbols for a mathematical function
d	Change (in mathematics)
∂	Partial derivative (in mathematics)
$\sum$	Summation (in mathematics)

Executive summary

Climate change will have an effect on the European Union. The repercussions will be regionally varied, with impacts on several sectors in the economy. Climate change has the particularity of being global with respect to the sources of emissions and local in the consequences (whether positive or negative). The sources of emissions are linked to the most basic aspects of human activity, from energy consumption to farming, while the impact of climatic changes are broader, affecting inter alia economic activities, land use, biodiversity, public health and water systems. This means that for the first time in history there is a need to align large parts of fiscal and regulatory policy with environmental concerns, from the local to the national and supranational levels.

Weather impacts will hit agricultural production, the tourism industry and public health, be it negatively or positively; they will also increase or reduce the risks of river floods and droughts, as well as affect the hydroelectric power stations and the cooling systems of other generators. Rises in sea levels will also pose considerable threats to many coastal areas. Studies on these large impacts abound, and show sizable differences in the quantification of impacts and their time scale. Now that we are starting to perceive some contours in the picture of impacts, a number of fundamental questions emerge: What should be the response of planners to these events? What are the costs of action or inaction to the economy and the state, and in particular the fiscal implications of the costs?

This report seeks to provide guidance on how to answer these questions. It is divided into two parts. PART I is dedicated to the conceptual framework, while PART II focuses on impact studies and data analysis to bring together the latest knowledge in this area. PART I of the report includes the following elements:

1) a theoretical framework that uses cost-benefit analysis tools to analyse the autonomous response to climate change impacts by individual economic actors, i.e. autonomous adaptation. It studies the potential market failures that may contribute to a suboptimal adaptation by individual agents. It addresses the reasons why autonomous adaptation alone cannot reach a socially optimum adaptation level. Finally, it also studies the response of individuals to various kinds of policies along with the role of insurance markets and combined, public–private partnership intervention through the insurance markets for extreme events;

2) a description of the driving factors of the fiscal impacts, listing the areas of concern depending on the level of exposure, existing infrastructure, fiscal capacity, etc.;

3) policy options to reduce the level of exposure to important fiscal impacts;

4) a summary of case study results on the fiscal implications for Germany, Italy and Finland; and

5) a summary of the knowledge gaps and required future work.

PART II of the report covers these elements:

6) a literature review of the existing cost estimations of climate change;

7) case studies for Germany, Italy and Finland on the impacts and their associated costs, with an analysis of the implications for budgetary costs and state fiscal balances; and

8) a knowledge gap analysis identifying the areas in which studies are missing and the adaptation costs and fiscal implications are still unknown.

The theoretical framework

The theoretical framework studies the behaviour of economic agents and how to alter it to reach a social optimum level of adaptation. It centres on rational economic decision-making in the face of climate change by individual agents, taking into account their profit-maximising objectives, the existence of market failures and uncertainty.

We thus distinguish two types of adaptation to climate change, autonomous and planned adaptation, which can furthermore be either anticipatory or reactive. Autonomous adaptation is defined as the unaided and unguided actions of private individual agents; this type may also entail collective action as long as it does not emerge through public policy intervention. Planned adaptation involves the intervention of the state to address market failures in the adaptation process, including the issues of equity and the security of supply of public goods or essential goods and services. Anticipatory actions are those that prepare for future impacts, while reactive actions are taken at the time of or after the climatic effects.

Policy interventions to assist adaptation should take place when autonomous adaptation is suboptimal and social costs are higher. This may be because the optimal adaptation for a profit-maximising individual is lower than the adaptation required for a social optimum or simply because the individuals do not have the means to cover the adaptation costs they have to bear. Other causes of suboptimal adaptation are imperfect information and moral hazard, which lead individuals to adapt insufficiently.

The study presents a theoretical framework that analyses the complex relationship between climate change impacts, socio-economic repercussions and fiscal policy implications. From a fiscal and economic policy perspective, the objective of a planner is to maximise social welfare while minimising the negative fiscal effects. This requires an understanding of the autonomous adaptation that is taking place, alongside the market and policy failures that emerge from such actions as well as other potentially unacceptable consequences for society (affecting equity, for example). The theoretical framework concentrates on the use of cost-benefit analysis tools for climate change adaptation. The theoretical framework develops the steps needed for policy-makers to address the fundamental questions about where, when and how to intervene.

For the policy-maker, the most difficult issue to address is the uncertainty of the timing and magnitude of impacts and how these factors translate into fiscal effects. Policy intervention may lead to an inefficient result with negative ramifications for the economy if adaptation measures are either too paltry or too ambitious. Different options also have different implications for fiscal costs and government revenues. The potential impacts of extreme events are seen in the study as important and presently underestimated, and policy-makers need to consider the kinds of actions needed for events of very low probability but very high cost. Such events are difficult to predict and generally absent from studies on climate change impacts, which often only look at gradual changes and average effects.

We determine that one of the most complex issues in the analysis of climate impacts is timing. When should an adaptation measure take place? Models diverge widely on both the extent of impacts and their timing. The study presents the theoretical treatment of time in a cost-benefit analysis, where the net present value of an action is estimated taking into account the value of the action under different risk levels, the costs and benefits of early or delayed action and the influence of maintenance costs.

Given the uncertainty of the expected regional effects of climate change, the benefits of the investment – by both private or public actors – in an adaptation project have to exceed the costs by a positive amount (the so-called 'hurdle rate') in order to justify the investment. The amount above the investment cost is called the 'option value' of not investing but waiting and delaying the project. In other words, the classic rule according to which the present value has to cover at least the cost of the investment does not hold under these circumstances. The optimal solution to this problem involves comparing investment costs and present values at all possible time slots, i.e. it must be taken into account that the investment is possible at different time slots. Using the option to wait, an investor can possibly gain new information about future benefits (but also about better adaptation techniques that may reduce costs) and can adapt his behaviour to changed conditions. Real option effects can work in the opposite direction, too: cheap options for adaptation or mitigation may disappear or become more costly as climate change intensifies over time. Therefore, appropriate analysis of an adaptation strategy has to incorporate this aspect as well.

One of the cornerstones of the report is the analysis of insurance markets. Functioning insurance markets are central to limiting the liability of the state and ensuring optimal adaptation. Public authorities need to explore further the use of insurance markets and the potential of public–private partnerships, such as state guarantees for excessive uninsurable damages. This could also include the creation of supranational reinsurance markets to support, at the EU level, national insurance schemes in cases of extensive damage across large territories. The way insurance is offered will be crucial to avoiding moral hazard, which is clearly present across a number of countries, whenever state guarantees provide a disincentive to take private insurance and thus shift private insurable costs unnecessarily to the state budget. Local government authorities may also avoid taking the necessary precautionary actions because they anticipate compensation for damages from the state or even from the EU.

The report presents a palette of options for insurance systems that could be efficiently deployed. Member states and the EU have to review their policy frameworks in this respect, to make certain that the private–public insurance combination is the most appropriate and least costly to the economy and the public finances.

Drivers of fiscal costs

While the theoretical framework studies the behaviour of agents, it does not directly address the question of what will drive the level of fiscal impacts. This study dedicates a large section to identifying and presenting the main drivers behind fiscal impacts:

1) the degree of exposure to gradual and extreme climate events;

2) the level of protection already in place in areas at risk, i.e. preparedness;

3) the state's liability for damages;

4) the potential and impacts of autonomous adaptation and remedial actions;
5) the cross-border effects of climate change; and
6) the fiscal capacity of the member states and the role of the EU.

There has not yet been any study that satisfactorily addresses the way in which these factors affect the state budget and in particular its stability. This study offers a first attempt at classifying the fiscal risks involved. From the case studies and other literature reviews, it is clear that the fiscal consequences are not negligible. A number of predicted climate changes and in particular extreme events could severely affect the fiscal stability of some member states.

In general, the gradual changes caused by climate change are considered manageable from the point of view of direct budgetary costs. Yet in relation to the costs arising from extreme events, along with the related indirect effects on growth and thus government revenues, the impacts are not necessarily manageable. Furthermore, the indirect effects of gradual climate change and the impacts in other countries can also threaten fiscal stability. A few impacts have been identified as having negative fiscal implications that are particularly significant. These are primarily related to the risks of floods owing to rises in sea levels, increases in sea surges and changes in river flows. For example, the annual costs of maintaining the necessary protective infrastructure for rivers and reacting to damages from extreme river flood events has been calculated to exceed 1% of GDP in some member states. This being an average, it is clear that the costs in any given specific year can be much higher.

After highlighting the main drivers, the study presents a number of recommendations for how to reduce the negative fiscal implications, which can be summarised as follows:

- selecting the right level of protection using appropriate, cost-benefit analysis tools;
- investing in research and development;
- providing a high level of public information;
- limiting state liability through innovative public–private partnerships with the insurance industry;
- adopting appropriate regulations on land use and on the use of other natural resources;
- using appropriate mixtures of legal and fiscal instruments to guide autonomous adaptation;
- reinforcing coordinated action across Europe; and
- ensuring that appropriate assistance is provided to countries whose internal fiscal resources are insufficient to undertake the necessary adaptation measures or to react to catastrophic events.

Literature review and case studies

PART II complements PART I. It presents the current state of knowledge about adaptation costs to climate change in Europe and presents a country-level impact analysis based on existing knowledge. Adaptation to climate change will predominantly take place at the regional and local levels, and it is at these levels that adaptation needs and costs can be assessed. Three case studies have been performed on climate impacts and adaptation needs in three representative EU member states, namely Germany, Finland and Italy. The analysis of climate change impacts in the three countries reveals that climate change is a multi-faceted phenomenon in Europe and that although in both northern and southern Europe temperatures are expected to rise, other physical outcomes and consequences of this temperature rise are by no means the same. While precipitation is projected to rise in Finland, in Italy severe droughts in summer may occur more often. In Finland, the expected climate-related damages are small and in some sectors climate-induced gains are even possible. In contrast, in Italy and in some economic sectors in Germany, climate change may entail high economic costs, such as capital losses due to floods and other extreme weather events. Some sectors, such as the tourism sector in Germany, call for more detailed regional studies, because climate change provokes economic losses in one region while it creates opportunities for other regions.

Concerning adaptation, the analysis distinguishes between planned centralised adaptation and autonomous adaptation. In the analysis of the countries studied, it becomes clear that some sectors are particularly prone to autonomous adaptation, but most autonomous adaptation measures need a supportive framework set by the government. Among the different actions, the most cost effective and influential is information provision on the expected regional impacts of climate change. But information provision is far from sufficient. For some adaptation actions, the state is the central provider of protective infrastructure and provider of assistance in catastrophic events. The state also takes on the main burden of maintaining transport and other public infrastructure.

The detailed, country case studies lay the groundwork for a more systematic approach to a literature-based review of adaptation costs. The results of the case studies, complemented by top-down cost estimates of adaptation measures in Europe, are listed in an adaptation cost matrix. The purpose is two-fold: first, the knowledge gaps become visible at a glance, as the cost estimates available in the literature are sorted by region, underlying scenarios, time periods and affect sectors. The matrix shows that to date most research has been done in the field of coastal protection, while little is known about public health impacts or the potentially costly adaptation measures in the transport sector. Furthermore, the adaptation of infrastructure in response to the increasing severity and frequency of extreme weather events may be relatively expensive, but detailed estimates of costs in the EU are mostly missing. The second purpose of the matrix is the systematic review and classification of various literature sources. Taking into account time periods, scenarios and methodologies, one can – inter alia – approximate total adaptation costs through the compilation of various sectoral assessments. So far, this application has mainly been hypothetical – there are very few studies that are comparable in terms of regional and temporal coverage, scenarios and assumptions; hence transferring the results of one bottom-up study to another time frame, region or climate scenario is largely a speculative exercise. Nevertheless, the cost estimates in the matrix show relatively high adaptation costs for agriculture, coastal protection and transport infrastructure (and possibly high negative costs in energy demand).

The theoretical framework for government intervention in adaptation is used to develop rough estimates for the direct public costs of adaptation. Therefore, sector-specific shares of public costs and the total adaptation costs are estimated. Coastal protection and transport infrastructure remain those aspects for which the impacts would entail the highest public costs; adaptation in the agricultural sector does not play a major role for public budgets, as the measures can mostly be assumed to be taken and funded privately, while support will generally be channelled by restructuring existing subsidies. Savings from the reduction of heating energy demand may provide for significant decreases in public expenditures, albeit only in some regions of the Union (northern Europe) and under uncertain assumptions regarding the technical developments.

It has been possible to estimate to a certain extent the direct costs to the state budget of gradual climate change (approximately €5 to 15 billion a year depending on the scenario), but the far more serious impacts from extreme events and indirect effects through ramifications on the economy are missing. Based on just one estimation for Germany by Bräuer et al. (2009), the indirect effects of climate change on public costs will amount to 87% of all public costs. Thus there is a signal that yearly average costs can treble to around €60 billion a year, i.e. 1% of total public expenditure for the EU, and not be evenly distributed territorially. For extreme events, there are very few indications of the expected costs, but studies by Costa et al. (2009), the IMF (2008) and the Dutch Deltacommissie (2008) on the protection of the Dutch coast give some flavour of the serious costs of damages from flood events in the event of insufficient adaptation.

The review of the case studies and the literature revealed a considerable lack of data and quantitative cost analyses. Research on adaptation costs is still in its infancy, so statements concerning the budgetary burdens related to adaptation are necessarily very uncertain. Still, the present analysis identifies the sectors with potentially high public costs and the sectors for which more research is necessary.

What emerges from PART II is the need to increase the number of bottom-up studies with cost-benefit analyses of alternative adaptation options, with a clear identification of the direct costs of the infrastructure, the level of state liability and the long-term costs to the economy, and the consequences of inaction.

1. Introduction and overview

Evidence suggests that the impacts of climate change are already being felt and will be increasing in significance over the years. Large uncertainties exist as to the nature of the impacts and the consequences for the European Union. Some trends are relatively clear, however, along with the fact that the effects will hit different regions in the EU in different ways. While not all regions will be adversely affected, the negative impacts will be larger on average and, as the Commission's Region 2020 (EC, 2009) and the JRC's PESETA report (2009) clearly indicate, the largest negative impacts are expected to fall principally on the already economically weakest or financially most vulnerable regions of the EU.

What also emerges from the studies is that there will be many impacts regardless of the mitigation efforts undertaken, as the stock of greenhouse gases already in the atmosphere will have an effect. The potential trade-off between mitigation and adaptation is therefore limited in the short term, and many adaptation actions are already unavoidable. Unfortunately, the exact nature of the impacts is shrouded by uncertainties, but the potential costs of inaction on adaptation measures are expected to be too substantial to ignore.

1.1. Potential types of adaptation and their fiscal implications

Adaptation is not an exclusively public responsibility, nor will it always create negative fiscal implications. There are different types of adaptation responses. There is *autonomous* adaptation, where agents adapt their behaviour as a response to climatic changes without intervention by the state. In contrast, there is *planned* adaptation, which is assisted by the intervention of public authorities. Each of these adaptation responses can be either anticipatory or reactive. Anticipatory adaptation is based on agents taking steps to avoid expected costs in the future, while reactive adaptation occurs as a response.

Autonomous adaptation alone by individual agents will play a central role, but it will likely lead to socially suboptimal results. There are many reasons for this. Many required actions have a large public good aspect, and individual costs will not reflect social costs, so steering adaptation to achieve a socially optimal level is thus necessary. In addition, climate impacts are complex and uncertainties hamper appropriate actions by individuals, again leading to the need for the government to enhance the availability of information for the economic agents concerned. An OECD (2008) study notes that many regions and sections of society remain poorly adapted to the current climate even if in line with historical trends. This is due to market failures, asymmetric information, policy failures and particularly a different private-to-public discount rate of the value of anticipatory action. Climate change poses new risk factors and these have to be incorporated in private and public decision-making.

Adaptation is expected to have manifold fiscal effects. These effects depend partly on the ability of private actors to autonomously adapt to changing climate conditions and partly on how much governments engage in the adaptation process. Below we explore the rationale for government interventions, namely the existence of market failures, equity concerns and the need to ensure security of supply. Since for the latter two issues additional political and social value judgements are required, from an economic point of view it is difficult to predict where and to what extent governments will actually intervene.

1.1.1. Autonomous adaptation

Much of the burden of financing the reallocation of resources to adapt to climate change will fall on the private sector. Negative or positive effects on the productivity of the private sector (e.g. higher energy expenditures, higher or lower crop yields in agriculture) will also have fiscal effects, for example owing to increasing or decreasing tax revenues. Autonomous adaptation (both domestically *and* globally) may also cause changes in the relative prices of goods and services, not only in the sector where adaptation takes place but also in other sectors of the economy (Aaheim and Aasen 2008). Therefore, fiscal effects may be observed in sectors for which adaptation to climate change does not have direct relevance.

The following potential kinds of fiscal pressures may be caused by autonomous adaptation (Heller 2003):

- financing for private adaptation in the production sector. A high degree of vulnerability, particularly in the agricultural sector, may create a demand for subsidies or transfers to facilitate adaptation (e.g. financing technological innovations and management practices). The extent of political pressure will also depend on the adaptive capacity of the farming sector.

- financing for private adaptation in the private sector, especially for low-income households (see section 2.3 on equity aspects and section 2.4 on security of supply). It is important to note that the prices of basic goods such as food or energy will probably increase because of climate change and adaptation policies.

- risks to the tourism industry, which may differ substantially within a country. In Germany, for example, summer tourism in the northern regions is expected to become more important while winter tourism in the mountains will become less so (Matzarakis and Tinz 2008). While on average the fiscal effects may be negligible, *regional* fiscal effects may be significant. Claims for transfers may be one reaction to impaired incomes from tourism.

- increasing or decreasing tax revenues from changes in the earnings or expenditures of private agents. A country's trade balance, the development of commodity world prices and changes in relative prices will play an important role in determining the fiscal implications.

Autonomous adaptation, without any intervention by the state, may thus create considerable costs to society and ultimately to the state. Autonomous adaptation may involve a suboptimal level of adaptation, resulting in higher overall social costs than under different levels of planned adaptation (which in economic terms would reflect a permanent fall in GDP as well as adverse effects on other indicators, such as life expectancy, health costs or biodiversity loss). The impacts of extreme events or events for which the extent of autonomous adaptation is too low because of uncertainty, moral hazard, adverse selection or the under-provision of public goods could be mitigated by planned adaptation. Appropriate planning for adaptation is also necessary to avoid the doubly negative fiscal effect of a fall in growth and thus fiscal revenues and an increase in public expenditure for reactive public intervention for adaptation. In countries especially vulnerable to climate change, growth may be adversely affected, putting additional pressure on the economy. Such growth impacts are going to have the most damaging effect on national welfare, rather than any direct fiscal costs arising from direct expenditure.

The results of no state intervention – even in cases where it would be optimal in pure efficiency terms – could also be unacceptable, based for example on equity considerations. In cases where planned adaptation is deemed necessary, it should consist of actions that maximise welfare and minimise fiscal costs. This does not imply minimising public expenditure, as a scenario with higher growth and increased public revenues can allow for more public expenditure and be fiscally beneficial overall.

1.1.2. Planned adaptation

In planned adaptation, government intervention is used for the provision of specific public goods as well as to correct for market failures and impacts that violate accepted standards of social equity. The costs of intervention may be very different depending on the kind and level of autonomous adaptation taking place and the kind of instrument used to correct for insufficient or socially suboptimal adaptation levels.

The objective of the planner, i.e. public authorities, should be to minimise the costs of climate impacts, while maximising the net benefits of intervention, more specifically maximising economic welfare and minimising fiscal costs. Planned adaptation may be anticipatory or reactive and may take many forms, such as information provision, regulation, taxation, subsidies and emergency support, as well as the state acting as a guarantor for insurance or financial engineering schemes.

Planned adaptation will need appropriate funding, which has to be financed for example through taxes. Thus, the overall economic costs comprise not only the tax itself but also the excess burden, which depends on the market conditions. The type of fiscal instrument used to raise the necessary resources will also be an influential factor.

Areas of public sector involvement will include outlays on infrastructure (urban water control, irrigation systems and public health systems) and subsidies (to facilitate the population resettlement). Planned adaptation may also involve preventing or regulating adaptation measures that generate negative external effects (e.g. uncontrolled flood protection measures in an upstream river segment or increasing water discharge from an aquifer). In this regard, the fiscal effects may differ significantly from the support for adaptation measures that generate positive external effects (e.g. the greening of city areas in order to mitigate the heat island effect). Taxing activities (such as water usage in heat periods) that generate negative externalities would have positive fiscal effects, while subsidising activities with positive externalities (like the planting of trees) have negative effects on the public budget.

With respect to planned adaptation, the following types of fiscal pressures are important (see also Heller 2003):

- requirements for building up or relocating infrastructure to address potential risks in coastal zones, notably for long-term infrastructure (bridges, ports). The requirements include the costs of coastal protection, building dykes, beach nourishment and maintenance. The fiscal effects in this regard will mainly depend on a country’s coast length and the extent of development of the coastal areas (population density, tourism, biodiversity). The fiscal effects will also depend on the timing of adaptation measures;

- required regulatory policies to deal with land use and settlement management, especially in coastal zones and areas prone to flooding. These policies may have minor effects on the public budget but in terms of opportunity costs the effects may be consequential;

- required regulatory policies to adjust standards and prescriptive limits (e.g. environmental standards, construction guidelines);

- requirements for redistribution within the EU and development policies to avoid moral hazard by national or subnational jurisdictions arising from a failure to undertake adaptation activities. Again in terms of opportunity costs, the fiscal effects may be relevant (Heller 2008b);

- the fiscal component of costs to restructure and reform energy systems. Adaptation may cause effects on the demand side as well as on the supply side of energy markets. Additionally, changes in the energy grid may have fiscal effects;

- costs of adapting all publicly-owned buildings, facilities and infrastructure; and

- costs of providing information and monitoring early-warning systems, which are mainly relevant in the public health sector.

Another field of governmental intervention, the provision of basic information on the climate system and on expected local effects, may be of minor fiscal relevance but quite important in terms of facilitating autonomous adaptation.

It is also crucial to take into account the fiscal pressures already expected in the member states as a result of demographic ageing, chiefly with respect to public health and mobility. Adaptation considerations need to be taken into account in assessments of fiscal sustainability.

Planned adaptation actions should of course concentrate on the costliest and most probable events, but should also consider extreme but rare events, for which meeting the costs could result in considerable social harm. There are, however, also a large number of cheap and easily implementable actions even for smaller impacts, for which the benefits exceed the costs and which should be implemented quickly. The fiscal and regulatory policies in place should be reviewed and adapted based on the growing information on possible expected impacts. Fiscal and regulatory instruments have generally not been designed to ensure that private behaviour matches the need for climate mitigation and adaptation. Some of the policies may provide negative incentives in this respect. Climate change has the particularity of being global in relation to the sources of emissions and local in the consequences (whether positive or negative). The sources of emissions are linked to the most basic aspects of human activity, from energy consumption to farming, while the impact of climatic changes are broader, affecting inter alia economic activities, land use, biodiversity, public health and water systems. This means that for the first time in history there is a need to align large parts of fiscal and regulatory policies with environmental concerns, from the local to the national and supranational levels.

In addition, owing to the existing fiscal pressures, public authorities should concentrate on achieving cost effectiveness and maximising leverage effects, i.e. using private mechanisms in conjunction with public policy in the most efficient configuration. For adaptation, the role of insurance mechanisms will be crucial.

For policy-makers, one of the most complex barriers to formulating effective policies is the high degree of uncertainty surrounding the impacts of climate change. This brings considerable complexity to the planning process, thus entailing a risk of generating too much or too little adaptation; similarly, time considerations further accentuate the complexity of the decision process. Optimal adaptation to uncertain events may require early preparation. Some events, whose probability appears to be low in the medium term, may also occur earlier than predicted by the models (or later or never). For political decision-makers, events with a low probability of occurrence but very large costs associated with them will pose difficult dilemmas. Presently, contradictory claims on the speed and severity of some climate impacts just increase the uncertainty about optimal timing.

It must be emphasised, however, that climate change will not only bring negative impacts, but also benefits to some regions. There are areas that are expected to suffer less from river flooding for example or areas previously uncultivable that will become available for farming. It is important for governments to be reactive to not only negative but also positive effects, and to alter policy instruments to facilitate adaptive behaviour on the part of agents to avoid negative impacts as well as benefit from potentially new opportunities.

This report aims at providing policy-makers with conceptual criteria and guidelines on how to approach the issue of the fiscal implications of climate change.

1.2. Overview of the study

This report is divided into two parts. PART I presents a theoretical framework that analyses the complex relationship between climate change impacts, socio-economic impacts and fiscal policy implications. From a fiscal and economic policy perspective, the objective of a planner is to maximise social welfare while minimising the negative fiscal implications. This requires an understanding of the autonomous adaptation that is taking place and the market and policy failures that emerge from such action, as well as other potentially unacceptable consequences for society, affecting for example equity. The theoretical framework concentrates on the use of cost-benefit analysis (CBA) tools for assessing measures for climate change adaptation. The report discusses in section 2.2 the treatment of adaptation as a public or private good. This is important for determining when and to what extent public intervention, referred to as planned adaptation, is required. Based on the economic theory of social vs. private costs, this section looks at the potential market failures emerging from private autonomous adaptation leading to socially suboptimal results. It also gives an overview of the potential causes of suboptimal results, which may actually stem from perverse incentives under existing policies that could easily be altered. Apart from the correction of market and policy failures, efficient markets can entail consequences for social equity or for the security of supply (sections 2.3 and 2.4) of vital public or semi-public goods, which may justify some sort of policy intervention to cushion impacts or compensate for damages. Even after determining the need for action, acting to address potential adaptation needs through public policy instruments involves complex uncertainty and timing considerations. Generally, public policy-makers are uncertain about the size, frequency of recurrence and the expected timing of climate change developments or extreme weather events. The study presents a theoretical approach to these issues in sections 2.6 and 2.7 and concludes with a lengthy discussion of the potential uses of insurance markets (section 2.8).

Chapter 3 analyses the drivers influencing the fiscal implications. It describes the transmission of climate impacts to fiscal impacts. For each driver it proposes policy options to mitigate the negative fiscal implications, concentrating on those actions that have low fiscal costs but large benefits, from the basic provision of information to the use of fiscal instruments (such as taxes and subsidies) to change the behaviour of individuals and improve autonomous adaptation.

Chapter 4 presents a summary of the areas for which autonomous or planned adaptation will need to take place in the case study countries examined in PART II.

Chapter 5 outlines the potential fiscal implications derived from the case studies in PART II.

Chapter 6 discusses the results of a knowledge gap analysis discussed in PART II, indicating the areas of research required to assess the fiscal implications.

Chapter 7 presents the overall conclusions of the study, including those of PART II, which provides examples of the implementation of the theoretical framework in case studies and the structure for applying the methodology in European regions.

PART II accompanies PART I and presents a literature review on adaptation costs, three case studies (for Germany, Finland and Italy) and a list of knowledge gaps on the impacts and adaptation costs of climate change at present and in general equilibrium modelling.

The literature review in chapter 2 of PART II identifies the knowledge gaps concerning data and methodologies and ends with a note on modelling adaptation costs using computable general equilibrium (CGE) models. Chapters 3 to 6 of PART II present the implementation of the theoretical framework in three case studies, based on a bottom-up approach. Chapter 3 gives an overview of the existing work on National Adaptation Strategies in the case study countries. In the strategies and in the case studies, the focus is mainly on those critical sectors and fields considered particularly exposed and vulnerable to climate change developments. Thus, besides water resources, water supply and health, economic sectors such as agriculture and forestry, energy, transportation and tourism are examined. Adaptation measures – those realised as well as potential ones – are indicated for each sector and country and the fiscal implications are derived as far as possible.

2. Theoretical framework of adaptation policy

In this chapter, we focus on the key aspects that a theoretical framework for adaptation has to consider. Cost-benefit analysis is a basic tool in economic policy and can serve as the starting point for analysis. Then we examine several aspects that may help to identify the driving forces of the costs and benefits and the appropriate level of adaptation. In particular we discuss i) adaptation as a public or private good, ii) equity aspects, iii) security of supply, iv) the role of markets and collective action, v) the timing of adaptation, vi) uncertainty and irreversibility, and vii) adaptation of insurance markets.

2.1. Cost-benefit analysis

Starting from a global perspective, adaptation and mitigation are – to a certain extent – policy substitutes as both policy strategies reduce the impact of climate change, albeit with very different time dimensions and with considerable differences in the certainty that is associated with policy actions. Therefore, a joint analysis is necessary. From an economic point of view, cost-benefit analysis (CBA) is the appropriate tool in order to answer the questions how much adaptation and how much mitigation, respectively, is necessary. The question to be answered is, "If the world were ruled by a benevolent dictator, a philosopher-queen who is in control of the entire planet and is up to speed with the latest scientific insights, what would she do about climate change?" (Tol 2005, p. 573). Since real politics cannot possibly deliver a better result, global CBA provides a useful benchmark for evaluating real policies.

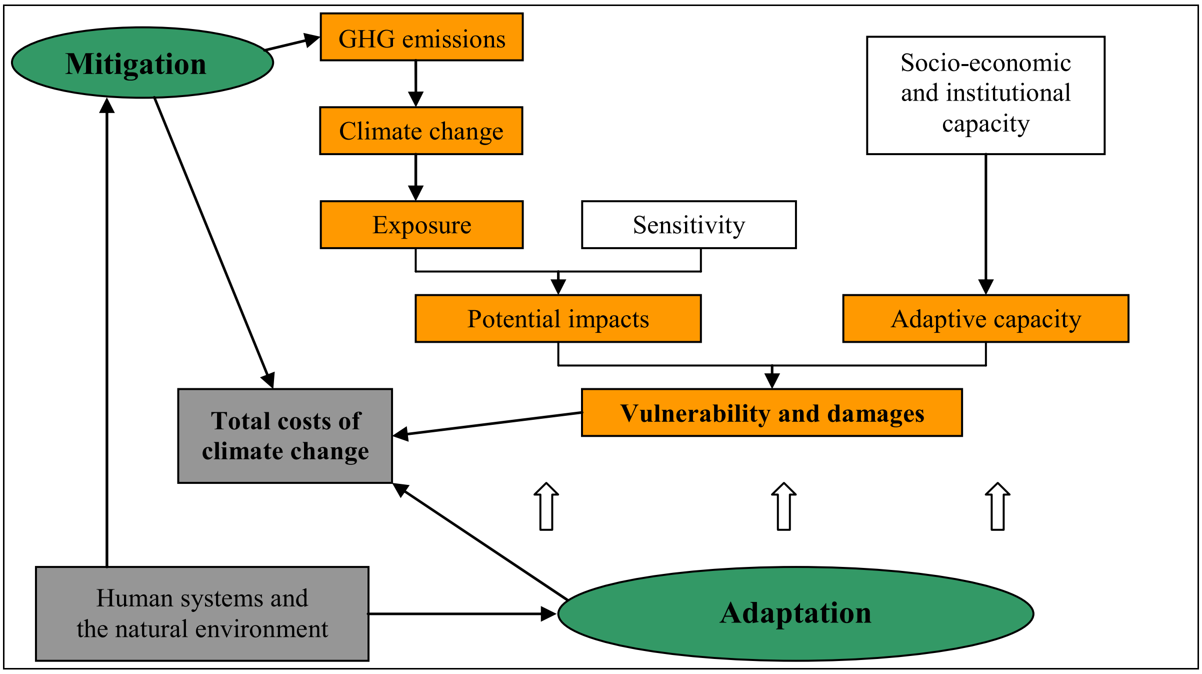
In a first step, we ask which factors determine the total costs of climate change. Three cost factors can be identified: i) mitigation, ii) adaptation, and iii) residual damage. How mitigation, adaptation and residual damages influence the total costs of climate change is depicted in Figure 2.1. Countries' mitigation efforts marginally influence GHG emissions and the extent and impacts of climate change. The resulting impacts depend on the sensitivity of regions and the actual economic activities exposed to the various physical effects of climate change. Human systems and the natural environment are furthermore characterised by their *adaptive capacity,* which in turn depends, respectively, on existing socio-economic and institutional capacities as well as on the responsiveness of fauna and flora in the ecosystem. Adaptive capacity is the ability of a system to provide the requisite resources to i) adjust to climate change (including climate variability and extremes), ii) moderate potential damages, iii) take advantage of opportunities, or iv) cope with the consequences (IPCC 2007b). Both potential impacts and adaptive capacity, determine a country's vulnerability and, finally, the climate change *damages*. Adaptation – as the second available policy strategy – is the direct response of human systems and the natural environment in order to reduce potential impacts (e.g. change in land-use policy), damages (e.g. building higher dykes) or to enhance the adaptive capacity (e.g. increase the level of education).

The task for the benevolent dictator, therefore, is to decide whether to invest in adaptation (*A*) or mitigation (denoted as emissions reduction *R*) in order to minimise the total costs of climate change, i.e. to minimise

$$TC = C_R(R) + C_A(A) + C_{\text{Res}}(A,R) \qquad (1)$$

whereby TC are the total costs of climate change, $C_R(R)$ are the costs of emission reduction, $C_A(A)$ are the costs of adaptation measures and $C_{\text{Res}}(A,R)$ are the residual costs of climate change damages. All costs are discounted value terms. The third cost term, $C_{\text{Res}}(A,R)$, depends negatively on both adaptation and emissions reduction.

Figure 2.1: Mitigation, adaptation and damages



Source: EEA (2008).

The costs of emission reduction include, inter alia, costs for higher energy efficiency, fuel switching or the development of carbon-free technologies such as CCS. It is reasonable to assume increasing marginal costs of abatement.[1] The costs of adaptation comprise, for example, the climate-proofing of infrastructure, measures against sea level rise and higher expenditures for air conditioning. There may also be some benefits, for instance in the form of less heating or more agricultural production. We assume that marginal costs of adaptation are an increasing function of adaptation efforts – and are likely to rise over time, particularly if mitigation efforts fail to prevent an increase in climate change in the second half of the century and beyond. The reason for this increase is simply that cheaper and more effective adaptation measures will be realised first, and more expensive and less effective measures will be implemented later (de Bruin et al. 2007). There also exist some links between adaptation and mitigation costs, for example, more air conditioning increases emissions. Finally, the residual costs of mitigated climate change include damages caused by extreme weather events and other climate impacts despite mitigation and adaptation measures.[2]

The minimisation problem (1) results in two FOC, which are

$$R: \quad \frac{\partial C_R(R)}{\partial R} + \frac{\partial C_{\mathrm{Res}}(A,R)}{\partial R} = 0 \Leftrightarrow \frac{\partial C_R(R)}{\partial R} = -\frac{\partial C_{\mathrm{Res}}(A,R)}{\partial R} \qquad (2)$$

[1] See, for example, the meta-study of Dannenberg et al. (2008).

[2] Tol et al. (1998) estimate the relation of adaptation costs to residual damages. Depending on the study, residual damages are 4 to 14 times higher than adaptation costs for a doubling of the atmospheric concentration of carbon dioxide. Using the AD-DICE model (a modification of the DICE model developed by Nordhaus) de Bruin et al. (2007) report residual damages for the year 2100 which are about 10 times higher than adaptation costs and mitigation costs respectively. Thus, residual damages seem to be much higher than the other costs components.

$$A: \quad \frac{\partial C_A(A)}{\partial A} + \frac{\partial C_{\mathrm{Res}}(A,R)}{\partial A} = 0 \Leftrightarrow \frac{\partial C_A(A)}{\partial A} = -\frac{\partial C_{\mathrm{Res}}(A,R)}{\partial A} \tag{3}$$

Avoided marginal costs can be written as marginal benefits, i.e.

$$-\frac{\partial C_{\mathrm{Res}}(A,R)}{\partial R} = MB(R) \qquad \text{and} \qquad -\frac{\partial C_{\mathrm{Res}}(A,R)}{\partial A} = MB(A)$$

Then, from (2) and (3) we get

$$\frac{\partial C_R(R)}{\partial R} = MB(R) \tag{4}$$

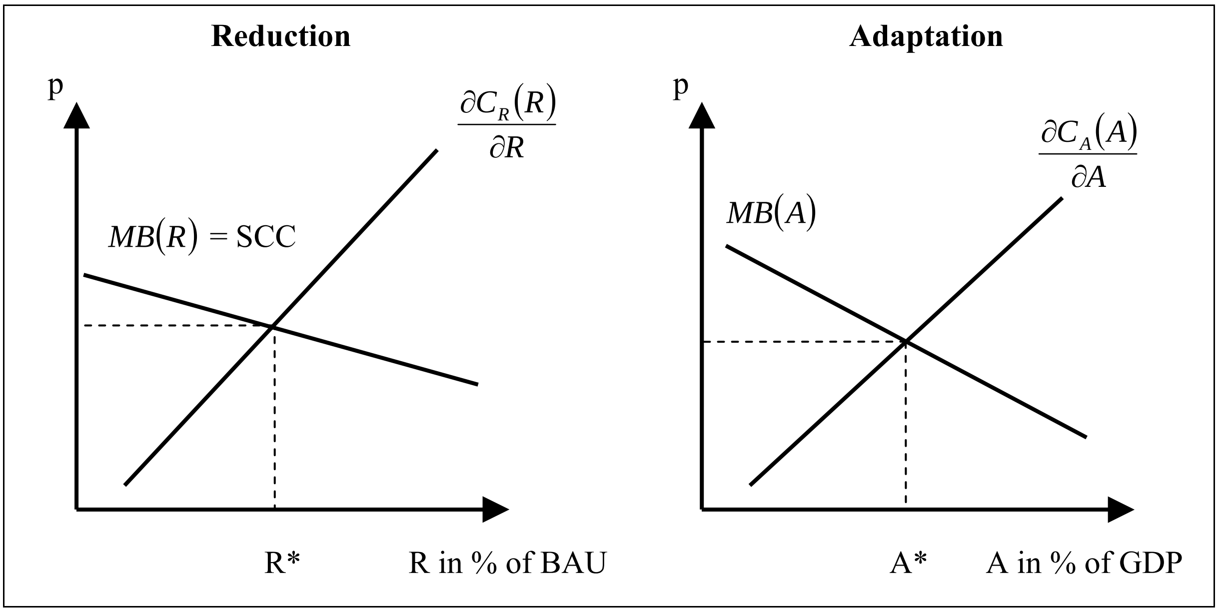
$$\frac{\partial C_A(A)}{\partial A} = MB(A) \tag{5}$$

In order to attain a total cost minimum, the marginal costs of emissions reduction should equal the marginal benefits of emission reduction (i.e. the avoided marginal residual costs of climate change) (see also Nordhaus 1991). Condition (4) delivers the optimal amount of emission reduction, $R*$. The term $MB(R)$, the marginal benefit of not emitting one additional ton of GHGs, is also called the *marginal social costs of carbon* or SCC (Stern 2007, Tol 2008), i.e. the total damage from now into the indefinite future of emitting one extra ton of GHGs now. Thereby, one has to take into account that the $MB(R)$ curve for a given period depends on future emissions (Stern 2007).

The second FOC states that adaptation should be realised up to the point where the marginal benefits of adaptation equal the marginal costs of adaptation. From condition (5) we get the optimal level of adaptation, $A*$.

Therefore, based on the costs minimisation problem (1) we get the optimal levels for reduction and adaptation, $R*$ and $A*$ (see Figure 2.2 for a graphical presentation). For both policy strategies, the marginal benefits (avoided marginal costs) have to equal the marginal costs. Thereby, emission reduction is depicted in percentage of business-as-usual emissions (BAU) and adaptation costs and benefits in percentage of GDP.

Figure 2.2: Cost-benefit approach to reduction and adaptation



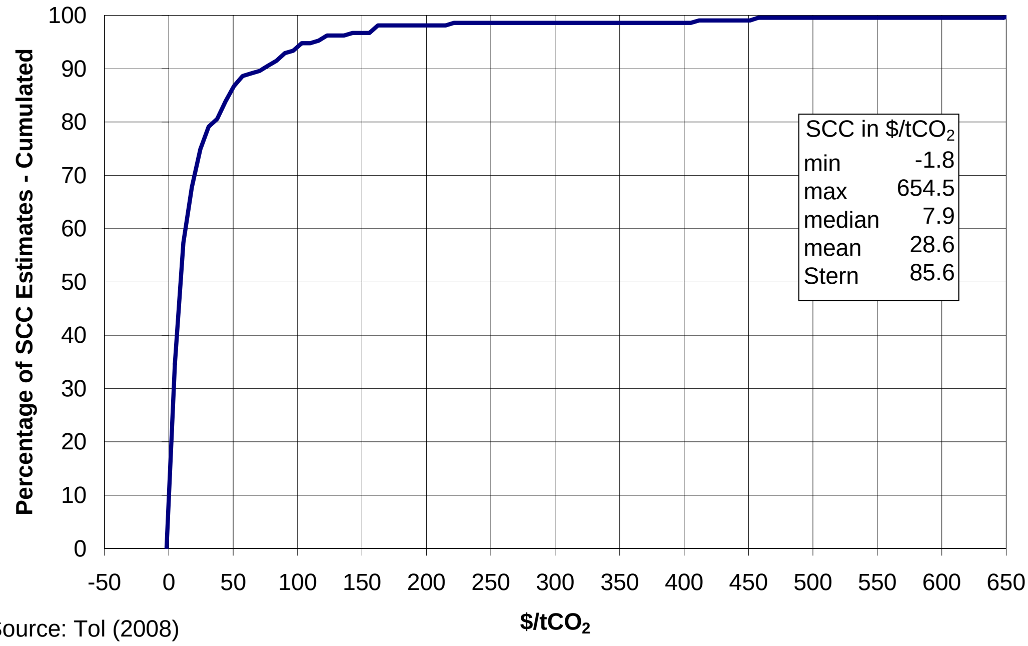
Given the costs curves in Figure 2.2, a simple comparative static analysis can give some insights how the optimal levels of both policy strategies react to changes in the economic systems. In particular, two aspects should be considered. First, a new technology which enables abatement at lower costs leads to a downward shift in the marginal abatement costs curve, $\partial C_R(R)/\partial R$, thus leading to more abatement in the optimum. On the other hand, more abatement makes less adaptation necessary as the marginal benefits of adaptation shift downwards.[3] In other words, there is a *trade-off* between mitigation and adaptation in this case. Second, if better information about future climate damages indicates that the expected damages of climate change will be higher, marginal benefits of mitigation as well as marginal benefits of adaptation will move upwards. In this case more mitigation and more adaptation will be necessary. The magnitude of the increase, however, will depend on the ascent of the marginal costs functions. An increase in risk aversion should have the same effects. In this case, the weight of the uncertain bad outcome increases leading to higher expected marginal damages.

If the SCC is computed along a trajectory in which the marginal costs of emission reduction equal the SCC, the SCC is the Pigou tax, which internalises the negative externality caused by GHG emissions. In order to get an idea of the magnitudes for SCC, Figure 2.3 depicts recent estimates, which are evaluated in a meta-analysis by Tol (2008). This analysis includes 211 estimates of the social cost of carbon. The median (mean) SSC value is \$7.9/tCO_2 (\$28.6/tCO_2). The estimate of the Stern Review is \$85.6/tCO_2 and higher than 90% of all estimates available. The right tail of the SCC distribution is strong, i.e. there is a low but positive probability of very high SCC values. An important result of Tol’s study is that equity-weighted estimates of the SCC are substantially higher than estimates without equity-weights. Higher SCC values would lead to more mitigation. From the viewpoint of the global decision-maker equity weighting is necessary because climate change will affect people with

[3] Remember that both adaptation and mitigation negatively influence the residual damage costs. More mitigation leads to a downwards shift in the marginal residual costs of adaptation and therefore also to a downwards shift in the marginal benefits of adaptation.

disparate incomes in different regions of the world (Anthoff et al. 2009). Economic theory assumes a declining marginal utility of consumption, i.e. the same absolute consumption change results in a smaller welfare change for a rich person than a poor person. Looking for the welfare effects of climate change one has to take into account this difference.

Figure 2.3: Cumulated relative frequencies of SCC estimates



Source: Tol (2008)

The global perspective above may not be appropriate for real politics for at least three reasons. First, as mentioned above there is no benevolent dictator who may enforce a global cost-benefit analysis. Second, emissions reduction is a global public good and the prospects for a global agreement – where industrialised and developing countries commit to binding reduction targets – are rather dim (Helm 2008). The December 2009 Copenhagen Accord represents proof of the difficulties in reaching any binding agreement. Despite the defined objective of limiting climate change to 2ºC the Accord is based on voluntary pledges for reductions to greenhouse gas emissions without enforcement mechanisms, which according to the IPPC already fall 50% short of the required cuts[4]. Therefore, the socially optimal approach to climate change may not be realistic and even more may not be helpful in order to analyse the potential fiscal effects of adaptation measures. Third, as is pointed out by Tol (2005), adaptation and mitigation are done by different people operating at different spatial and temporal scales. This hampers theoretically possible trade-offs between adaptation and mitigation.

Given this background the following nationally oriented perspective seems to be more appropriate in order to analyse adaptation from an economic point of view. From the perspective of a single (small) country the amount of global mitigation (R) is given, because this country has no influence on the global level of mitigation and on climate change in general. This is also largely true for the EU as a whole, as its emissions are estimated to be 'only' around 22% of global emissions (2004 data from the IEA). However, as adaptation has many private good properties at the national level, this country has a strong incentive to

[4] See http://www.climateactiontracker.org/.

provide this good efficiently (see Box 2.1 for an example at the regional level). Therefore, as reduction R is given for a single country, only A^* has to be determined by the social planner in this country (following condition (5)).

Box 2.1: CBA for hurricane protection system in the City of New Orleans

The proposed national perspective for a CBA of adaptation projects is also relevant for single local projects. A prominent example for this approach is the question whether and how the city of New Orleans should be rebuilt after the Hurricane Katrina. There has been a controversial debate about this question (Hahn 2005, Schwartz 2005). Hallegate (2006) implements a CBA with respect to the issue whether the additional costs of a category 5 hurricane protection system (Katrina was category 4) for New Orleans are lower than the benefits from reduced flood damages. This study is remarkable because on the one hand it demonstrates the applicability of CBA to a large-scale and climate related disaster protection project and on the other hand the key elements determining the results are identified. A first standard CBA rules out category 5 hurricane protection. The additional costs of category 5 protection are $27 billion. Using an annual 1/500 probability of having a category 5 hurricane, the expected present benefit of a category 5 protection system in New Orleans is between $1.5 billion (with a 7% discount rate) and $6 billion (with a 3% discount rate). This calculation clearly rules out an upgrade of the protection system to make it able to cope with category 5 storms. However, taking into account effects such as climate change related effects to the environment, indirect impacts of large scale-disasters, and possible changes in the discount rate might still make such a hurricane protection a rational investment. Hallegate's study also emphasises the importance of the difference between direct costs (such as costs evaluated by insurance companies) and indirect cost. Direct costs may be amplified in the case of large-scale events, for instance by production losses during the reconstruction phase or by negative long-term effects on tourism.

There are the following potential limitations to the above presented cost-benefit approach. First, possible interactions between adaptation and mitigation are not considered. The IPCC (2007b, pp. 759-760), in discussing this issue, comes to the result that such interactions are of minor importance. However, more in-depth studies are needed to estimate the magnitude of interaction effects. The most important example for an interaction between both climate policy strategies is agriculture (Rosenzweig and Tubiello 2007). Some very specific adaptation practices may not be conducive to mitigation. For instance, increased or new cultivation due to a longer growing season may lead to losses of organic carbon in the soil, i.e. the reduced sequestration of atmospheric carbon in agricultural soils. Furthermore, with respect to the livestock production levels, warmer conditions in the coming decades may trigger the implementation of enhanced cooling and ventilation systems, which would increase energy use and (possibly) CO_2 emissions. Discussing those and other interactions between adaptation and mitigation, which may lead to increased CO_2 emissions from adaptation efforts we have to bear in mind that economic (cost) efficiency requires setting an equal price on all emissions sources in an economy. Therefore, in the case of increased GHG emissions in agriculture due to changing cultivation or livestock production techniques, one should set a price on the emissions (or at the production level) in this sector. Furthermore, the increased energy use due to enhanced cooling systems *in Europe* does *not* increase the CO_2 emissions. The reason for this is the existence of the EU emissions trading scheme (EU ETS), which sets an overall cap on the emissions of the regulated sectors. Since the electricity sector is under the EU ETS cap, higher electricity use does not increase CO_2 emissions but has only price effects on the emissions market. Actually, adaptation in Europe may even lead to a decrease of total CO_2 emissions. Higher winter temperatures will lead to a lower level of carbon intensive heating (mainly based on oil and gas) which is currently not under the EU ETS cap. The empirical evidence is quite clear: De Cian et al. (2007) estimate temperature elasticities of demand for different countries. For most European countries, the temperature elasticity of demand for electricity is positive while it is negative for gas and oil. On the other hand, increased need for air conditioning due to higher summer temperatures will lead to more electricity consumption, which is CO_2 neutral because the electricity sector is under the EU ETS cap. Thus, anticipating the final consequences of adaptation and mitigation measures, one has take into account the existing institutional framework.

Second, uncertainty about climate sensitivity and economic impacts may pose a serious challenge to CBA. Recent studies (e.g. Tol 2003 and Weitzman 2007, 2008) suggest that uncertainty about low-probability-high-impact events may limit the applicability of a cost-benefit framework. The reason is that – due to the possibility of a catastrophic event – there may be situations where society's expected marginal rate of substitution between current and future consumption is indefinite. On the other hand, Lange and Horowitz (2009), Tol and Yohe (2005) and Howarth (2003) show that even in cases where the economic value of avoiding a catastrophic event is infinite, the criterion of maximising expected present-value net benefits is operational.[5]

Given this scope of theoretical explanations, we analyse the *institutions* that can facilitate the provision of the efficient adaptation level at the national level, recognising both the governance challenges that might arise and the potential difficulties that can arise in the interaction of the government with the private sector (and even across levels of government). In particular, the importance as well as the limitations of markets with regard to the provision of adaptation measures will be analysed.

2.2. Adaptation as a public or private good

From an economic point of view, the distinction between adaptation as public or private good is essential because this procedure determines who should be responsible for providing the adaptation measure (see e.g. OECD 2008). In this section we show with a simple theoretical model how different adaptation measures may be characterised as private or public good. Thereby we closely follow Mendelsohn (2000). Furthermore, we analyse the role of government in this context.

Private adaptation

We start with a simple model of an economic sector that is climate sensitive. We assume that individuals or firms can engage in some expenditure that will tend to reduce the damages or increase the benefits from climate change. Furthermore, there is no market failure. The question is to what extent private adaptation leads to a social optimum.[6]

Reduced damages and increased benefits are defined in terms of a benefit function that depends only upon the amount of adaptation, A:

$$B = f(A) \qquad (6)$$

[5] Sections 3.7 and 3.8 discuss uncertainty with respect to adaptation.

[6] Mendelssohn (2000) refers to *private* adaptation, which is here equivalent to *autonomous* adaptation.

where $dB/dA > 0$, and $d^2B/dA^2 < 0$.[7] Benefits are non-linear. They are assumed to increase at a decreasing rate with adaptation. That is each monetary unit invested in adaptation reduces the residual climate change damage but the reduction is decreasing with more adaptation. The reason for this assumption is that adaptation measures that generate high benefits are first implemented.

Adaptation is not free. There are costs associated with adaptation, from either lost opportunities or explicit outlays. The cost function has the following properties:

$$C = g(A) \tag{7}$$

where $dC/dA > 0$, and $d^2C/dA^2 > 0$. Thus, also costs are non-linear. They are assumed to increase at an increasing rate. This cost curve reflects rising production costs due to a potentially higher demand for resources. Furthermore, if several adaptation options are available the low-cost measures are first implemented. For example before a house owner insulates her house from heat she may decide to use an air conditioning system.

The first order condition (FOC) implies

$$\max_A \; B(A) - C(A). \tag{8}$$

The FOC delivers an optimal level of A^* where the marginal benefits equal the marginal costs:

$$MB = MC \tag{9}$$

It is commonly assumed in economics that marginal benefits and costs are linear (see Figure 2.4). Although the real costs and benefits may jump at certain threshold levels, in particular in case of adapting infrastructure, this assumption seems to be a good approximation due to the potentially available adaptation measures the create different costs. For example, if people wish to respond to rising sea levels, they may decide to either build a new sea wall or raise the height of the old one. If the expected benefits from the new sea wall exceed the additional costs then the landowners should choose the new sea wall. This is what condition (9) implies.

If the individual must pay all the costs and yet enjoys all the benefits, then it is individually rational to choose the optimal amount of adaptation. Individually rational behaviour leads to a social optimal solution. Of course, if the strong assumptions of the above model are violated, efficient adaptation may not be selected. For example, if some of the costs of the adaptation are not paid by the individual, then the person may make the wrong choice from the social point of view. For example, what would happen if the government subsidises adaptation by an amount, γ, equation (8) will change to

$$\max_A \; B(A) - (1-\gamma)C(A) \tag{10}$$

The individual will choose an amount of adaptation where marginal benefits are equal to marginal costs:

[7] The effect of temperature on benefits – which could be positive or negative – is not modeled here, because this does not generate an added value at the moment.

$$MB = (1-\gamma)MC \tag{11}$$

The result will be too much adaptation. Although it is an individually rational behaviour, the subsidy encourages the individual to invest more than the efficient amount.

Another and perhaps more relevant example of incorrect costs occurs when there is an externality from an adaptation decision. For example, suppose that a forester switches tree species in order to take advantage of a warmer climate. Suppose that the forester only considers the timber benefits against the cost of encouraging the species switch. However, suppose that wildlife species dependent on the old species cannot survive with the new species in place. If the wildlife is valued by others, but the landowner does not consider this effect, the switch in species introduces a negative externality, $E(A)$, a cost which must be borne by others. The landowner will make the decision based only on his own costs and benefits (such as in (11)). However, society would face the choice below:

$$\max_{A} \quad B(A) - C(A) - E(A) \tag{12}$$

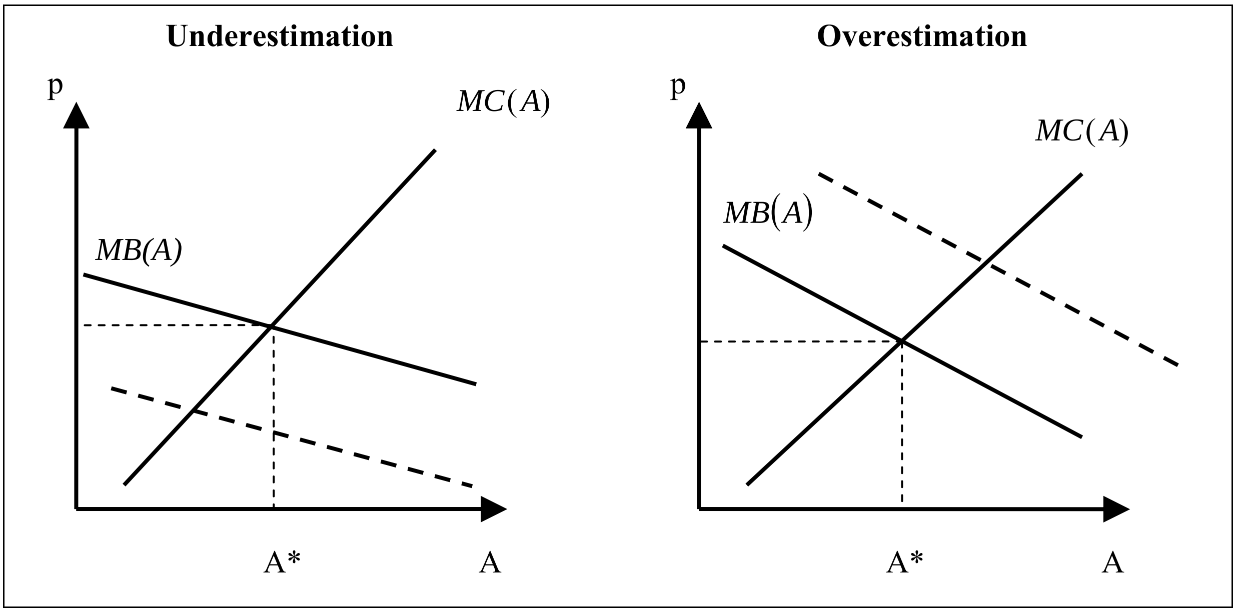
whereas the landowner would choose a level of adaptation that dealt with only the first two terms above as in (8), the optimal choice would now be the following:

$$MB = MC + ME \tag{13}$$

The optimal choice would weigh the wildlife effect as well as the cost of the conversion against the benefits of the new species. The landowner, in this case, would be too eager to make the change. Private adaptation can be inefficient if it involves substantial externalities.

The analysis can easily extended to the case that individuals underestimate or overestimate marginal benefits of adaptation. If there is substantial uncertainty about the future benefits of adaptation but the current costs are reasonably clear, people may make poor decisions about private adaptation. The result will be too little adaptation if people underestimate marginal benefits (left panel of Figure 2.4) and too much adaptation if people overestimate marginal benefits (right panel).

Figure 2.4: Uncertainty about the benefits of adaptation



Joint adaptation

Joint adaptation involves responses to climate impacts where there are many beneficiaries to each action. From an economic point of view, joint adaptation resembles a public good (Samuelson 1954).

The general model of joint adaptation reveals that the benefits of actions are shared across more than one decision-maker:

$$\max_{a_i} \sum B_i(a_1, a_2, ..., a_n) - \sum C(a_i) \quad (14)$$

where a_i is the amount of adaptation committed by individual *i*. With joint adaptation, the benefits to individual *i* depend not only on what individual *i* chooses but also on what many other individuals choose as well. The fact that the benefits of individual actions are shared by others is the defining characteristic of joint adaptation. This interpersonal complexity explains why joint adaptation is more difficult to manage efficiently.

In the social optimum, the sum of all marginal benefits from adaptation is equal to the marginal costs:

$$\sum_{j=1}^{n} dB_j / da_i = MC_i \quad (15)$$

The adaptation a_i^*, which would result from (15), would be efficient as it would maximise (14).

In contrast, if the individual only considered the effect of his expenditure on himself, then the individual would use a more limited definition of marginal benefits:

$$dB_i / da_i = MC_i \quad (16)$$

This would result in a level of adaptation a^0. Since $\sum dB_j / da_i > dB_i / da_i$, then it follows that $a^* > a^0$. The selfish individual would spend too little on joint adaptation.

In theory, a collective action through the government could solve the problem of joint adaptation by supplying protection levels based on an efficient allocation (15). The government, acting on behalf of society at large, would choose the efficient level of adaptation that maximised the group's net benefits. Total benefits and costs would be considered in every decision. Thus, government decisions, in addition to being concerned about direct group benefits, could also take into account externalities. In the remainder of this report, collective action, joint adaptation, planned adaptation and government intervention are used as synonyms, that is collective action is assumed to always involve some form of government regulation. However, other forms of collective action apart from government intervention could play a role in adaptation. Firms of the same branch may cooperate in a national or international association in order to share information or business strategies. For example, the German Insurance Association currently funds a research project on climate change and adaptation and their implications for the German insurance market. As these forms of collective action do not involve government regulation they belong to private or autonomous adaptation in this report. In other words, the fact that some firms or individuals may choose to respond to climate change the same way does not make it joint adaptation (Mendelsohn 2000). In contrast, public–private partnerships (PPP) belong to collective action because they imply some form of government intervention.

To sum up, the market will not always lead to efficient levels of joint adaptation, i.e. in the case of adaptation measures, which are public goods or at least have strong positive externalities. Joint adaptation will be efficient only through collective action. In general, governmental intervention is necessary if there is market failure and if the costs of the intervention are lower than the welfare loss due to market failure. Negative externalities due to private adaptation are another kind of market failure (such negative externalities can also arise from planned adaptation measures where there are negative cross-border effects). In this case governmental action is necessary to reduce the amount of private adaptation measures. Two examples can illustrate this issue. First, building dykes in order to prevent river floods up-stream increases the risk of floods downstream. In a non-cooperative environment, an up-stream decision-maker will not take into account the negative externality for the down-stream region generated by the dyke. Second, adaptation measures such as changes in mobility behaviour may increase emissions of pollutants such as CO_2 and NO_x. Again, rational and selfish subjects will neglect the negative externality leading to a social dilemma situation.

Facilitating autonomous adaptation

Besides the provision of adaptation measures with strong public good properties, there is a second important aspect of governmental intervention: autonomous adaptation to climate change may need to be 'facilitated' by governmental action. Politicians may i) help economic agents to better understand the nature and impacts of the expected climate change, i.e. to produce and distribute information, and ii) create an institutional framework where autonomous adaptation can be successful (Heller 2008b).

Rational subjects need information in order to adapt efficiently. *Information* on the expected regional effects of climate change, however, has strong public good characteristics. Given the non-rivalry, the marginal costs of information dissemination are close to zero. Furthermore, excludability of information on the expected climatic effects is difficult to enforce. Therefore, private agents will not be able to provide sufficient information on the expected regional impacts. In other words, governmental action is necessary in order to provide the efficient amount of information about the expected regional effects of climate change.

The importance of the institutional framework will be illustrated by property rights. Without a functioning property rights system, long-term investments, which are crucial for several adaptation strategies, will not take place (see Box 2.2). The absence of such facilitating adaptation may ultimately lead to inadequate autonomous adaptation and a higher level of necessary planned adaptation in the future.

Box 2.2: Property rights in Finland

Property rights systems are the basis for efficient long-term adaptation. Hilden et al. (2005) give a good example. The current legislation in Finland restricts the land tenancy period to ten years only, while in many other EU countries such short tenancy periods are exceptional. The short tenancy period in Finland results in land tenure insecurity and provides little incentives for investments in drainage systems of fields or in improving soil quality. While the proportion under lease farming has increased up to 35% in Finland in the last ten years, the investments in drainage systems, as well as lime application on land, have decreased. The projected increase in annual precipitation by 30-40%, and an increasing probability of heavy rainfall and storms due to climate change require efficient drainage systems. Hence, farmers need appropriate economic incentives and a suitable institutional setting for making investments in drainage systems whose operating time is typically 50-100 years, if properly installed.

Another important point is that autonomous adaptation actions may not only be induced by governmental incentives, but also may be influenced by *planned* adaptation efforts by the government (Heller 2008b). This arises from the potential for 'moral hazard' effects. As has been discussed by Wildasin (2008), Goodspeed et al. (2007), and others in the context of recent US terrorist and hurricane events, the amount of autonomous adaptation to some climate change-related events may be lower if there is a perception that ex post, the government will reimburse economic agents for much of the damages arising from such events. Even with the recognition that there may not be full compensation, the ex ante precaution would not reach the efficient level. In other words, planned adaptation by a government may deter autonomous adaptation actions by private economic agents.[8]

Such moral hazard effects have mostly been discussed in relation to the effects of US Federal Governmental actions after Hurricane Katrina. These may have led *state and local governmental units* to invest less in future climate change preventive adaptation measures. But the issue is equally relevant to the extent that governmental action – whether reactive or anticipatory – may also discourage the *private* sector from engaging in autonomous adaptation efforts. There is a similar situation in Germany (Schwarze and Wagner 2003). The German flood disaster in summer 2002 highlighted a dilemma concerning insurance against damages caused by natural forces. On the one hand, owing to the rising incidence of natural disasters, private insurance companies are increasingly withdrawing coverage of floods. On

[8] See also section 3.8 for the effects governmental intervention may have on the natural disasters insurance scheme.

the other, the availability of emergency relief funded by the state and private donations in case of a natural catastrophe is systematically weakening the incentive for potential private victims to implement preventive measures, i.e. the contracting of insurance that can reduce the risk of damages. Local authorities may also believe that the government will cover the cost of repairs and decrease their efforts towards risk prevention.

Thus, in trying to characterise what might be required in the form of governmental adaptation actions (and in assessing their fiscal consequences), it becomes important to assess how such actions might affect autonomous adaptation of nongovernmental agents (or even adaptation by lower levels of government). Indeed, some might argue that governments should not intervene in the case of extreme events other than for basic welfare-provision in order to avoid provoking such moral hazard problems.[9]

2.3. Equity aspects

Another justification for governmental intervention to facilitate private autonomous adaptation is equity. We propose the following structure for analysing equity issues: i) equity issues within countries, ii) equity issues between EU member states, and iii) equity issues between industrialised countries and developing countries.

Let us first consider equity issues in the national context. Although private adaptation may be efficient, it may not be considered as just (Mendelsohn 2000). Here, both vertical and horizontal equity (Atkinson and Stiglitz 1980) matter for public policy, i.e. aspects of redistribution between high and low income households and the equal treatment of individuals by the law. With respect to vertical equity, low-income households may not be able to afford adaptation measures and equity concerns may thus motivate the need for governmental action. The intense debate about the introduction of lower energy prices for fuel- or energy-poor households[10] in order to protect these households against adverse effects is an example for this kind of distributional problem. In the future, there may be a similar discussion about the 'right' prices for adaptation measures or prices for inputs for such measures. Essentially, society has to decide which human needs it considers to be elementary and deserve insurance by public authorities if a citizen cannot provide for himself. Adaptation may require new answers to this old question of social policy. Economic policy has to find measures to ensure these entitlements without excessive efficiency losses. In principle, the preferable solution from an economist's viewpoint is to give lump-sum transfers to low-income households. Thereby relative prices will not be distorted and the governmental support is transparent. The case of health insurance shows, though, that in some cases satisfying entitlements may require more complex answers, in particular when moral hazard and adverse selection render first-best solutions impossible. These can arise in the case of energy poverty, too: poor households tend to live in rented rather than self-owned homes and will thus have little influence on the insulation. Real estate companies, on their part, will rather not invest into insulation when they cannot charge higher rents. This may justify government handling of social housing.

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[9] See, for instance, Epstein (1996).

[10] See for example "Barroso urges lower energy prices to help poor", 6 July 2008, http://www.eubusiness.com/news-eu.

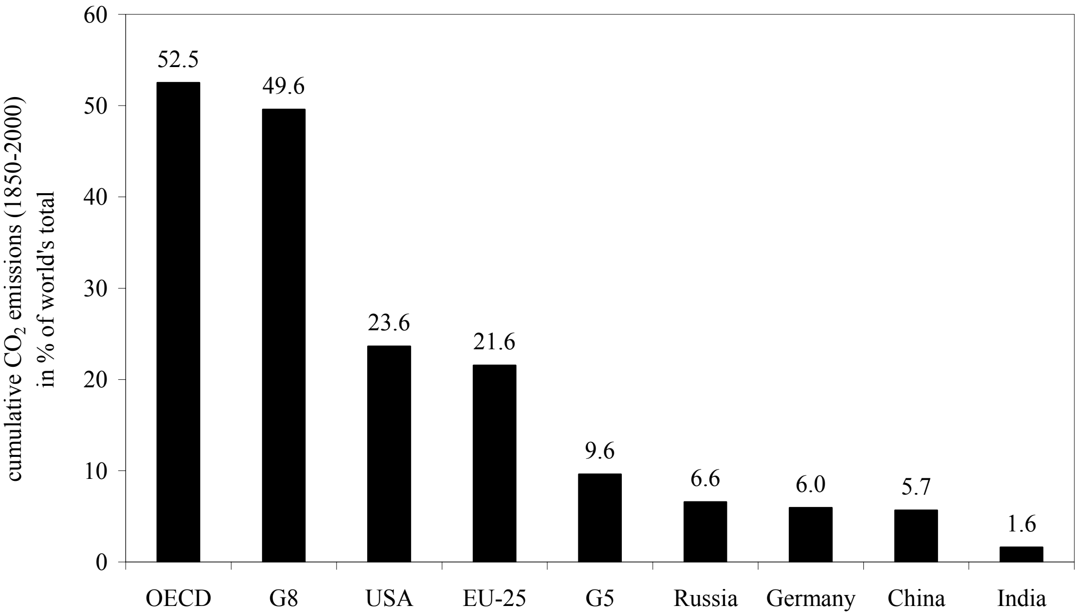
The matter of horizontal equity may well prove to be trickier. For example, it may well be efficient to shelter one agglomeration from flooding while giving up another agglomeration, depending on the relative costs and benefits. Clearly, however, such a policy decision has very different impacts on real estate property rights. If taken by a central government, the unequal treatment would surely provoke lawsuits. In the future governments will have to develop rules (and limits) for compensation for households whose property is not protected. Federal states will have to device a framework of local, regional and national responsibilities for adaptation. Given the huge fiscal consequence of both collective adaptation and compensation, this is a great challenge.

Second, since climate change damages will vary among regions (EEA 2008), in particular between southern Mediterranean and northern European states, the question arises to what extent the EU will provide *intergovernmental transfers* from the winners to the losers (Heller 2008b). The EU has to decide whether it has a responsibility to help finance adaptation actions that would reduce the burden of climate change to citizens of a negatively affected country. Thereby, a moral hazard issue arises, because loser countries may anticipate the help of the EU and therefore reduce their adaptation efforts in order to get more financial assistance.

Third, the equity argument seems to be especially powerful in an international context where climate change is currently being caused by relatively wealthy northern countries and yet the victims may well be largely poorer southern countries.

As shown in Figure 2.5, both OECD and G8 countries are responsible for approximately half of the world's cumulated CO_2 emissions between 1850 and 2000. On the other hand, G5 countries represent only a fraction, viz., 9.6%. In terms of individual countries, the largest emitters are the US (29.3% of the world's emissions), the EU-25 (26.5%), Russia (8.1%) and Germany (7.3%). China, which recently became the world's largest CO_2 emitter (MNP, 2008), is only responsible for a fraction of 7.6% of the world's cumulated CO_2 emissions (WRI estimates for emissions 1850-2002). These numbers underline in which ways groups of countries and individual countries are responsible for causing the climate change problem.

Figure 2.5: Cumulative CO_2 emissions

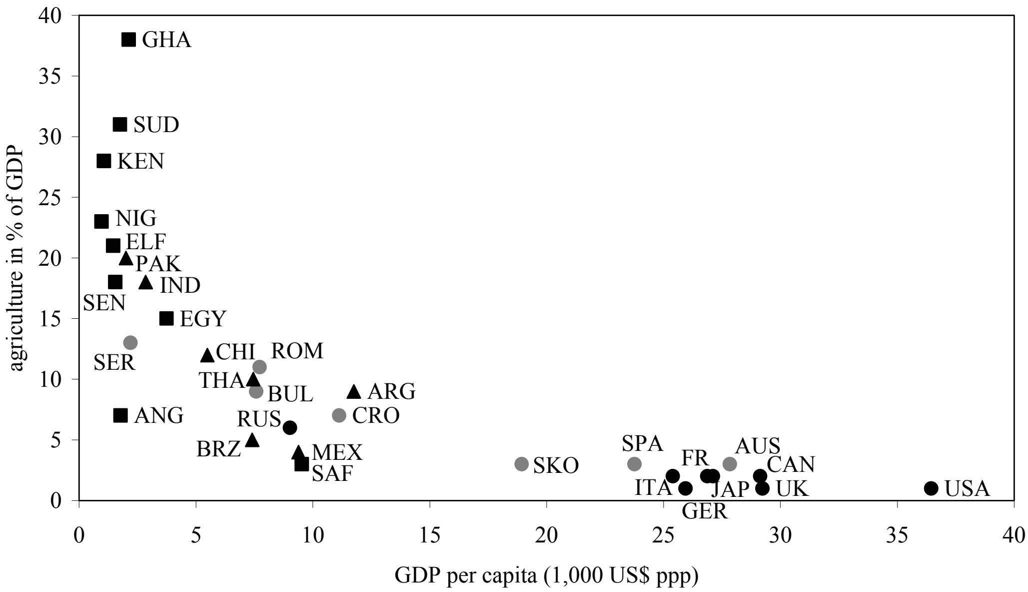


Source: World Resources Institute.

While developed countries bear the main responsibility for the strong increase in CO_2 emissions during the last century, climate change damages are expected to be higher for developing countries. According to Parry et al. (2005), who evaluated the implications of climate change for food production and risk of hunger, the region most at risk is Africa. In order to compare the vulnerabilities of different countries, a comprehensive vulnerability index would be helpful, which encompasses all the possible impacts on a country's economy, society, and nature. Creating such an index is not an easy task, for at least two reasons: a) there are multiple concepts of vulnerability in the different sciences and schools; and b) vulnerability often refers to a particular situation which is hardly comparable to other countries or societies (Füssel 2007b, O'Brien et al. 2004, Vincent 2004). An example of a fully described vulnerable situation would be "the vulnerability of the energy sector along the river Rhine to climate change up to 2050" (Füssel 2007b). Therefore it is difficult to construct a comprehensive vulnerability index that allows a comparison of climate change vulnerability between different countries on different continents. Figure 2.6 is an attempt to illustrate the different vulnerabilities of selected countries. The figure shows a scatter plot where the fraction of GDP that is generated by agriculture is plotted versus GDP per capita. In addition to African countries (depicted as black squares) and G8 countries (black dots), emerging countries in Asia and South America (black triangles) and other developed or European countries (grey dots) are displayed. Since for abovementioned reasons comprehensive indicators quantifying the climate change vulnerability of a country are lacking, we display the fraction of GDP originating from agriculture. Agriculture is the economic sector that is probably most climate dependent, and the fraction it contributes to the GDP may at least provide a first order approximation to what extent the GDP may directly be affected by the climate. GDP per capita on the other hand indicates the average ability to pay, for example in order to buy food at increased world market prices or to invest in climate-change adaptation measures to prevent climate damage. The figure shows that for most African countries the GDP per capita is much lower than in the developed countries while at the same time agriculture plays a major role in those nations' economic systems and accounts for as much as a third of some countries' welfare. While this welfare contribution is at risk in case of extreme weather events, the GDP per capita of these countries is often below $2,000. This is less than a tenth of developed countries such as Germany or Spain, and the difference is even greater with regard to Great Britain or the United States. Vincent (2004) proposes more indicators as determinants of a country's vulnerability: economic well-being and stability, demographic structure, institutional stability and strength of public infrastructure, global interconnectivity, and natural resource dependence (which is solely included in Figure 2.6). Although her analysis focuses on African countries, at least some of the indicators are also applicable in the EU. A proposal for a vulnerability index particularly for EU countries can be found in European Commission (2008c). The variables used here are the change in population affected by river floods, population in coastal areas below 5 m, potential drought hazard, and the regional shares of agriculture, fisheries and tourism in gross value added. However, for illustrating the global equity aspects of climate change, Figure 2.6 gives a reasonable approximation for a global comparison of vulnerabilities.

In short, the bulk of carbon emissions in the past that have caused the man-made part of global warming are due to the activity of industrialised countries, which have fuelled their economic development by burning fossil fuels. Since the heaviest burden due to climate change will be borne by the least developed countries, it is evident that climate change also poses severe distributional problems. Consequently, to break deadlocks in future international climate policy, equity and justice will inevitably play an important role in addition to the efficiency considerations outlined above.

Figure 2.6: Vulnerability and ability to pay



Source: World Resources Institute, The World Bank (2008).

For Europe, in particular, the situation in North Africa and the Middle East is relevant (Heller 2008b). The effects of climate change in terms of heightened summer temperatures and extreme water shortages, coupled with continued high population growth rates in these countries, may result in pressures for migration to Europe that could be an important source of tension.

2.4. Security of supply

Security of supply is one of the stated goals of energy policy in the EU (e.g. COM 2009). While mostly discussed in relation to energy, arguments of security of supply are also – directly or indirectly – used in debates on food and water supply. All these sectors face considerable challenges by climate change, and thus security of supply matters for the debate of adaptation, too.

From a theoretical economic perspective, the issue is odd at first sight: energy carriers, food and water are private goods in the economic sense of the word, and efficiency of markets in their provision should be guaranteed by the basic welfare theorems of economics. In the case of energy and water, transport provides an economic argument for government intervention: electricity grids, gas pipelines and water sewage systems are typical examples of natural monopolies. Their provision of the transport service is characterised by increasing returns to scale, i.e. the larger the network, the lower per-unit costs of transport (this is also called a 'network externality'). Therefore competition between several providers of transport service is inefficient because a single network can provide the service at lower cost. This gives an economic rationale for network regulation, since a monopolistic provider is likely to overcharge his service.

However, the argument for government intervention on grounds of security of supply goes beyond regulation of networks. Rather it is based on the presumption that the good in question is indispensable for economic production and individual welfare: indeed a prolonged shortage of drinking water in a certain region would have devastating effects on public health.[11] Similarly, albeit to a lesser extent, public welfare and economic production are vulnerable to blackouts of the electricity system.

The policy issue arises because companies providing water or energy in a free market are not likely to insure their consumers sufficiently against interruptions of the supply: given the short-term inelastic demand for the goods, markets are likely to clear at very high prices in the case of a shortage – an efficient outcome, but unacceptable from the viewpoint of public welfare, at least for some basic human needs. Private supply of drinking water is likely to be profitable during a drought period, but – given the elementary needs of the population – the government's objective would be to ensure that there are sufficient provisions for such a situation.[12]

The same reasoning applies to the energy sector, where security of supply is viewed as an important pillar of energy policy (Helm 2002, Abbott 2001). This does not imply, though, that the provision of the good has to be organised by public authorities: in the case of liberalised electricity markets, in many countries the grid is operated by a private monopolist that is regulated by a public agency. In particular, the grid company is obliged by law to ensure the security of the network, i.e. the security of electricity supply. The costs are incorporated into

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[11] Northern China is an example – contamination of surface water and desertification endangers the drinking water supply and consequently the health of the population, in particular, rural areas (World Bank 2007). This is widely perceived as a public policy issue, both in China and outside.

[12] While water is certainly not a public good – its consumption is rival – economists refer to it as a common-pool resource, justifying regulation on grounds of negative external effects (McGuiness 1999, Hardin 1968). Given the basic need for drinking water, the regulation of water supply may in practice be governed by both efficiency and equity concerns.

the usage fees. In other words: Specific regulation can be used to enforce security of supply in otherwise free markets, carefully trading off security against efficiency.

Apart from problems to be discussed in a national context, security of supply can be a geopolitical issue: the supply of gas from gas-exporting countries with a monopolistic position may lead to political pressure on the importing countries. Similarly, in some world regions access to drinking water is seen as a right enforceable by political and – if necessary – military means. However, this problem is beyond an economic welfare analysis, because any market rule or property right in this context is vulnerable to political manipulation. Economists may contribute to a positive analysis of these aspects of adaptation to climate change by the study of international negotiations. These may for example arise in the context of access to scarce water resources or agricultural land with disputed property rights.

As in the case of equity issues, adaptation to climate change sheds a new light on old questions of security of supply: Which goods and services are elementary, so that government intervention should guarantee their security of supply? What are the costs of such a policy? What is an acceptable level of security of supply, for instance in the case of drinking water? Public policy on adaptation will have to find answers to these questions.

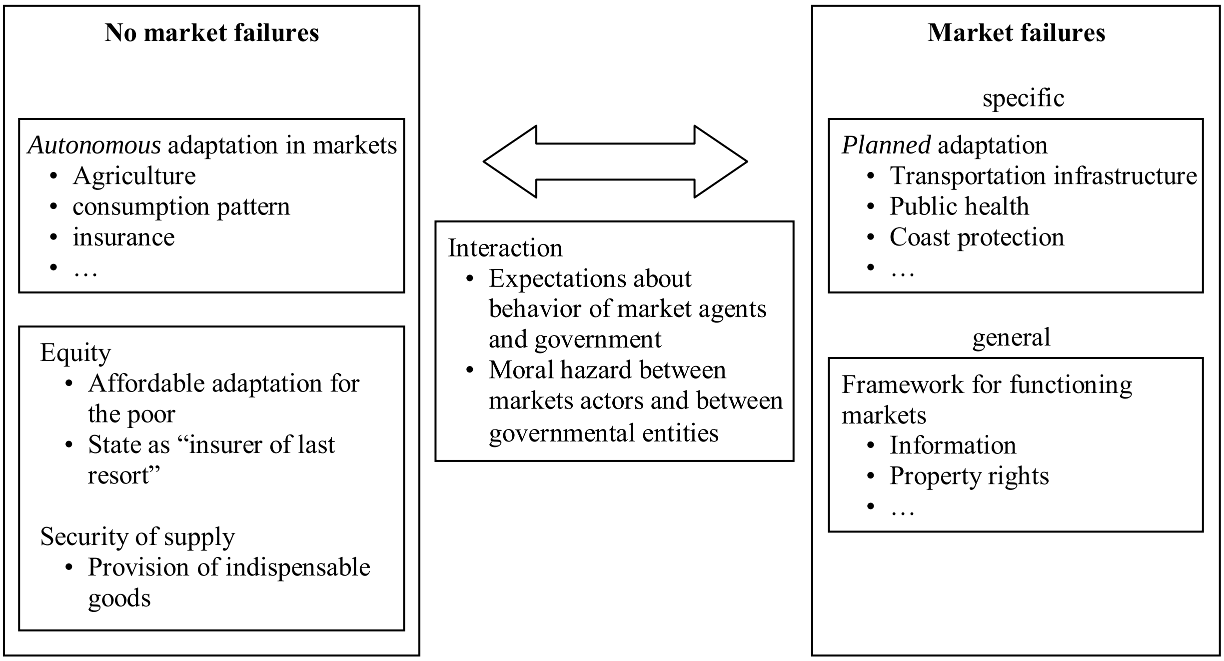
2.5. Role of markets and collective action

The central question in the previous sections was about the role of markets and collective action, i.e. governmental intervention, in order to ensure an efficient adaptation to global climate change (see also OECD 2008). Figure 2.7 summarises the results of our discussion. The economic concept of market failures is the central tool in order to structure adaptation measures. If no market failure can be detected, autonomous adaptation is the appropriate choice. Typical examples are change of crops and cultivation methods in agriculture, changing consumption pattern and the emergence of new insurance products. Equity considerations and security of supply do not constitute a market failure. However, collective action in order to redistribute income and to ensure the provision of indispensable goods is generally seen as task for the state.

In case of market failure, two different types can be distinguished. First, ‘specific’ market failures directly related to adaptation, which has to be planned centrally. Adaptation in transportation infrastructure, public health system and coastal protection are examples for this. Second, ‘general’ market failures concern the framework for functioning markets such as information or property rights.

The interaction between autonomous adaptation and planned adaptation is an important and often neglected aspect. More planned adaptation (or expectations of such projects) may lead to less autonomous adaptation and vice versa. The interaction between planned and autonomous adaptation can be influenced by moral hazard issues between market actors but also between governmental entities.

Figure 2.7: Adaptation and market failures



2.6. Timing of adaptation

Climate change is a long-term issue. Therefore, one key question is *when* adaptation measures should be undertaken. As the opportunity costs as well as direct investment costs and benefits may differ over time, this is an important issue. Below we analyse theoretically which facts determine the optimal timing of adaptation (Fankhauser 2006). Conceptually, the analysis applies as much to the considerations relevant to autonomous adaptation as to planned adaptation.

Considering the optimal timing of adaptation, the net present value of the costs of adaptation now (NPV^N) have to be compared with the net present value costs of adaptation at a later period (NPV^L).[13] Let us assume that adaptation now ($t = 0$) costs A^N. Annual maintenance costs amount to M^N over time. Thereby we assume that there are no maintenance costs in the first period, i.e. $M_0^N = 0$. Adaptation will reduce annual climate damages to D^N over the lifetime of the project. If the damage is discounted by the rate δ, the net present value costs of *adapting now* can be written as

$$NPV^N = A^N + D_0^N + \sum (D_t^N + M_t^N)\delta^t \qquad (17)$$

If adaptation is undertaken a period later (e.g. say a decade later), the costs of adaptation are discounted, but climate impacts in the initial period will not be avoided. That is, they reach a

[13] Here one also needs to recognise that i) there may be choices among projects, with some involving longer longevity than others. For the shorter-lived ones, the decision-maker may be faced with the issue of whether the costs of a new project that would carry you to the same time frame as the longer lived project, may prove greater; and ii) that many projects have only a limited time scale so that the decision-maker will be forced to initiate new projects in the future and that (like the subsequent discussion on later adaptation), may lead to a very different situation in terms of the cost and damages averted.

level of $D_0^U > D_0^N$, where D_0^U are the climate damages now when adaptation is undertaken later (*U – unadapted*). It is also possible that adaptation costs (A^L), maintenance costs (M^L), and subsequent damage costs (D^L) will change. This may be the case because of innovations in adaptation techniques (see Box 2.3). The net present value costs of *adapting later* can be written as

$$NPV^L = A^L\delta + D_0^U + \sum (D_t^L + M_t^L)\delta^t \qquad (18)$$

The difference between the two value streams, (17) and (18), represents the net benefit of early adaptation, which is as follows

$$\underbrace{\left(NPV^N - NPV^L\right)}_{\substack{\text{Net benefit of}\\ \text{early adaptation}\\ \text{if} < 0}} = \underbrace{\left(A^N - A^L\delta\right)}_{\substack{\text{Difference in}\\ \text{adaptation}\\ \text{costs over}\\ \text{time}}} + \underbrace{\left(D_0^N - D_0^U\right)}_{\substack{\text{Short-term}\\ \text{benefits of}\\ \text{adaptation}}} + \sum \left(\underbrace{D_t^N - D_t^L}_{\substack{\text{long-term}\\ \text{effects of early}\\ \text{adaptation}}} + \underbrace{M_t^N - M_t^L}_{\substack{\text{Difference in}\\ \text{maintenance}\\ \text{costs}}}\right)\delta^t \qquad (19)$$

The expression (19) shows that the optimal timing of adaptation depends on four cost components. *First*, adaptation costs may change over time,

$$A^N - A^L\delta \, .$$

Discounting would generally favour a delay in adaptation measures (because $\delta < 1$). Similarly, the prospects of potentially cheaper and more effective adaptation techniques to be developed in the future would support a delay of adaptation (i.e. $A^L < A^N$).

Box 2.3: Technical innovations reducing adaptation costs

A recent example for the fact that R&D may lead to lower adaptation costs is the development of a new synthetic material that can be used to strengthen dykes. The material (called Elastocoast® developed by BASF) is able to bind crushed stone (which is the basis for dykes to protect coast and river banks) in order to enhance the strength of dykes. This procedure is already in practice, for instance at the river Elbe near Hamburg and at the coast of the island Sylt in Germany.

Source: http://www.basf.com/group/corporate/de/content/news-and-media-relations/science-aroundus/imperiled-dykes/index.

However, there are also adaptation measures where *early action* is cheaper. This class of adaptation measures includes long-lived infrastructure investments such as water and sanitation systems, bridges and ports. In each of these cases, it will be cheaper to make adjustments early, namely in the planning phase of the project, rather than incur the costs and inconvenience of expensive retrofits (i.e. $A^L > A^N$). In these cases it is therefore necessary to anticipate future changes in the climatic conditions, because given the long-life cycle of investment the flexibility to adapt is very low.

The *second* component in expression (19) concerns the short-term benefits of adaptation

$$D_0^N - D_0^U .$$

Early adaptation will be justified if it has immediate benefit effects (i.e. $D_0^N < D_0^U$), for example by mitigating the effects of extreme weather events, i.e. adaptation to climate variability. This cost component also includes adaptations that have strong ancillary benefits, such as health investments or poverty alleviation.

The *third* component includes the long-term effects of early adaptation

$$\sum \left(D_t^N - D_t^L\right)\delta^t .$$

Early adaptation is justified if it avoids long-lasting or even irreversible damages, for example to ecosystems.

Worth mentioning is that the analyst's expectations of D_t – damages in some future time period t – are a function of *when* the cost-benefit analysis is done and the specific expectations of how climate change will eventuate in the future (reflecting what we assume about which climate scenario, like the SRES scenarios by the IPCC, is likely to prevail and how future mitigation will modify that scenario). If we delay adaptation to the future, our views on how climate change will eventuate may be very different at that point in time.[14]

The *fourth* costs component considers the maintenance costs

$$\sum \left(M_t^N - M_t^L\right)\delta^t .$$

Many adaptation measures not only consist of expenditures now but also entail maintenance costs spread over time. If these costs are likely to decrease over time due to technological change ($M_t^L < M_t^N$), then a delay of that adaptation measure may become preferable.

To sum up, early adaptation is useful if i) adaptation costs will not decrease over time, ii) there are strong short term benefits of the adaptation project, iii) the project will avoid long-term and irreversible damages, and iv) maintenance costs will not decrease over time.

2.7. Adaptation strategies under uncertainty and irreversibility

So far we have neglected the aspect of uncertainty in climate change. Clearly, uncertainty matters for climate change: there is scientific uncertainty concerning the expected regional effects, assessment uncertainty concerning the economic impacts, and policy uncertainty (Heal and Kriström 2002). In this section we describe the framework to analyse optimal strategies of adaptation under uncertainty.[15] The next section will discuss another aspect of

[14] Also, the analysis could be extended to contain a possible relationship between the level of *A* and the level of *D*. Presumably, the higher *A*, the lower will be *D*, though, the sensitivity of the *D*(*A*) function in future periods will depend on what is assumed about how the climate is changing in future periods.

[15] We refer to Arrovian uncertainty only – i.e. uncertain events where the probability distribution is known. There has been little to no study so far how to assess Knightian uncertainty in the context of climate change, i.e. uncertainty over events with unknown probability distribution.

uncertainty, namely adaptation of insurance markets to changing climate conditions and a higher likelihood of extreme weather events.

Uncertainty and the option to wait for better information may have an effect on the optimal adaptation behaviour, in particular if decisions are irreversible. This is the topic of real option theory (Dixit and Pindyk 1994), which studies optimal behaviour under irreversibility, uncertainty and learning. Uncertainty about the exact nature of climate change impacts at the local and regional level makes it difficult to fine-tune adaptation measures. However, private actors and the government are likely to learn more about local impacts as time proceeds (see Box 2.4). Adaptation benefits (avoided climate damages) occur in the future – so they should be interpreted as expected benefits. In contrast costs for long-term adaptation projects, such as investment in climate-proof infrastructure (e.g. for transportation or energy networks) are certain and typically irreversible (i.e. after the investment costs are sunk). At the same time, the timing of the investment is for the investor to choose and can be delayed if appropriate – for instance, instead of building a dyke now the policy-maker can wait for better information regarding the likelihood of flooding in his agglomeration. Real option theory studies the effect of flexibility on optimal action.

In the case of adaptation measures – both by private or public actors – given uncertainty with respect to the expected regional effects of climate change, the benefits of the investment in an adaptation project have to exceed the costs by a positive amount (so-called 'hurdle rate'), in order to justify the investment. This amount is the 'option value' not to invest but to wait and to delay the project. In other words, the classic rule according to which the present value has to cover at least the costs of investments does not hold under these circumstances. The optimal solution to this problem includes the comparison of investment costs and presents values at all possible time slots, i.e. it has to be taken into account that the investment is possible at different time slots. Using the option to wait, an investor can possibly gain new information about future benefits (but also about better adaptation techniques that may reduce costs) and can adapt his behaviour to changed conditions. Real option effects can work in the opposite direction, too: cheap options for adaptation or mitigation may disappear or become more costly as climate change intensifies over time. An appropriate analysis of an adaptation strategy has to incorporate this aspect as well.[16]

Box 2.4: Regional climate projection models for Germany

Germany has made considerable progress in enhancing regional climate projections for its territory. Currently Germany's Federal Environmental Agency uses two main approaches of regional climate models: WETTREG (UBA 2007) and REMO (MPI 2008). REMO is based on a dynamic approach using the boundary conditions of the global model ECHAM5/MPI-OM. WETTREG uses a statistical downscaling approach of the same global model as REMO. Both models are based on the IPCC socio-economic storylines and their derived scenarios A2, A1B and B1 (representing high, middle and low emission rates of GHG). The climate scenarios are calculated with a resolution of 10 km x 10 km, which is significantly higher than the available scenarios of the IPCC (used in EEA, 2008).

[16] See Fankhauser (2006) for a discussion of incentives for early investments in adaptation projects when climate change damages in the near future can be avoided.

To sum up, as far as our knowledge about climate change impacts at the regional level will become better in the future, there may be a good reason *to wait* for better information, in particular when adaptation costs will be sunk after the investment. In other words, there is an 'option value' to wait for better information or better adaptation techniques and *to delay* costly adaptation measures. This incentive is opposed to the incentives for early adaptation measures in the case of long-lived infrastructure mentioned above (see section 2.6).

2.8. Adaptation of insurance markets

This section analyses the theoretical framework of insurance markets and their relevance for adaptation. Climate change tends to increase the frequency and severity of extreme weather events (IPCC 2007a). That is, the probability of extreme weather events is not only uncertain but also changes with global warming (Müller-Fürstenberger and Schumacher 2008). Worldwide damages from extreme weather events have clearly increased in the last decades. Schmidt et al. (2009) calculate that even if controlling for effects such as population changes, inflation, increased wealth or changes in settlement behaviour, there is a significant positive correlation between natural disasters and global temperature.

The insurance sector can play an important role in addressing the uncertainty with respect to local effects of climate change (OECD 2008). Principally, insurance markets are able to provide protection against climate-induced losses. The transfer of risk from risk-averse subjects to risk-neutral insurance companies leads to welfare improvements and, if well designed, an efficient level of precaution. Given an appropriate institutional framework – in particular a property rights system and functioning credit markets – insurance markets will find an efficient reaction to climate change. The effectiveness of insurance markets for climate adaptation may be hampered, though, by informational problems (*adverse selection* and *moral hazard problems*), covariate risks, uncertainty, and a lack of demand. In the following we briefly discuss all these issues and the implications thereof.

Let us briefly recall the basic paradigms of insurance markets, as studied by the theory of expected utility (Schoemaker 1982, Gollier 2000). The theory of insurance generally assumes many risk-averse customers facing independent risks who pay premiums to a risk-neutral insurer in exchange for protection against possible future losses. Using the law of large numbers and knowledge about the distribution of risk an insurance company in principle takes a risk-neutral position – the total expected value of damages is equal to the total value of expected revenues. When customers have no real influence over risks, insurance policies are relatively simple and parties frequently purchase complete coverage, which is the socially optimal outcome. More often, however, customers can influence risks – think of settlement behaviour that can influence the risk of flood damages or the construction of a building that can influence the risk of storm damages. This type of problem in insurance markets, which arises from the impossibility to completely control the behaviour of the insured, is labelled *moral hazard problem* (Arrow 1963). Most often, the socially optimal outcome – perfect insurance and sufficient precaution – cannot be achieved under these circumstances, but only a second best insurance contract with varying premia and partial coverage, trading off the insurance motive and the reduction of moral hazard. The degree of moral hazard will depend on the ability of the insurance company to gather information. In principle it is free to control the construction or the site of a building and incorporate the information in the insurance contract. Yet at least in some cases the individual risk evaluation may prove to be too costly and the company will offer standard contracts with partial coverage only. The incident of moral hazard can also arise from public intervention: many natural hazards have shown that politicians as well as the private sector provide financial aid for victims (see Box 2.5). The effort to help the victims of natural disasters is an act of emergency and humanity. As in the case of private insurance anticipation of loss compensation by the government may lead to insufficient precaution and – as mentioned above – to the crowding-out of private insurance. Therefore, ex-post emergency relief should be limited to most elementary protection (see Box 2.5 for an example).[17]

Box 2.5: Moral hazard and insurance in Germany

Moral hazard may lead to an insufficient demand for insurance coverage. One possible solution may be the recent approach of the Bavarian state government for natural hazard insurances for private homes (Bayerische Staatsregierung 2009). The government of this federal state in southern Germany currently runs an information campaign in order to sensitise private households to the risks of natural hazard damages on homes and contents. Effectively, this campaign is a publicly financed marketing campaign for private insurance. In this context the government emphasises that state relief is only possible in exceptional cases where private insurance is not applicable (less than 2% of Bavarian private households). Although this specific approach of the Bavarian state government targets only the market of insurance for private homes, a comparable strategy may also hold for government intervention in other sectors.

The second type of informational problem is commonly known as *adverse selection* (Rothschild and Stiglitz 1976): as an insurance company cannot distinguish between high-risk and low-risk customers – the risk may be partly private information – it has to offer one insurance contract to all, pooling all risks. The implicit redistribution of such a scheme from low to high-risk type may lead to the breakdown of the insurance market when low-risk types find the premium too high and withdraw. Generally, we can say that distortions of insurance markets occur if insurance takers or insurance companies have incomplete information or if they misperceive risks, i.e. information is distributed asymmetrically. Sometimes insurance is not offered because risks are hard for insurance companies to estimate. In particular this is the case if the probability of a catastrophic event is very low so that the law of large numbers can no longer be applied.

Another problem arises if the risks faced by different insurance takers are *non-independent,* which is likely to be the case with climate change damages. For example, the risks of flood damages are positively correlated within one area. Insurance companies then cannot be confident of meeting their costs and they will therefore tend to charge higher premiums, presuming some degree of risk aversion on their part. In this case, the insurance takers' expected utility will be maximised if they obtain less than full coverage of damages (Shavell 1987). This effect could be alleviated if (international) re-insurers pooled the risks facing different (national) insurers.

[17] As has been discussed by Wildasin (2008) and Goodspeed et al. (2007) in the context of recent US hurricane events, the amount of autonomous adaptation to some climate change-related events may be lower if there is a perception that ex post, the government will reimburse economic agents for much of the damages arising from such events. Even with the recognition that there may no full compensation, the ex-ante precaution might not reach the efficient level.

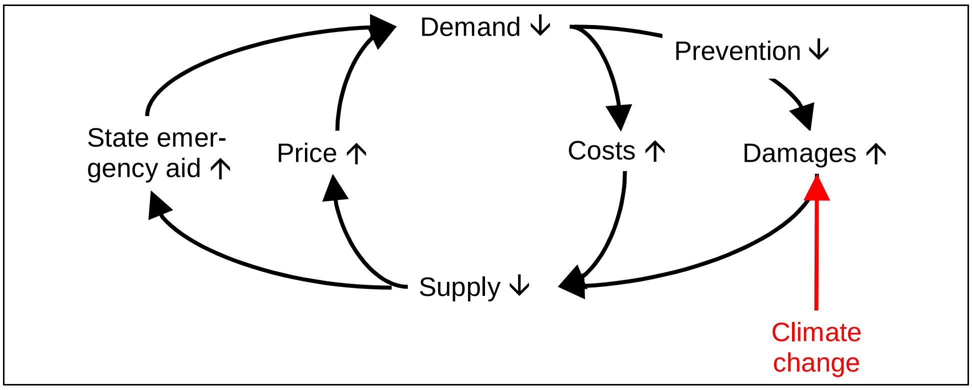
The next issue concerns *uncertainty*. Extreme weather events are uncertain, i.e. they occur with a certain probability, but it may be that also this probability is unknown. If the insurance overestimates the risk then it will charge too high premiums and request too much precaution. In contrast if the insurance underestimates the risk then it will demand premiums and precaution that are below the efficient level. This problem should lessen over time as the parties gather more information about the true risk.

Finally, one often observes that the free market produces a rather low insurance density (Schwarze and Wagner 2002). The example of Germany (Box 2.6) indicates that the low level of natural hazard insurance coverage is mainly due to a *lack of demand*. There are several possible reasons why the demand for insurance coverage may be too low: i) lack of information about risks, ii) potential victims underestimate risks, iii) anticipation of ex-post emergency relief, and iv) interaction effects between distorted demand and insufficient supply. The last aspect is graphically presented in Figure 2.8. It shows the interconnection between demand and supply. The two factors mutually escalate each other's effects. A lower demand for insurance coverage leads to higher costs due to less risk pooling. As a consequence the supply decreases and the price increases which further decreases the demand.

Box 2.6: Natural hazards and insurance in Germany

In Germany, storms cause most of the natural disaster damages (64%) followed by floods (19%), hail (15%), and earthquakes (1%) (Schwarze and Wagner 2002). Only a few natural disaster damages are covered by insurance. With the exception of windstorm and hail, the insurance density is less than 10% in the exposed areas. Therefore damages caused by natural forces are often compensated by public emergency relief and private donations. For example, Schwarze and Wagner (2003) estimate that the emergency relief and reconstruction programmes for the flood damages of summer 2002 in Germany (approx. €9.8 billion) have exceeded the actual damages (approx. €9.1 billion). This results not only in an unnecessarily large withdrawal of private purchasing power and government investment but also systematically reduce the incentive for potential victims to take precautions and to buy insurance coverage.

Figure 2.8: 'Disaster syndrome' in natural hazard insurance markets



Source: Schwarze and Wagner (2006).

State intervention does not necessarily resolve all these problems but all issues have to be taken into account in order to provide an efficient regulation of the insurance market. As people are likely to underestimate and highly discount the full extent of the risk of rare events (Kunreuther 1996, Schwarze and Wagner 2006) the acquisition and distribution of information about risks could be spotted as a task of governmental action, leading to an increase in the demand for insurance coverage. As the example of the federal state Bavaria in Germany (Box 2.5) shows, the government can take the role of an information provider. Running such campaigns will imply some expenditures for the government and therefore have some fiscal effects, but they are not expected to be high. Given that natural disasters are mainly local phenomena, because of the geographical situation, the provision of information should especially be the task for local and regional authorities.

The distribution of information about risks could increase the demand for insurance coverage but the anticipation of ex-post emergency relief could still prevent potential victims to buy full coverage. Therefore, ex-post state aid should be limited to a minimum (see Box 2.5).

The anticipated ad-hoc emergency relief involves private and public donors. Private charitable giving could decrease the expenditure of the government but at the same time it influences the insurance market. Schwarze and Wagner (2003) claim that an overcompensation of losses as well as an overestimation of the actual costs of damages are often the result of such interventions. The governmental relief is two-fold: first is direct financial help for the victims of a disaster and second is the provision of emergency help, which includes technical and administrative assistance. The European Commission reregulated the rules for state aid (EC No. 1857/2006) to agricultural producers in the event of natural damages. The restriction for ad-hoc aid came into effect on 1 January 2010. The limitation to the offered compensation is reduced by 50% (EC No. 1857/2006).

Funds

The governmental aid could be financed by funds. Within the European Union the European Solidarity Fund (EUSF), which was founded in 2002, provides emergency relief and reconstruction aid. There are two main disadvantages of disaster funds compared with an insurance-based system: first the existence of a fund could lead to the wrong market signals. The potential victims have nearly no incentive to take any prevention measures, if they can count on governmental help by funds (Schwarze and Wagner 2003). In the case of EUSF there are two main restrictions to overcome this problem. The payments are in principle restricted to non-insurable damages (EC No. 2012/2002 Article 3(3)), which are not further defined. Furthermore, the annual budget of the EUSF is only €1 billion for all possible natural disasters of the member states or countries in EU accession negotiations (EC No. 2012/2002 Article 1), which guarantees that in case not the whole damage costs are taken by the fund. These limitations ensure to some extent the motivation to reduce the risks in advance. Another drawback of funds is that previously negotiations are necessary. Within this process the countries will try to impose their own interests. This could not only lead to extensive negotiations but also to costly lobbyism (Schwarze and Wagner 2003). For that reasons not only the payments into the fund have to be taken by the countries but also further costs for the negotiation process before implementing the fund. Additionally, decision-making in case of a disaster will also cause expenditures. In case of EUSF the affected country has to apply for a funding (EC No. 2012/2002 Article 4(1)), which has to fulfil criteria defined by the EC Council Regulation. After that the EC is responsible to decide whether a country gets help and to which amount (EC No. 2012/2002 Article 4(2)). Since the establishment of the EUSF in 2002, Germany has received €610.9 million against a damage amount of €13,850 million. The damages were caused by flooding in 2002 and a storm in 2006 (EUSF, 2009 (annual report 2008)).

Types of insurance

Because of the disadvantages of funds compared with insurance-based solutions, different possible designs of insurance for natural disaster damages are presented. The focus is on Germany, but in principal can be transferred to other countries as well.

German insurance market concerning natural hazard

Within the purely private insurance system of Germany it is possible to insure against storm and hail. For an overall coverage against the main natural hazards, a supplementary, natural hazard insurance (*Elementarschadensversicherung*, ESV) is available. The risk differentiation is based on a system called ZÜRS, which was developed by the German Insurance Association (GDV) to classify the risk. Four different risk groups – low to high risk – provide the indication for insurance restrictions. The insurance density against storm and hail is with 95% on a very high level (Schwarze and Wagner 2009). According to the Annual report of the German Insurance Association over 20% of the buildings are insured by an ESV (GDV 2009).

Mandatory natural hazard insurance

On that account, mandatory natural hazard insurance has been suggested (Schwarze and Wagner 2003). As opposed to emergency relief, a mandatory insurance scheme would allow the insurance companies to calculate the amount of compensation based on a large pool of customers and distributions of risks, because it would guarantee comprehensive demand for and supply of insurance coverage, thus reducing the premiums and provide certainty to the insured on what the compensation level is. Moreover, appropriately designed policies would provide incentives to exercise the optimal level of precaution. At the same time, the scheme could be open to new domestic and foreign insurance companies and permit competition within the industry.[18] Furthermore, it should be monitored whether (international) re-insurers offer coverage for the insurance companies so that they can handle covariate risks. However, also in designing the insurance mandate, the government has to trade off likely insurance benefits and possible moral hazard costs that arise whenever private precautions against damages are influenced by the presence of insurance.

In Germany the proposal for a mandatory insurance for natural disasters was rejected. According to Schwarze and Wagner (2009) four main reasons were decisive: the failure to recognise the role of state guarantees in enabling private insurance, the mistaken legal objections against mandatory insurance, the distributional conflicts between central and state governments and the re-election considerations of politicians. A European-wide solution is not to be expected, because the insurance system differs not only from country to country but also within regions, as the example of the federal state Bavaria in Germany (Box 2.5) shows.

[18] For detailed discussion of mandatory natural hazard insurance, see Schwarze and Wagner (2003).

Index-based insurance

Climate change tends to cause more frequent and severe extreme weather events (IPCC 2007a). Therefore the losses of the past cannot serve as criteria for the risks of future damages.

Especially in the agricultural sector developing an index-based insurance is on the agenda. Traditionally insurance payments are based on the average of former output yields, which serve as a basis for anticipating future crop outputs. This system is also called ‘loss-adjusted insurance’, because the assumption is based on the loss of expected outputs, whereas an index-based mechanism provides verifiable data. The indices are mainly measurable weather variables like temperature and rainfall. These weather variables are used to make estimates for yield. To get reliable predictions a complex index is needed. Such systems require expenditures to get the necessary measured values. Furthermore, the data is only for small local areas and is not applicable to different regions or cultures. The advantages of such index-based solutions could be seen in the independent assessment of variables, which cannot be influenced by the farmer. Therefore moral hazard and adverse selection problems could be reduced. Furthermore, the ascertainment of damages is straightforward, because the data only have to be compared with *a priori* defined threshold value. Moreover, costly field visits can be eliminated and therefore expenditures are reduced. Along with these possible advantages the measurable factors can make it easier to reinsure the risks.

The implementation of an index-based insurance system might be possible for property/building insurances. In Germany ESV is already based on geo-information provided by the ZÜRS system, where areas of different risks are determined. The input of further data could provide more precise risk projections and in case of damage an index-based mechanism can lead to faster decision-making.

Agricultural insurance solutions

Within the agricultural sector of the EU ad-hoc payments by the governments are common. This practice leads to different problems such as lack of transparency, no guarantee of payment, dependence of availability of a governmental budget, high administrative expenses and the damage being only partly covered (Munich RE 2007). To overcome the disadvantages of anticipated governmental relief, insurance-based mechanisms could be used. One possible solution might be the limitation of governmental reliefs only to damages that are not insurable (see Box 2.5). Such a strict course of action might be difficult to get through especially in the agricultural sector. There are other aspects like food security and saving the artificial landscape that are reasons to provide ad-hoc reliefs.

Another incentive for farmers to insure is the partnership of the government in form of proportional payments of the insurance premium. This option was also offered by the European Commission to launch a broad discussion on the common agricultural policy (CAP) to deal with the risks in agriculture (EC 2005, SEC(2005) 320). There the governmental financial participation should not exceed 50% of the total premium. Poland, the Czech Republic, Slovakia and Austria offer such subventions for premiums of crop insurance (Munich RE 2007 and 2009), whereas in Germany crop insurances are available but none with a public–private partnership design.

Box 2.7: SystemAgro by MunichRE

The Munich RE suggests an agricultural insurance concept on a national level, which includes public–private partnerships. It is called SystemAgro and is based on four basic factors called BLOC, standing for backing, loss sharing, open and central and uniform. The backing is the subsidy of the premiums by the government, which should give an incentive for the farmers to insure. Furthermore, the government should take a share of insured damages within years of extreme losses. In contrast to the current governmental relief aid, this loss-sharing mechanism includes a legal claim for the farmers to financial support, which is a further motivation to insure. The openness to every farmer should secure a high market penetration. The central and uniform structure should guarantee the sustainability and observing the legal rules and the public expenditures. This suggestion includes incentives to insure but on the other hand the government is involved on three levels: first to introduce a law and rules for provision, second the regular payments of the premium share and third still to help out in case of extreme damages. If the subventions are as high as the current ad-hoc payments, like the Munich RE demands (Munich RE, 2007), the public expenditures could even be higher as in the existing mechanism at least on the short run. Therefore the current suggestion is to cut other agricultural subventions and use them instead for financing the shares of the insurance premiums. This might lead to rejections by the agricultural lobby.

Source: Munich RE (2009).

Especially the use of public–private partnerships should be carefully reconsidered. Concerning insurance in the agricultural sector, the practical experience in the US and the literature about these schemes can provide valuable insights.

The Federal Crop Insurance Act of 1980 was introduced to replace disaster programs by subsidised crop insurance. It was amended by the Agricultural Risk Protection Act 2000, which main aim is the increase of insurance coverage.

Although the coverage of acreage has been increased (Babcock and Hart 2005), the government still provides supplemental disaster aid (Glauber and Collins 2002, Glauber 2004). Moral hazard and adverse selection problems are affecting the US scheme. The former may appear in changed planting decision or changing the application of inputs like fertilizers or chemicals due to increases in subsidies (Glauber and Collins 2002, Goodwin 2001). Just et al. (1999) go much further by claiming that the participation in crop insurance is mainly caused by the possibility to exploit the system of subsidies fraudulently and results in adverse selection. They provide empirical evidence to this statement by examining farm-level data for the US. The adverse selection problem is according to Goodwin (2001) due to the design as multiple peril insurance with an average risk measurement, which leads to over- or undercharging of individual risk. Furthermore, Glauber and Collins (2002) mention that farmers fear a lowering of crop prices as a result of crop insurance subsidies that are too high.

The problems within the US design of crop insurance show that the premium subsidies have severe shortcomings. Consequently, Glauber (2004) claims that “crop insurance subsidies are less efficient than lump sum transfers”. Nevertheless, an insurance concept including public–private partnerships may lead to higher insurance coverage, but implementing such a model would require a careful design and should take into account possible shortcomings. This means for example that governmental ad hoc help should be withdrawn. This strict course might in reality not work due to other reasons of governmental intervention like security of supply. Furthermore, there may be strong political incentives for governmental ad hoc aid (in particular before elections).

All-risks coverage

All-risks coverage should include all possible natural hazards. Especially in the agricultural sector such insurance solutions are discussed. The damages could range from storms and hail, which are the content of the most insurance packages, to drought, frost, continuous rain or high tides. Today in Germany there is no possibility to cover all risks with insurance. The insurance companies select risks and cultures. Hail insurance is common for the most cultures but for other natural disasters the culture is decisive and for special cultures only hail insurance is available. Similar circumstances of selection can be found in other European countries. Insurances covering more than a single risk are offered for example in Austria, Czech Republic and Slovakia and include a public–private partnership, but the insurance is only available for a choice of cultures.

The German Insurance Association made a proposal for crop insurance with all-risk coverage to overcome the problems with risk and culture selection (GDV 2008). The suggestion is for common cultures and excludes special cultures. The main aspect is that the risks are divided into two categories. The first one includes the risks of hail, storm, continuous rain as well as early and late frost. The GDV integrates these kinds of risks due to their local effects and their causality to short-term occurrence of extreme weather events. They suggest using the integral franchise method by 8%, as is common for insurances against hail. This means that the first 8% of the insured yield losses have to be taken by the producer and the further damages will be covered by the insurance.

The second risk group covers floods, droughts and damage due to frost, ice and snow. The damages of these risks are extensive and normally not of local or regional nature. The extension and severity of the damage depends also on non-insurable factors like soil quality. The GDV intends to use threshold values, which should be determined for the different kind of risks.

All-risk insurance systems could be combined with the public–private partnership solution and the index-based mechanism, but each of the mentioned methods are at a level where more research is needed to figure out the effects and their interactions.

State as insurer of last resort

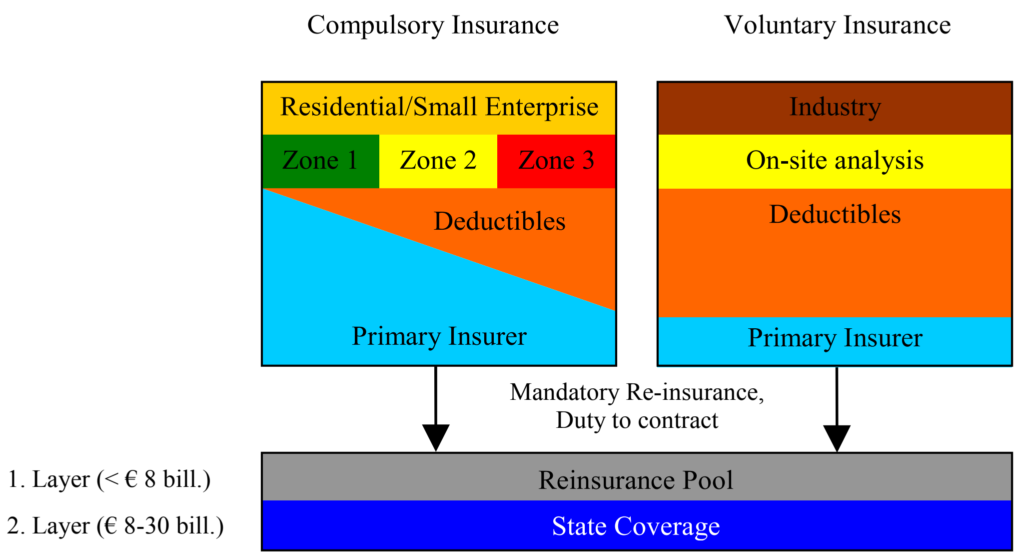
Finally, depending on the national circumstances there may be the responsibility of a government to act as insurer of last resort in case of extreme weather events. The fiscal effects will depend on the design of the implemented natural disaster insurance scheme and the role of the government in this scheme. Given the available information on damage estimates the necessary funds for the former may be considerable. The examples of natural disasters in Boxes 2.1 and 2.6 indicate how much damage costs could be expected after extreme weather events. These effects will presumably increase over time i) because temperature and therefore the frequency and severity of natural disasters increase and ii) because of increasing wealth, population changes, inflation, and changes in settlement behaviour. The design and organisation of the insurance scheme do also influence the fiscal consequences. If the insurance density is low the state has to be prepared to compensate victims for losses caused by natural forces. The financial aid may withdraw important public investments or increase the ‘fiscal gap’ that already exists in some countries owing to public debt and demographical change.

In contrast, if the insurance scheme is designed in a way that the density is high, many natural hazards can be compensated without governmental intervention. In this case public emergency relief would be necessary only if damage costs exceed the capacity of insurers and re-insures. That is state participation is strictly limited to cover the ‘mega-damages’. For example, Schwarze and Wagner (2006) propose a market-oriented mandatory insurance against natural disasters for Germany (see Box 2.8). They estimate the state coverage for the flood module to be between €8 and €30 billion. It is important to note that not only does this reduce the need of state intervention but also damage costs can be expected to be lower in case of high insurance density because appropriately designed insurance policies induce potential victims to take preventive measures.

Box 2.8: Mandatory insurance scheme against natural disasters in Germany

Schwarze and Wagner (2006) propose a market oriented mandatory insurance scheme against natural disasters for Germany. For the industry insurance is voluntary. For households and small enterprises insurance is compulsory. In highly exposed areas where floods occur frequently (Zone 3) only partial coverage is provided. With lower risk (Zone 2 and 1) deductibles decrease. Primary insurers must contract with re-insurers and the state steps in as insurer of the last resort. State intervention is strictly limited to ‘mega-damages’ above a threshold of €8 billion.

Scetch of the insurance scheme (Flood Module)



Source: Schwarze and Wagner (2006).

International pooling

The provision of risk coverage in very vulnerable areas is more feasible if risks are internationally pooled. Therefore a global market is necessary to diversify losses across the world. The three main practices to transfer single risks and pool them are reinsurance, catastrophe bonds and weather derivatives, which are discussed below.

Reinsurance

If risks are locally dependent, they might be globally independent and globally insurable (Cummins 2007). This is the case of reinsurance companies. A single insurance company can transfer its risks by reinsurance. The worldwide biggest reinsurance companies are Munich RE and Swiss RE. The reinsurance system is based on risk distribution by geographical and sectored diversification, including different business fields. Furthermore, reinsurance companies reinsure themselves, which is called 'retrocession' or transfer their risk to other instruments like catastrophe bonds and weather derivatives.

The two main types of reinsurance are proportional and non-proportional reinsurance. Proportional means that the losses are shared by a fixed ratio between insurer and reinsurer. The non-proportional reinsurance only takes losses, when they exceed a certain amount.

A study by Froot (2001) shows, that reinsurance by insurers against catastrophe large events is relatively small. This is verified by data of a large insurance company in the US. Furthermore, he found out that premiums are high comparing to the expected losses. According to Froot (2001) this is mostly caused by supply restrictions associated with capital market imperfections and the market power of reinsurers. Despite these critic aspects reinsurance is still an important instrument for natural catastrophes.

Catastrophe bonds

Catastrophe bonds, also called 'cat-bonds', are mainly used by reinsurers to transfer their risks to investors. Therefore special purpose companies offer bonds as over-the-counter deals to investors. Common are special bonds called 'principal at risk' with the whole nominal value at risk. The Munich RE suggests that bonds with different risks and probabilities of occurrence of damage might be useful to satisfy the potential investors (Munich RE 2007). Investors buy the bond and then two events are possible: the natural disaster happens or not. In the second case without any damages the investor will get interest rates and a premium paid by the reinsurer. If no damage happened after a fixed term then the investor gets his payments back. On the other side, when a natural disaster takes place the investor will not get the interest rates and the premium. Furthermore, the reinsurer will get payments for the damages. There are two main incentives for investors. On the one hand the high interest rates make investing in them attractive. On the other hand the catastrophic bonds should be designed in a way that there is no correlation with other bonds. Therefore they provide an option for risk differentiation.

Crucial for catastrophe bonds is the choice of a trigger, which is the basis of decision at which level of damage the payments will be made. The parametric trigger is similar to the index-based insurance method. The measurement of a natural parameter (e.g. wind speed) builds the basis for decision. If a certain threshold level is reached the bond is triggered. The indemnity trigger is based on the real losses of the sponsors due to an event of damage in comparison to the trigger indexed to industry loss, which is based on the claimed insured damages. Another method is to create a catastrophe model, where the parameters of a natural disaster are implemented into a reference portfolio. The simulation provides the extent of the losses. If they reach a specified level, the bond will be triggered. The indemnity and parametric triggers are prevalent for catastrophic bonds.

In 2006 catastrophic risk at a value of almost $5 billion were confirmed (Munich RE 2007). In the future the market of catastrophe bonds is expected to grow (Cummins and Weiss 2008).

Weather derivatives

In general derivatives are financial instruments that value is derived by other market values of goods or assets. Weather derivatives are comparable to other derivatives but are based on the index weather. The base values are temperature, wind speed, precipitation, humidity and other weather variables. There are two main differences of weather derivatives comparing to other derivatives. First, weather trends are independent of human factors. That means not that climate change is uninfluenced by human beings, but the weather is a physical phenomenon on the short run, which we cannot influence. Therefore weather is not correlated to the stock market. Second, weather has no price itself, because it is not tradable. Cao et al. (2003) classify three valuation methods for weather conditions, especially temperature: i) insurance or actuarial valuation, ii) historical burn analysis and iii) valuation based on dynamic models. The first one is based on statistical analysis of historical data, where the probability is connected to the insured event. In case of weather this method is useful for extreme and rare events, which can be a matter of subject for a contract. The reason is that normal weather conditions are recurring and predictable and therefore probabilistic assessment is not useful (Cao et al. 2003). The assumption of the second method is that the distribution of the past payoffs reflects the distribution of the future payoffs, so the past can be transferred in future payoffs on average (Cao et al., 2003). Especially with climate change weather variables like temperature will change and therefore using historical data is critical. Furthermore, Cao et al. (2003) claim that the insurance valuation and historical burn analysis are only useful for single dealers but not to create a unique market price. Contrary to use historical data, dynamic models simulate directly the future behaviour of temperature. Therefore a stochastic process for the temperature is needed, which can be constructed as continuous or discrete process. The proposal of a temperature process relies on studies about observed temperature behaviour with which the temperature derivatives are valued by simulation (Cao et al. 2003).

Contracts that arrange the conditions for buying, selling or compensatory payments are the basis for derivatives. The main types are options and swaps. Options are differentiated in call and put options. The call option gives the owner the right to buy an asset whereas a put option includes a right of selling. To become an owner of an option one has to arrange a contract with another player and pay a certain price for the option. Furthermore, the players specify the duration of the option and the strike price, which is a certain price at which the sale takes place. Another crucial subject in the contract is the tick size. This is in general the minimum allowed change of the value of an option.

For weather derivatives, degree-day options are common to hedge risks caused by temperature fluctuation. The decision basis for degree-day options is a comparison of the average temperature of a specified period with a reference temperature as an absolute difference, which is comparable to the strike price in other options. Here it is called ‘strike value’ because – as explained earlier – temperature has no price itself. If the difference reaches a special level, the option payment, determined in the contract, takes place. The tick size is the amount of the payout. Furthermore, contracts for weather derivatives include a cap for the payout, which is called a ‘limit’.

Swaps are contracts between two parties for payments. Swaps for weather derivatives include fixed and variable interest payments. The variable interest payments can be designed in a way that they depend on specified weather conditions, whereas the fixed interest rates remain unchanged (Munich RE 2007).

At first weather derivatives were mainly used by energy companies to smooth the demand volatility by protecting against temperature fluctuation. However, weather derivatives are becoming ever more attractive for other sectors depending on the weather like agriculture and tourism. Munich RE also mentions that it is common practice that organisers of open-air events (e.g. sports or cultural events) try to cover their weather risk by options (Munich RE 2007). The Weather Risk Management Association (WRMA) claims that the total limit of weather transactions had an executed amount to $45.2 billion in the period 2005-2006, according to the Price Waterhouse Coopers survey on behalf of WRMA. Comparing to the period 2003-2004 it is almost ten times higher.[19]

Weather derivatives as a complementary tool to the common reinsurance system can provide positive welfare effects. Cao et al. (2003) mention that weather derivatives can improve the risk-return trade-off in asset allocation decisions. Dosi and Moretto (2001) claim that weather derivatives may provide coverage at a lower cost than ‘standard’ insurance coverage schemes. There are also limitations, however: weather conditions differ not only among countries and regions but also among small local areas. It will not be practicable to measure the weather variables of every single vulnerable area. Furthermore, the measurement of the variables of interest should be taken by an independent institution. Therefore it will be the task of the government to provide credible data.

The innovative insurance methods may provide incentives for individuals to insure and in a next step the international pooling of risks with new systems like catastrophic bonds and weather derivatives can offer solutions to overcome the convergence of the capital markets and the insurance and reinsurance sector. On the other hand, Dosi and Moretto (2001) address the issue that not all risks can be covered and therefore differences in risk coverage among countries may occur.

Apart from providing general information on climate change risks and establishing rules for the introduction of innovative insurance schemes the role of the government in insurance markets is one of control and enforcement of contracts and in general the improvement of conditions for viable private insurance. In developed countries, for example, governments set building standards to prevent dangerous and faulty construction work. Such legislation can be in some conflict with the freedom of consumer choice, but basic standards in construction work are a prerequisite for contracts between a building company and its client, defining quality standards of construction work. Building standards are relevant for insurance markets, too: they create a level field for insurance by making more explicit likely risks associated with buildings. Therefore these standards can reduce the scope for moral hazard and adverse selection.

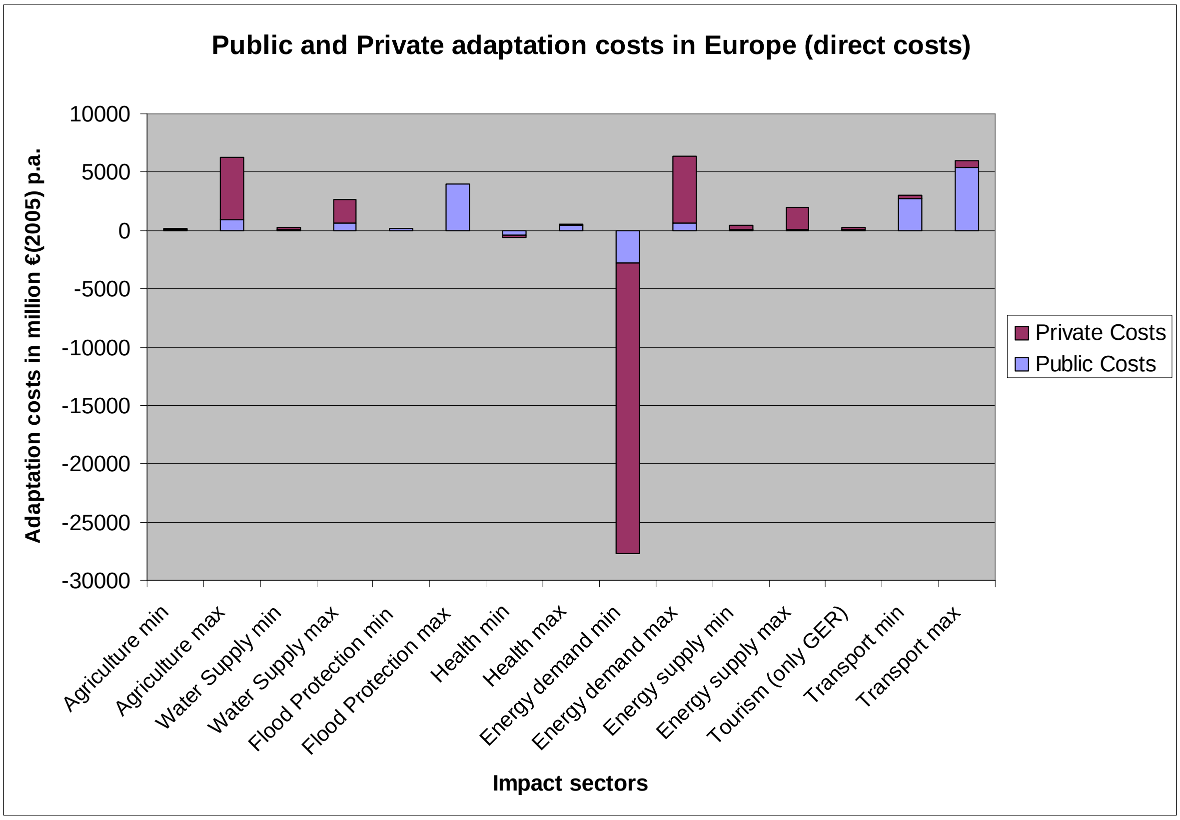
[19] See http://www.wrma.org/risk_trading.html (2010-03-02).

In summary, the regulation and monitoring of the insurance markets play an important role in the efficient adaptation to climate change. There are several problems that may hamper the effectiveness of the insurance market. Governments have different possibilities to improve the effectiveness including 'soft' measures, such as information campaigns, as well as 'strong' regulations, such as a mandatory insurance scheme. In a later section the fiscal implications of the regulation of the insurance market is explored.

3. Drivers of the fiscal implications of climate change

The fiscal implications of climate change have generally not been studied, with the exception of some studies on direct costs, notably related to government infrastructure investments. There is little if any literature on the overall fiscal impacts, which takes into account both the direct and indirect costs as well as the indirect impacts on fiscal revenues. A rare exception is a case study on Germany that is presented in PART II of this report. The summary analysis of adaptation measures in PART II is presented in a matrix in section 7.3 and an attempt to derive fiscal costs is made in chapter 5 of this PART, but these pertain to direct budgetary costs. In fact, the figures show public costs for the EU of around €15 billion a year maximum for adaptation (Figure 3.1), but with a minimum far below this figure. Still, these results do not indicate the highest threat from climate change for budgetary balances – extreme events and indirect effects.

Figure 3.1: Direct public and private costs of adaptation (annual average costs)



Source: Figure 5.2 in section 5.3.

The results plainly show that very little work has been done in this respect, with most estimates based on vague welfare implications or a few specific infrastructure costs. The lack of a unified methodology and assumptions also make the comparisons and a coherent description of the fiscal implications rather impossible. The results nonetheless give clear indications of the areas in which the fiscal implications are of special concern.

It can be expected that climate change will affect (almost) all economic activities and thereby growth, which in turn has implications for the level and composition of tax revenues. At the same time, climate change may also affect the expenditure side through spending on social benefits such as unemployment or health. Climate change will create a multitude of impacts, comparable to the complexity of the effects of population ageing. A rare study incorporating such effects exists for Germany. Bräuer et al. (2009) estimated that the indirect effects of climate change on public costs will amount to 87% of the total effect. Direct costs are thus not the main fiscal repercussion, and would mean that the total cost of adaptation for the state could be more than triple the direct costs, implying an average, annual fiscal impact ranging from €10 to 60 billion a year.

Therefore further study of the fiscal implications and interactions is needed. Such research is especially needed in countries where the negative impacts caused by climate change are expected to be the strongest. In addition, another important theme is the handling of extreme events in fiscal terms. Lis and Nickel (2009) have studied the budgeting for extreme weather events by governments. They found that developed countries in and beyond the EU tend to ignore and treat climatic extremes as something that has no strong fiscal relevance and as easy to absorb over time, based on a simple inter-temporal spread of costs. No differentiation among different kinds of catastrophic events is made and estimates are based on an econometric analysis of trends and average costs of state intervention.

What we do know, however, is that climate change will gradually impact the sectors of the economy that are sensitive to climatic conditions, such as tourism, fishing and agriculture. A simple amalgamation of relief costs and trends based on past expenditures is likely to be insufficient to prepare for the changes. The projections of the European Commission's working group on ageing (EC and EPC, 2009) show one case where past expenditure shares are not an appropriate guide for longer-term budgetary expenditure projections. The economic crises have also put into question the economic growth trends and thus the fiscal capacity of the states to afford the costs of population ageing. Climate change just adds another layer of complexity with a very significant margin of uncertainty, notably surrounding the costs and recurrence of extreme events.

The fiscal implications of climate change can be altered, however, by introducing planned, anticipatory adaptation measures to avoid the negative impacts of climate change and even foster potentially positive, new opportunities. To do so, states need to understand the drivers leading to negative or positive fiscal implications, similar to the way changes in pension, unemployment, education and health costs are analysed in the projections of the budgetary costs of population ageing. The objective of this chapter is to present the drivers identified in the reviews of the literature and the case studies.

Six drivers have been identified that will determine the size and importance of the fiscal implications:

1) the degree of exposure to gradual and extreme climate events;
2) the level of protection already in place in areas at risk, i.e. preparedness;
3) the state's liability for damages;

4) the potential and impacts of autonomous adaptation and remedial actions;

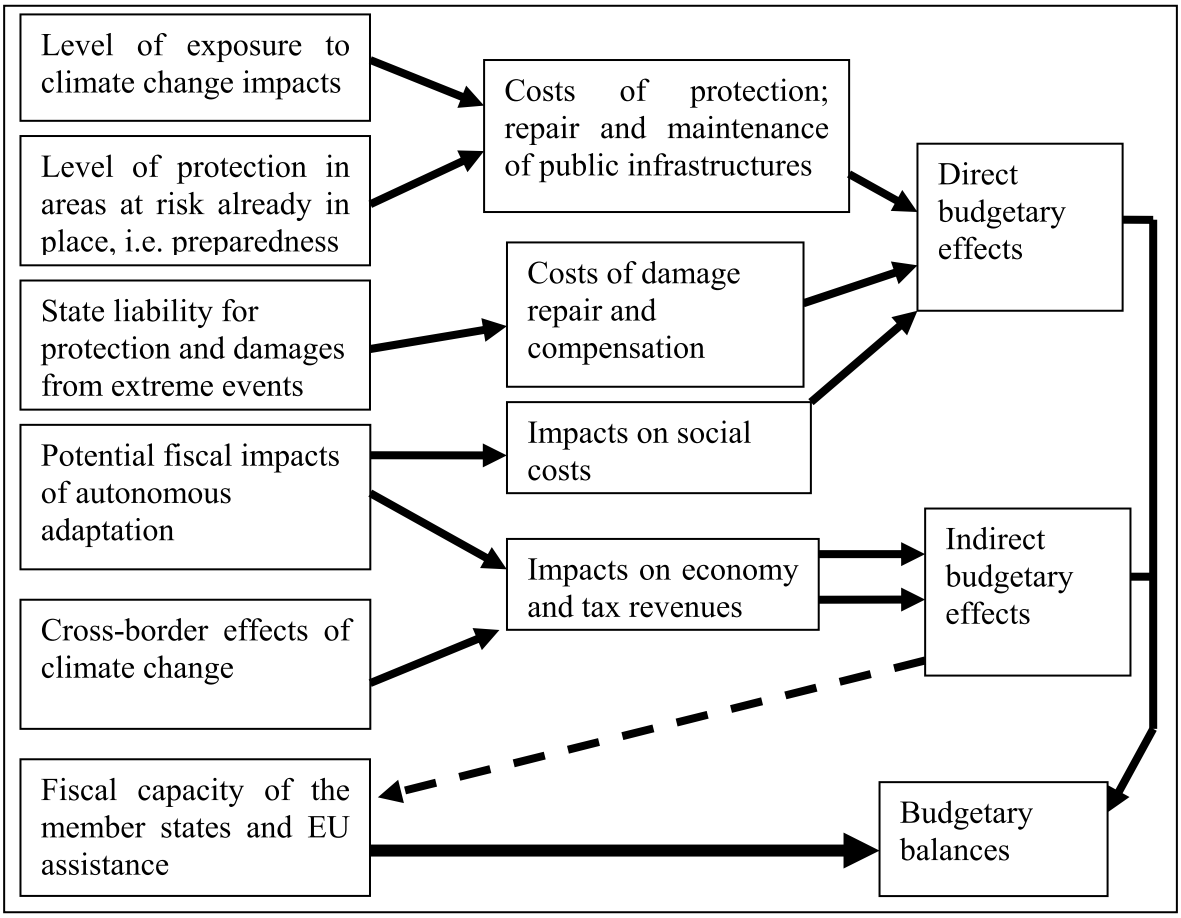
5) the cross-border effects of climate change; and

6) the fiscal capacity of the member states and the role of the EU.

Figure 3.2 presents in a simple diagram the changes that lead to fiscal implications. These are classified according to the kind of primary impact they may have, either as direct budgetary costs or indirect ones.

Direct costs to the budget come from the construction and maintenance of protective infrastructures, as well as from the additional maintenance of public infrastructures affected by climate change (i.e. climate proofing). Other direct effects on the budget are changes in social expenditures, mainly from potential repercussions on employment or alterations in health expenditures. Fiscal balances are also likely to be affected by fiscal revenue changes, brought by changes in the national economy as well as in the economy of trading partners. They may likewise be affected by negative spillovers from residual damages originating from adaptation actions in neighbouring countries. The indirect effects on the state budget will in turn affect the fiscal capacity of the state to deal with the impacts as well as the eventual level of support by the EU. Of course, some climatic changes may reduce costs in some areas, for example damages from extreme winter events if the weather becomes milder.

Figure 3.2: Drivers of fiscal impacts



This chapter discusses in more detail the origins of fiscal impacts based on the findings from the theoretical framework in chapter 2 and the case studies presented in PART II. It discusses how to translate – mainly qualitatively – specific climate impacts into fiscal effects based on the six drivers/parameters mentioned above. The chapter concludes with policy options to mitigate the negative effects of the drivers. It is not the role of the chapter, however, to go into detail on policy actions.

3.1. Degree of exposure to climate events

The impacts and costs of climate change will depend greatly on the exposure of the individual countries to climate change. The case studies show important differences among the member states, which are in line with the broader findings of other studies, such as the PESETA study published by the JRC in 2009.

The case studies identify the climatic impacts that will have consequences for the economy, more specifically, changes in

- average temperature in the seasons, along with an expected rise in temperature extremes;
- precipitation patterns;
- snow cover;
- water systems – particularly river flows (flood and drought risks) and groundwater levels; and
- coastal regions – with sea level rise and flood risks.

Some regions are especially vulnerable to one or several such changes, which can lead to very costly state intervention to mitigate the direct impacts, as well as affect social transfers, changes in state revenues, etc. In areas where exposure to negative impacts is high, appropriate measures to reduce the negative impacts of climate change can considerably reduce the economic and fiscal effects of the events. Ensuring an ‘adequate’ level of autonomous and public anticipatory adaptation becomes a key determinant.

Sea level rise is expected to threaten important economic centres on the Atlantic coast, the North Sea and the Mediterranean. Studies have shown very different levels of protection in equally exposed regions. For example, most of the Atlantic and North Sea coast is highly exposed but at the same time generally also highly protected by existing infrastructures. In Germany, the existing infrastructure greatly cuts the costs of further protection. In the Mediterranean, protection from sea level rise has never been a central issue. While not exposed to the same level of extreme sea surges as on the Atlantic coasts, peninsulas like Italy with a very large coastline and a significant share of the population and economic assets concentrated along the coastline are highly exposed to the gradual rise of the sea level. Only Venice is developing a defensive strategy, but it pre-dates a climate-induced change in the sea level, instead originating from the land subsidence under the city.

Costa et al. (2009) have estimated the costs of protecting EU coastal areas and have pinpointed countries with high exposure that would also find the costs too high to bear. While the benefits of proper protection at the EU level are considered high in studies like PESETA, studies by Costa et al. (2009) and the IMF (2008) estimate that for smaller and poorer EU member states such as Cyprus, Malta or Estonia, the costs may be too high. In Estonia, the protection of the coastline highly exceeds the benefits in terms of GDP costs at the level of 2007. Following a purely ‘economic’ logic, it would therefore be rational to abandon large stretches of Estonia to the sea.

The Mediterranean countries are in general highly exposed not only to sea level rise, but even more so to drought, leaving aside the effects a reduction in snow in the mountain ranges of Spain and Italy on winter tourism. Considerable exposure to drought will entail large direct impacts on the agricultural sector and water infrastructures. Infrastructure costs and rises in extreme summer temperatures can increase social costs, such as those associated with health, and reduce productivity.

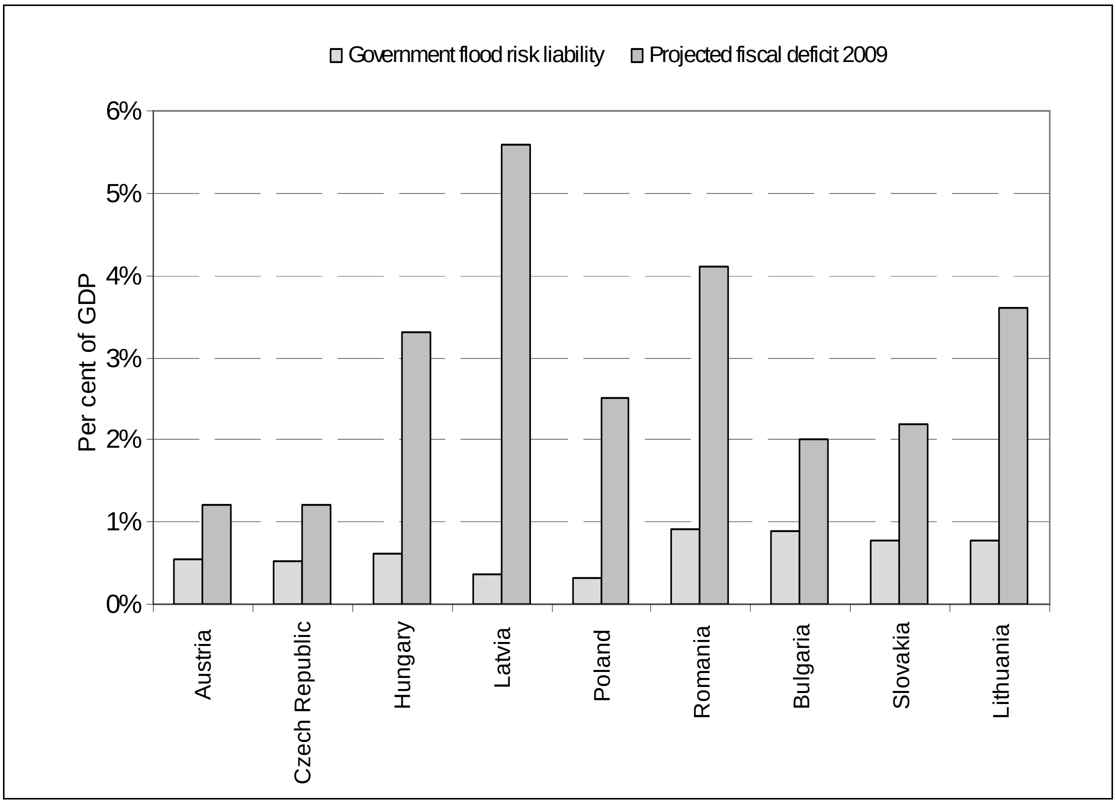
One of the only areas where the fiscal implications have been directly researched has been for sea level and river flood protection. This is due to the public nature of the infrastructures, which are mostly built and maintained by the state, and to the high level of state liability in responding to the damages caused by extreme events. However, most studies do not look beyond the direct costs towards the longer-term implications of changes and catastrophic events that may damage the growth rate of the economy for long periods of time.

Many parts of Europe are highly vulnerable to changes in river flows, affecting large areas, including many economic centres, and bringing a real risk of unsustainable fiscal impacts from repeated extreme events. Several countries are highlighted as being at major risk (‘hot spots’) with potentially significant budgetary costs from river flow changes, in particular floods. Poorer Central and Eastern European countries are facing potentially unsustainable costs, and even richer member states such as Austria are identified as hot spots of extreme flood events with the associated large costs to be incurred by the government. The example of Austria’s political and fiscal crisis after a flooding in 2002 reveals that extreme events can put the public finances of even economically more advanced European countries under strain. Figure 3.3 gives an indication of the average, annual expected damages already with today’s conditions in relation to the annual budget deficit. Some projections by Mechler et al. (2009) for the end of the century show that almost all of the EU member states with below average per capita GDP have a potential flood damage risk higher than 1% of GDP annually (Figure 3.4).

The impact of Hurricane Katrina in the US has also been a clear signal of the risks of underestimating the costs of extreme events. In New Orleans the potential damage costs were estimated at $16 billion before the event, while just the direct damage alone to dwellings, government buildings and public infrastructure reached $27 billion. An aid package of over €100 billion had to be unlocked to assist the city.

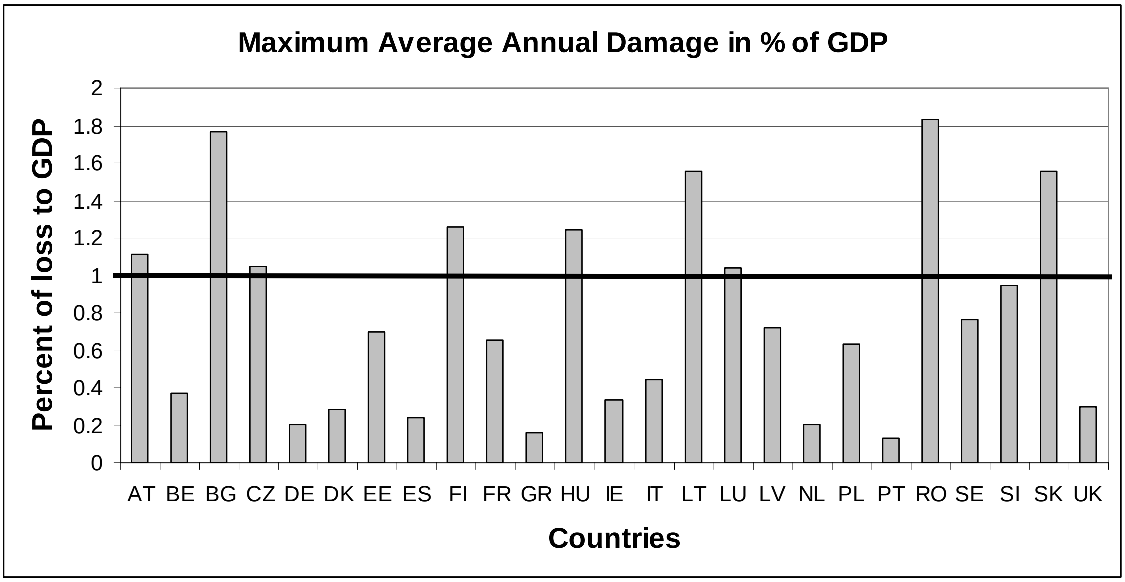
Other impacts that can have serious local repercussions are changes affecting the snow cover in Europe’s mountains, which will affect the tourism sector, at times positively, but in some regions it can badly damage the local economy. Similar situations may arise for droughts affecting the agricultural sector in several Mediterranean areas. These localised impacts may have budgetary implications, notably for transfers related to increases in unemployment.

Figure 3.3: Annualised disaster risks and fiscal deficits in selected flood-prone European countries (today's conditions)



Source: Adapted from Hulme et al. (2009, p. 13).

Figure 3.4: Maximum average annual flood risks across EU countries (% GDP)



Note: This is not loss of GDP, but loss measured in terms of GDP. Losses relate to assets, while GDP relates to income generated from those assets.

Source: Adapted from Mechler et al. (2009, p. 9).

Also important is the exposure of critical infrastructure to climatic impacts, in particular in the energy sector, which causes concern and has been the focus of studies, like that by Jochem and Schade (2009) for the ADAM project. Changes in river flows can affect hydroelectric power supply as well as the cooling systems of many thermal and nuclear power stations. Combined with atmospheric temperature changes and weather extremes, this may require substantial adaptation investments to weatherproof power plants as well as the energy transportation and transmission infrastructure, while decreases in efficiency and hours of operation may be unavoidable. Some countries and regions can be at particular risk or their cost structure may make them uncompetitive. The result may well be the closure of plants with the associated effects on the local economy. Exposure to one or a combination of several of the impacts could hit local economies and affect the state budget.

Finally, governments may see the costs of maintaining infrastructures affected because of damages caused by climate impacts. At the same time, some regions will benefit from the increased temperatures, with a reduction of snow and ice-related damages.

3.2. Level of protection already in place in areas, i.e. preparedness

The levels of existing protection and awareness influence the costs of climatic impacts considerably. An already high level of protection and enhanced awareness on the part of the population and governments can reduce the future costs of adaptation to sea level rise significantly. This has been documented in the case study for Germany. But for other European countries, this may not be the case, at least as far as we know. A sea level rise is expected to imply either a costly development of coastal protection in many member states or a difficult retreat from the sea, shifting settlements and infrastructures away from the coastline. In Italy, existing laws restricting construction close to the sea front will reduce some of the costs.

Nevertheless, the projected increases in the sea level are at times too high to avoid considerable costs of protection even in well-equipped areas. In the Netherlands the sea level rise over this century might go beyond the technically possible protection offered by the present dykes system. The Dutch state therefore asked a special commission to undertake a study, which in 2008 presented a plan to create new defences – mainly through an extensive beach nourishment programme that would expand the territory into the sea (Deltacommissie, 2008). Given the uncertainty surrounding the future sea level rise, the commission recommends building protections based on the upper limits expected, in light of the major consequences of any shortcomings in the protection level. To give the order of magnitude, the Delta programme was planned to start from 2010 onwards at an annual cost of €1.2 to 1.9 billion a year until 2050 and of €0.9 to 1.8 billion after 2050. The constant maintenance of the infrastructure means that these costs do not decrease over time.[20] It is interesting that the annual expenditure estimated by the Deltacommissie for the reinforcement of their protection alone exceeds by far most estimations of the studies undertaken for the EU as a whole, which puts into question existing methods of estimation in the top-down EU-wide analyses.

[20] The Deltacommissie performed a cost-benefit analysis to take a decision on the construction. According to the Commission, 65% of the Netherlands is an area at risk from sea surges. This means that about €1,800 billion of the nation's wealth is at risk (national wealth is estimated to be five times the GNP of the country). The estimated damages from flooding with the present protection until 2040 are expected to reach between €400 and €800 billion in direct and indirect damages and a cumulated €3,700 billion by 2100. The study was aware of the mistakes done in New Orleans in estimating the costs of exposure.

3.3. Extent of state liability

The theoretical framework and the case studies identify as a major fiscal cost the liability of the state in compensating victims from extreme events. The state is in many countries expected to cover the costs of natural catastrophes, be it by floods or droughts. Yet, private insurance schemes, combined with an appropriate regulatory environment and a limited liability of the state for damages beyond the insurable threshold, would reduce the fiscal consequences of extreme events considerably and needs to be explored extensively. The lack of private insurance against natural events is highlighted as a problem in the cases of damages from a sea level rise, river flooding and droughts, especially for the agricultural sector. There have been attempts to impose a certain level of compulsory insurance for natural extreme events in Germany, but they have failed for political reasons and a lack of understanding by policy-makers (see section 2.8).

For most countries the state bears responsibility for the totality of coastal protection, but there are exceptions. For instance in Finland, responsibility is shared with landowners. Even so, the state liability is still estimated at 90%. Other interesting cases are those of Denmark and Malta, where the state liability for coastal protection falls to 50%. There the liability of the state for building coastal protection is limited. This encourages private owners to seek insurance and invest in protection, at the same time reducing the level of moral hazard caused by an expectation of state intervention.

As highlighted earlier in section 3.1, a specifically problematic situation arises when state liability for extreme events is too high in relation to the national budget. This is a problem in smaller and poorer countries. In those countries, the economy is not large enough to cover the risks of extreme events through private insurance often because the law of large numbers cannot be applied and too great a share of the population is at risk of the same event to balance out gains and losses. A solution at the EU level will need to be sought.

3.4. Potential fiscal impacts of autonomous adaptation

The fiscal impacts will strongly depend on the adaptive capacity (anticipative or reactive) of individuals and on the kinds of adaptation actions they undertake. Autonomous adaptation, as identified in the theoretical framework, will be driven by their private utility-maximisation objectives and their assessment of risks. Individual adaptive behaviour will often not be in line with the required behaviour to maximise social welfare because of the differing social and individual objectives. This is not the only aspect that will lead to a socially suboptimal adaptation by individual actors; market (and policy) failures and moral hazard will also play a significant role.

Some of the adaptation actions by individuals may in the future result in negative fiscal implications. A fairly obvious case is the expansion of residential areas in zones at risk of flooding. This may happen because of the absence of laws, a lack of awareness among those moving to the zone, an underestimation of the risks by individuals and a component of moral hazard when it is expected that damages or remedial actions will be covered by the state. If an extreme event occurs, the costs to the state of direct damages and social transfers may be considerable, yet could be avoided.

Another case with fiscal implications is the increasing use of air conditioners in areas suffering from a rise in summer temperatures. The power-hungry cooling systems may strain the energy grid, which can cause disruptions in the power sector. Water shortages may also affect the turbines of the power stations. In Greece, during a heat wave, the country experienced a serious blackout.

Serious issues emerge from the indirect impacts of climate change if individuals are unable to adapt to them. Unemployment stemming from economic impacts, deteriorating health owing to new diseases, and inward or outward migration can all affect a state's budgetary expenditures considerably. For example, when regional economies are hit seriously, some important activities become impossible (e.g. winter sports tourism and farming). While there may be a tendency to subsidise the region, the state should be proactively assisting the diversification of economic activities, through awareness training and programmes to facilitate job change and even planned migration to avoid rises in socio-economic costs.

3.5. Cross-border effects of climate change

There are two cross-border effects of climate change to be considered. One is caused by residual costs from actions in another country. In the EU, adaptation measures in rivers upstream may affect another country downstream. Another evident fiscal impact is aid transfers to developing countries to adapt to climate change, but technology transfer from donor countries partially mitigates the impact.

These are not the only impacts that may provoke fiscal effects, however. In the case study for Germany and Finland a reference is made to trade impacts, i.e. reductions in the demand for exported products due to climatic impacts abroad. Negative effects on the economies of importers may reduce a state's exports. The revenue implications for the state can potentially be large. Finally, climatic impacts abroad may lead to immigration pressures in some EU countries, with the associated costs.

3.6. Fiscal capacity of the state and the role of the EU

The fiscal implications will clearly be greater for member states with less fiscal strength, highlighting the predicament of poorer member states. The financial impact of either building the necessary infrastructure or reacting to counter the impacts of an extreme event can be very high in relation to the state budget of poorer member states. As mentioned earlier, in the river flood hotspot of Central and Eastern Europe, the costs of repairing the damage of floods and protecting the riverbanks can be a considerable burden for the state. But fiscal strength is not just a problem for the poorer member states – wealthier countries may be threatened by extreme events as well. Strong fiscal pressures and downgrades in projected growth rates are reducing states' future room for manoeuvre to support adaptation to climate change.

Fiscal capacity is not only affected by direct costs, but also by the costs of social and economic repercussions. Climatic impacts may impair important economic activities, generate an increase in unemployment and thus social costs, and reduce tax revenues. In combination, the fiscal pressures can be extremely damaging. Larger countries can usually counterbalance the negative effects with the benefits of climate change in other areas. This is the case of a large country like Germany, where losses from winter tourism may be recovered by improvements in other areas of Germany benefitting from warmer weather, creating changes in the pattern of social transfers but not necessarily costs for the state. The smaller the country, the smaller is the capacity to counterbalance the effects of climate change.

The study has identified cases (e.g. Estonia, Cyprus and Malta) where there may be a need for assistance from supranational funds (i.e. the EU) to help such countries develop the appropriate protection and response capacities.

Another aspect relevant to fiscal stability is the increase in the temperature variability and thus of extreme events. It is generally expected that the various economic sectors will see a higher degree of income variability. In areas where the state intervenes to assist in extreme events, it may find itself incurring considerable costs with a more frequent occurrence than planned, creating budgetary problems.

3.7. Policy measures for minimising the impacts of fiscal cost drivers

Based on the theoretical framework and the case studies, there are a number of general recommendations that follow from the identification of the drivers of fiscal implications. There are different policy actions available to address climate impacts, but there are clearly some effective solutions that in turn reduce the negative fiscal implications or increase the positive ones. This subsection addresses the options for each driver identified.

3.7.1. Measures to reduce the negative fiscal implications of exposure

Appropriate balance between hard and soft protective measures. The fiscal implications from exposure to severe climatic impacts can be reduced by the appropriate combination of hard and soft public adaptation measures. Hard measures are those directed at blocking the threats, while soft measures are based on a strategic retreat from areas at risk and the creation of buffer zones using existing natural features. There are a number of examples in Europe of both types of adaptation. Land-use management and regulation can go a long way too in reducing unnecessary exposure to risk by individual actors.

Decisions on what measures to use should be taken based on appropriate cost-benefit analyses taking into account the value of the area to protect, using traditional cost-benefit tools such as contingent valuation methods.

Investment in research and development. Research and development can contribute to reducing the costs of future protection for a modest investment. New technologies can significantly affect the final cost of adaptation.

Help for individual actors in the economy to adapt. Governments should be careful to avoid using public policy solely to preserve present structures and activities; they should also strive to understand how to take advantage of opportunities created by the changed conditions and accept that there will be a shift in economic activities and infrastructures. Governments should additionally avoid protecting and subsidising declining activities, and instead concentrate on fostering new, alternative employment opportunities as part of an adaptation strategy and manage the transition.

Supranational provisions for catastrophic events that single countries cannot handle alone. There are areas in the study that call for collective action in the EU. The main point of concern is the existence of risks against which some small countries cannot ensure themselves (see point 3.6). Small countries may be unable to respond to a catastrophic event or may not have the financial means needed to develop optimal protection. This raises the issues of EU solidarity measures, such as an emergency fund for extreme events. Such a fund should be restrictive enough to avoid an absence of incentives and situations whereby local authorities and member states, counting on EU support, do not take their own necessary precautionary measures.

3.7.2. Measures to reduce the negative fiscal implications of state liability

Expansion of the insurance markets. As mentioned above, there is a case for expanding insurance markets, with the state intervening only in the event of damages beyond an insurable threshold. Compulsory natural hazard insurance would allow private insurance to sufficiently spread the risk and attract enough customers to cover the risks more efficiently. In very small countries the spread of risk may not be sufficient, thus an international mechanism with reinsurance or schemes covering more than one country could offer a solution.

Land and water use regulation. Land-use management is central to making certain that areas at risk are not used inappropriately. The study reveals that individuals tend to underestimate risks, and asymmetric information and moral hazard can lead to behaviour that puts people and capital at risk. Construction standards can also assist in reducing future damage costs. Water markets require some control, ensuring that prices reflect water scarcity and that infrastructures are appropriate to limiting waste and leakage, and efficiently managing water use and distribution.

Provision of appropriate information. There is a clear indication that lack of awareness and imperfect information does adversely affect autonomous adaptation, such as an underestimation of risks in the decisions of individuals. Information is a very cost-effective way of reducing risky behaviours.

A review of state liability. The case study of Finland highlights that there is a limit even in the provision of protective infrastructure for extreme sea-level surge events. It is important for the state to discourage risk-taking behaviour by ensuring, where possible, that individuals do not take risky actions in the expectation that the state will then intervene.

3.7.3. Measures to reduce the negative fiscal implications of suboptimal autonomous adaptation

The main problem with autonomous adaptation is the difference between the private objectives of maximising one's own utility and the needs for a social optimum. The role of the government is to understand the reasons for suboptimal adaptation and induce individuals to change their behaviour such that private adaptation is directed towards a social optimum.

Provision of adequate information. The first and most cost-effective action is the provision of information. Reducing imperfect information and the associated impacts is of paramount importance. This will ensure that private adaptation is optimised, leaving other interventions exclusively geared towards those residual effects of autonomous adaptation that do not reflect a social optimum.

Use of regulations. The regulatory arm of the state is crucial to steering autonomous adaptation. As noted earlier, land use and the use of other resources can be regulated to avoid damaging behaviour and even to open up new opportunities. It is also possible for climate change to free up land for agricultural production or other activities.

Use of fiscal incentives. Fiscal instruments, such as taxes and subsidies, can be highly influential in the choices of individuals. Taxes on damaging behaviour or subsidies to adopt positive actions are important.

Awareness of the net fiscal effects of incentives. It is clear that subsidies will entail direct costs for the state, but the impacts of changes in the tax composition and regulations can have a number of repercussions. It is recommendable to shift taxes in such a manner as to foster positive adaptive behaviour and reduce negative behaviour, for example by taxing water consumption in areas affected by drought, but reducing the taxes on water saving technologies. There is also a need to make sure that on balance, the state does not suffer negative budgetary outcomes by miscalculating either the effects on tax revenues or the impacts on the economy (and thus on social costs).

3.7.4. Measures to reduce the negative fiscal implications of cross-border effects

Reinforced coordinated action. The EU is in an enviable position compared with other parts of the world in view of its ability to reach agreements on common standards and compensation across EU member states, as well as with neighbouring countries. Coordinated action to ensure minimal cross-border residual costs and a system of financial assistance can help the EU reduce the EU aggregate and the separate national costs of climate change.

Coordination of standards. The case studies have pointed out that different countries and even regions within countries are using different assumptions about the impacts of climate change, dictating diverse levels of adaptation and thus putting neighbouring regions at risk of larger residual costs. Such divergences can be avoided by using similar standards and assumptions. In addition, residual damages that fall on neighbouring countries and regions will normally not be taken into account in cost-benefit analyses by local decision-makers, thereby potentially leading to inefficient responses from an EU perspective. Mechanisms at the EU level that make certain all costs are accounted for and that the EU (and even beyond its borders) is considered one territory can overcome this situation. The EU might need to coordinate cross-border financial transfer mechanisms that reflect a correct burden-sharing of costs.

Integrated use of resources. The expansion of interconnectivity, especially in the energy sector can help make sure that risks in the energy grids of one member state are spread across the EU, thus reducing the probability of blackouts. More will have to be done to address the efficient use of other resources (like water) at the supranational level.

3.7.5. Measures to ease the limitations on the fiscal capacity of some member states

Development of sufficiently robust EU assistance. As we have shown, there are several member states in the EU that face excessive fiscal pressures in relation to the size of the national budget, for either putting in place the necessary protection or dealing with catastrophic effects. While the EU may want to reinforce its cohesion policy to assist in the development of the necessary defences, this raises the question of providing rapid support at the EU level for extreme events in hotspots. Obviously, such assistance would need to be combined with governance rules that among other things avoid moral hazard, i.e. suboptimal adaptation at the national level in the expectation of a supranational bailout. Still, a functioning mechanism of financial support seems of central importance.

Integration of EU rapid response mechanisms. To cope with major impacts in specific hotspots, the EU should consider further integrating its response capacity in order to provide rapid, coordinated and effective action in the case of a catastrophic event. Hurricane Katrina in the US has shown how even in a unitary nation an appropriate response is time-consuming and difficult to set up; in Europe a similar magnitude of damages would probably entail a much deeper coordination problem, with economic, social and also political costs piling up in the process.

Higher multiannual budgetary provisions for extreme events. The study has highlighted that climate change will increase the variability in the incomes of economic sectors. Boom and bust cycles in weather-dependent activities such as agriculture and tourism will be more extreme and recurrent. Even in the case of Finland, which is expected to benefit from climate change, income fluctuations in the different sectors will become much more extreme as climate change progresses. The state will need to ensure that it has the provisions to react more flexibly and more often, smoothing the fiscal implications with multiannual budgetary strategies. Flexible labour markets, along with appropriate and flexible social systems, will be necessary to respond to this variability, with a higher provision of fiscal resources.

4. Cross-country summary tables of adaptation measures

This chapter provides a cross-country summary referred to the case studies in PART II, where various possible and realised adaptation measures in Germany, Finland and Italy are presented. As some impacts of climate change are the same throughout Europe, whereas some others have very different effects and therefore involve alternative coping strategies, it may be beneficial to compare the adaptation measures found in the case studies across the three countries. We therefore use the same sectoral order as in the case studies themselves. Tables 4.1 to 4.7 present the areas where adaptation efforts are required, either autonomous or public, in the three countries. This gives an overview of all areas that need to be analysed to understand the impacts on the economy and the government budget. These tables do not indicate that the adaptation measures should necessarily result in a fiscal impact.

Note that all the adaptation measures we outline below are conceivable in the particular country considered, albeit their implementation may not yet be realised, discussed or researched. Only a few measures are not considered feasible for a given country. One example is the use of air conditioning, which is pertinent in Italy but is not yet debated much in Germany or Finland.

4.1. Agriculture and forestry

The impacts of climate change on agriculture and forestry is mainly driven by projected temperature increase. Especially in Italy this may lead to conditions where the crop types are limited and forests face higher risks of fire. In contrast to Italy, Finland may gain from positive influences of climate change as increases in temperature may lead to expanding growing seasons or conditions for cultivating new crop types.

Table 4.1: Autonomous and planned adaptation measures in agriculture

Impact	Adaptation measure	Germany	Finland	Italy
Agriculture				
Increase in temperature	Change in cultivation to more thermophile plants (e.g. wine)	X		
Increase in extreme weather events	Use of insurance	X	X	X
	Floods: evaluating water protection guidelines	X	X	X
	Droughts: cultivation of more drought resistant breeds	X		X
	Droughts: Irrigation systems	X	X	X
	Redesigning drainage systems	X	X	X
	Rethinking short land tenancy period		X	
Earlier starting of vegetation period and elongation	Earlier seeding, potentially an additional crop rotation	X	X	
	Expanding variety of crops and plants	X	X	
	Developing of new crop types	X	X	X
General impacts	Rearing more resistant crop types	X		X
	Increased use of fertilisation and plant protection (neg. externalities)	X	X	X
	Water-saving cultivation	X		X
	Research on regional climate change	X	X	X
	Development of plant and animal disease and pest monitoring	X	X	
	Considering new insurance regulation	X	X	

Source: authors' compilation

Table 4.2: Autonomous and planned adaptation measures in forestry

Impact	Adaptation measure	Germany	Finland	Italy
	Forestry			
Pests	Control of pests and diseases	X	X	
	Earlier evacuation of trees after damage	X		
	Enhance resistance of forest by mixed stands	X	X	
Forest fires	Rethinking of precaution measures (not concretised)	X	X	X
	Developing monitoring systems	X	X	X
	Defining fire breaks in forest management	X	X	X
	Reconsidering normative framework for fire breaks	X	X	X
Change of favourable conditions for certain tree species	Cultivation of more productive tree populations	X	X	
	Use of alternative genotypes to prepare for different future scenarios	X	X	
Less frost – difficulty of harvesting in muddy conditions	Expansion of road networks		X	
General impacts	Rapid harvesting after wind damages		X	
	Developing of higher resolution climate change models suitable for regional projection	X	X	X
	Research and development of new harvesting techniques and tree improvement	X	X	X
	Forest transformation to higher diversification of tree types	X	X	
	Financial support for private owners	X		
	Field mapping and regional cultivation recommendation	X	X	X
	Knowledge transfer of experts	X	X	
	Evaluation of current water management concepts	X	X	X

Source: authors' compilation

4.2. Water supply, inland floods and sea level rise

The water sector includes water supply as well as flooding dangers like river or coastal floods. Adaptation options to the two latter ones mainly include early warning systems and protection measures. Water supply includes the quantity as well as the quality of water.

Table 4.3: Specific impacts and adaptation responses concerning water

Impact	Adaptation measure	Germany	Finland	Italy
Inland floods & heavy rains	Expansion of water supply and sewage networks	X	X	X
	Use of insurance	X	X	X
	Flood-adapted building	X	X	X
	Property construction out of risk area	X	X	X
	Rethinking of land use in endangered areas, Evacuation of flood endangered areas	X	X	X
	Urban and land use planning, preparation of general plans for flood risk sites	X	X	X
	Research on regional flood occurrence and impacts, SLR monitoring	X	X	X
	Early warning systems	X	X	X
	Coordination and cooperation with neighbouring authorities	X	X	X
	Improvement of flood protection construction	X	X	X
	Emergency Management	X	X	X
	Evaluating dam safety	X	X	X
	Evaluating drainage systems	X	X	X
	Recreation of retention areas	X		
	Awareness building in the population	X		
Sea level rise/ Coastal floods	Spatial planning, prohibition of building, near the coastline	X		X
	Land protection barriers	X	X	X
	Monitoring of SLR, coastal climate and the erosion of the coastal zone	X	X	X
	Awareness building of the population	X		X
	Evacuation of flood endangered areas	X		X
Droughts / Impairment of water balance (groundwater level)	Restrictions on water use	X	X	X
	Water quality protection	X	X	X
	Responsible water use	X	X	X
	Reconsidering land use management	X	X	X
	Infrastructural measures (e.g. sufficient storage of water in impounding reservoirs)	X	X	X
Moving on ice becomes risky	Information of the public		X	
Nutrient leach into water reservoirs	Monitoring measures and reconsidering fertilisation legislations	X	X	X

Source: authors' compilation

4.3. Human health

The adaptation measures in the human health sectors are strongly connected to rising temperature and possible heat stresses. Concerning this impact, autonomous as well as planned adaptation measures are necessary. Changes in individual behaviour and technical adaptations in homes are the former ones. The latter ones involve providing information, early warning systems, urban planning regulation, health care infrastructure and adequate housing conditions of publicly owned buildings. Although Table 4.4 shows the same adaptation measures in nearly every country of the case study, in reality the efforts of the single countries differ. This is also attributed to the different location of the countries and the current climate circumstances. In an already warmer climate, a further temperature increase may lead to important changes in the well-being of the inhabitants.

Table 4.4: Autonomous and planned adaptation measures concerning human health

Impact	Adaptation measure	Germany	Finland	Italy
Heat stress	Dissemination of information about correct reaction to heat-waves	X	X	X
	Development of early-warning systems for healthcare comprising regional particularities	X	X	X
	Technical prevention measures (e.g. air ventilation, cooling, isolation)	X	X	X
Vector-borne diseases	Provision of information for the population and medical staff	X	X	X
	Vaccination programs	X	X	X
	Research and monitoring of climate change related diseases (particularly vector-borne)	X	X	X
	Expansion of monitoring systems	X	X	X
General impacts	Behaviour modification in working life and leisure time	X		X
	Adaptation in urban planning (green-fields)	X	X	X
	Increasing use of health service	X	X	X
	Enlarging health sector capacity	X	X	X
	Enlargement of the knowledge base, particularly on city climate and diseases	X	X	X

Source: authors' compilation

4.4. Tourism

The tourism sector is small in Finland. Therefore the focus is on Italy and Germany. Especially in Italy the tourist sector is economically important (see PART II section 6.3.3) as a winter and summer destination. The cross-country table shows similar impacts and adaptation measures in winter destinations. Winter tourism mainly takes place in the Alps, where Italy's area is larger than Germany's. This advantage in size could offer more alternative opportunities in the winter tourism sector (e.g. switch to higher altitudes). For summer tourism, Germany has better adaptive capacities. If the already warm summers in Italy grow even hotter due to climate change, this could act as a deterrent for summer tourism.

At the same time, warmer summers in Germany may attract more tourists, especially domestic travellers. Therefore the difference is that in Germany new tourist destinations may arise whereas in Italy the existing tourist infrastructure has to adapt to the changing temperature conditions.

Table 4.5: Autonomous and planned adaptation measures in the tourism sector

Impact	Adaptation measure	Germany	Italy
Winter sport tourism			
Less snow reliability (particularly in low altitudes)	Artificial snowmaking	X*)	X
	Reconsidering of legislation	X	X
	Concentration of slopes in higher altitudes (constrained)	X	X
	Visit higher altitude winter resorts	X	X
Summer tourism			
Increased occurrence of algal blooms	Control of bathing quality	X	X
Sea-level rise at tourist sites	See PART II, section 4.5.1	X	X
Increased potential for summer tourism (particularly beach holidays)	Enlargement of tourism opportunities	X	
Hot summers (IT)	Increased use of air conditioning		X
	Innovative house design		X
	Normative framework for construction design		X
Total tourism sector			
General impacts	Changing in recreation and travel behaviour	X	X
	Increase of weather independent offers	X	
	Provision of information about regional features	X	
	Diversification of tourism industry (e.g. alpine tourism)	X	X
	Expansion of current research	X	X

*) Also public subsidies for artificial snowmaking are possible.

Source: authors' compilation

4.5. Energy sector

The data provision limits the comparison of all three case-study countries. It is only for Germany and Finland that the available data can be assessed and put into a cross-country matrix for a better overview. Nevertheless, Italy's possible impacts and adaptation measures were also included in the table as a best guess of common understandings in the energy sector as a whole. Higher temperatures in winter might cause a decrease in energy consumption, whereas rising temperatures in the summer will lead an increase in demand for cooling. The net effect is unclear, but the empirical literature suggests positive net effects in Italy (i.e. higher total demand) and by tendency negative net effects in Finland (lower energy demand). Along with the consumption side of the energy sector, the producer's side will also be affected by climate change. Under changed weather conditions the cultivation of biomass material might be possible and economically profitable. On the other hand, the grids and networks might be threatened by extreme weather events. Furthermore, the restrained availability of cooling water may possibly affect the power production adversely.

Table 4.6: Autonomous and planned adaptation measures in the energy sector

Impact	Adaptation measure	Germany	Finland	Italy
Higher temperatures in winter	Decreased use of electricity for heating	X	X	X
	Increased use of wind energy as less ice disturbs propeller blades		X	
Higher temperatures in summer	Increased use of electricity for cooling	X		X
Inland water transport unreliable	Risk diversification, less dependence on waterways.	X		
Limited water cooling capacity in summer	Research for alternative cooling-systems	X		X
Improved temperature conditions for biomass	Increased use of bio energy	X	X	
	Expansion of bio energy infrastructure	X	X	
Increase in precipitation	Investment in additional hydro power		X	
Extreme weather events	Extension of underground power cable	X	X	X
Changes of wind velocity	Clarification of future changes in wind velocity	X	X	
	Adapt to changing wind velocity	X	X	
General impacts	Research expansion in alternative power generation	X	X	X
	Provision of information how electricity needs can be reduced	X	X	X
	Increased investments	X	X	X

Source: authors' compilation

4.6. Transport sector

The transport sector differs from one country to another. Especially the location of a country plays an important role (e.g. access to the sea, neighbouring countries). In addition, the aspect of the direction of the trade route (e.g. transit country) has to be taken into consideration.

Quality and quantity as well as the composition of the current transport infrastructure have to be considered. Germany, as a Central European country, faces transit traffic from north to south as well as east to west and vice versa. In comparisons with Finland as a northern European country, mainly transactions from north to south have to be considered. Italy as a peninsula and a large north–south extension faces different circumstances. As in the energy sector, data availability limits the analysis, in particular for Italy.

Table 4.7: Autonomous and planned adaptation measures in the transport sector

Impact	Adaptation measure	Germany	Finland	Italy
Extreme weather events	Upgrading of drainage systems and increases in pumping capacity of tunnels	X	X	X
	Protective constructions, more resistant materials for roads, airport runways, and railways	X	X	X
Increased risk of accidents in summer because of loss of concentration	Changed drivers' behaviour	X		X
Land slides and erosion in flood endangered areas or due to intense precipitation	Elevation of roads and rail lines	X	X	X
	Early warning systems	X	X	X
	Building, heightening and strengthening of levees and dykes	X	X	X
	Monitoring and maintaining road and rail infrastructure	X	X	X
	Relocation of roads and railways	X	X	X
Shortening of ice and snow cover period	Less winter maintenance for road and rail networks	X	X[*)]	X
	Increase of winter traffic on maritime transport ways		X	
Increased snow intensity, more days around 0°C	More winter maintenance for road and rail networks		X	
Disturbance of inland navigation due to low and high water	Diversification of transport means	X		
	Upgrade of canals	X		
	Reconsideration of river regulation measures and other adaptation measures	X		
	Rethinking of alternative ship construction	X		
General impacts	Research and development	X	X	X
	New planning norms and guidelines for road and railway construction	X	X	X

[*)] Southern Finland

Source: authors' compilation

5. Fiscal adaptation costs

5.1. Outline of methodology

This chapter combines the numerical adaptation costs extracted from the literature (see chapters 3 to 6 in PART II, and as a summary chapter 4 of this PART I) with the theoretical considerations (chapter 2). The objective is to provide a reasonable, theory-grounded best guess of public adaptation costs. Adaptation costs are a central component of any cost-benefit analysis, which serves as the relevant economic tool for adaptation decisions (section 2.1). According to the developed theoretical framework for adaptation in a non-global context, mitigation is given as exogenous here.

Impacts on the government's budget from adaptation consist of direct and indirect effects (or first- and second-round effects). Direct effects mainly affect the government's expenditure, and result from, for instance, public investments in adaptive infrastructure or subsidies for private adaptation measures. These expenditures are surely the most obvious and visible budgetary effects, although they do not need to be the highest. Many will think of rising expenditures, like additional investment in dyke construction or in transport infrastructure. At the same time, one can also think of declining expenditures, for example in the field of heating energy for public buildings or winter road maintenance. The direct net effect of adaptation is therefore difficult to predict theoretically, but the results of the literature review and the case studies suggest negative impacts on public budgets in Europe.

Indirect effects, in contrast, become relevant when adaptation (whether private or public) as a side effect changes the tax revenue. To highlight the potential importance of indirect budgetary effects, we take a brief look at the results of Bräuer et al. (2009), who analyse the budgetary repercussions of climate change in Germany. The authors conclude that the indirect effects on public budgets may amount to approximately 87% of the total effect. For the case of adaptation, the net budgetary impact of these second-round effects is not obvious. We disentangle the indirect effects in a brief discussion (Box 5.1). Owing to data availability, however, we focus on the direct budgetary effects of adaptation in the rest of this chapter.

Box 5.1: Indirect budgetary effects of adaptation

In economic theory, it is assumed that firms would adapt if and only if adaptation increases their profitability (see e.g. Mendelsohn 2000, OECD 2008). Compared with a scenario involving climate change but without adaptation, the simplifying assumption of efficient adaptation suggests a clearly positive impact on tax revenue. Yet taking timing, uncertainty and other sources of inefficiency into account, the net effects on the public budgets may also be negative. Short-term negative impacts may arise from adaptation measures that incur costs (and thereby reduce the taxable income) today, while the benefits may only be realised in the long run (Fankhauser et al. 1999). The uncertainty of future climate impacts and consequently of the effectiveness of adaptation yields a further risk that the costs exceed the benefits, even in the long run (Mendelsohn 2000, OECD 2008). Moreover, myopic behaviour on the part of firms and individuals, as well as financial constraints may hamper efficient adaptation processes. If these drawbacks reduce the firm's overall productivity, the tax revenue also tends to decline.

The supra-industry perspective may also become relevant. As firm resources are limited, funds that have been spent for any non-adaptive activity x must now be spent on adaptation (activity a). Effectively, demand shifts from the sector providing activity x to the sector providing a. Given different effective tax rates for different sectors, the tax revenue may change owing to a shift in production towards adaptation-oriented sectors (e.g. construction or manufacture). In other words, the sign of the indirect budgetary effects of autonomous adaptation hinges on the question of whether production in the adaptation-oriented sector a yields relatively higher or lower tax revenues than the sector x where demand declines.

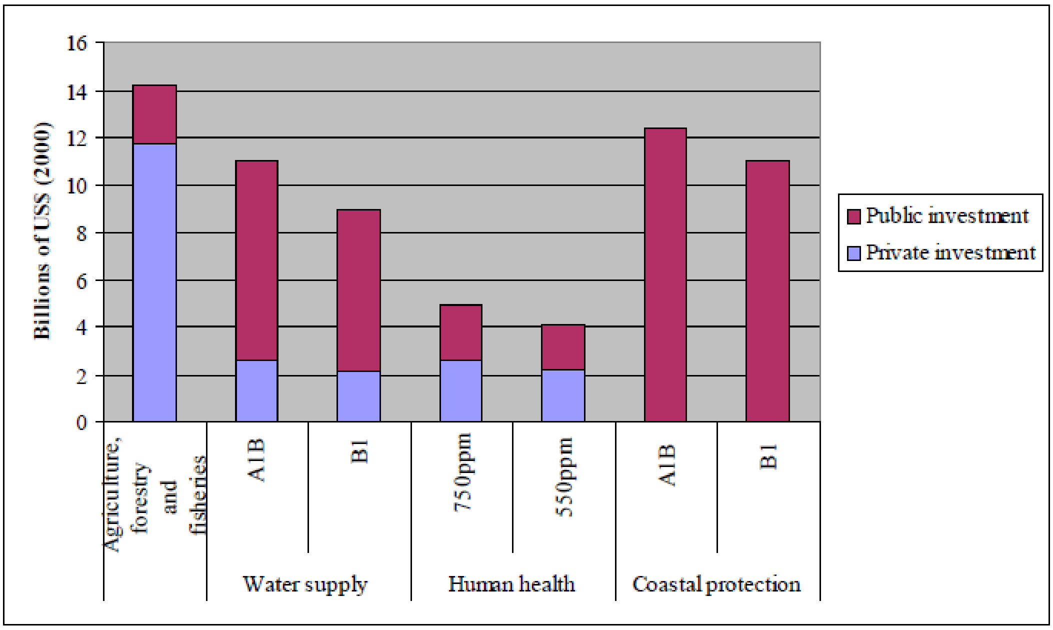
Eventually an adaptation-induced shift in production can also lead to changes in sectoral employment, such that labour demand follows the demand shift. This in turn can have positive or negative impacts on the government's social expenditures, depending on the sector-specific labour market situation.

Further indirect effects may rise in the context of open economies. A country with a relatively high degree of competitiveness in adaptation technologies will possibly gain from a global increase of adaptation demand, and probably achieve higher public revenues. In contrast, countries that import most of the adaptation technology and where adaptation demand crowds out domestic demand would feel additional pressure on their productivity and consequently public budgets.

Another aspect is the international dimension: an essential part of any binding international climate agreement, whenever it is accomplished, will be the payments of highly developed countries to developing countries.[21] Estimates of the financial needs for adaptation in developing countries range from $27 billion p.a. around 2030 (UNFCCC 2007, aggregated by Parry et al. 2009) to more than $100 billion p.a. between 2010 and 2050 (World Bank 2009). The latter figure translates in almost a doubling of current development aid, revealing the tremendous magnitude of the task. The Copenhagen accord commits developed countries to offering this level of support by 2020, starting in 2010 with $30 billion. It mentions that those funds are an aggregate of public and private financing, thus hinting at the need for reinforced instruments such as the Clean Development Mechanism set up by the Kyoto protocol, which creates incentives for private businesses to finance investments in developing countries. But a large share will need to be provided by public budgets. This additional burden will strain public budgets, besides the effects from domestic adaptation. Note that the indirect effects of exported adaptation technology may mitigate the negative impacts on the donor economies (Mendelsohn 2000 mentions this phenomenon with a negative connotation). That being said, we do not include these effects in our analysis, as they are highly uncertain and depend mainly on the outcome of the climate negotiation process, which is essentially a political issue. Furthermore, as soon as binding agreements are adopted, the additional burden should be relatively easy to foresee.

The subsequent sections focus on direct adaptation investments, disregarding indirect effects and international aspects. We base our analysis on an approach first used by the IMF (2008). The authors project the public adaptation investments in some of the impact sectors using absolute adaptation cost estimates by the UNFCCC (2007) and applying rough sector-specific ratios of public costs (see Figure 5.1).

Figure 5.1: Private and public adaptation investments (global perspective)



Notes: The A1 scenario makes the assumption of rapid economic growth and convergence among regions. The A1B scenario is like A1 balanced across all energy sources. The B1 scenario depicts a convergent world with

[21] The reasons highly developed countries should finance adaptation in other countries partly lie in international equity rationales and partly arise from considerations of future international migration and trade developments. They are, however, not the topic of this report. The point here is simply that payments will add to the budgetary burden in EU countries.

rapid development towards service and information economies. Ppm refers to parts per million atmospheric carbon concentration.

Sources: IMF (2008); absolute adaptation costs come from UNFCCC 2007; ratios are proposed by IMF staff.

We develop this method further by including more impact sectors and introducing theoretically and empirically grounded determinants for public shares in each impact sector, with references to the theoretical framework in chapter 2. We choose a sectoral approach because governmental intervention can be best described and reasoned in a sectoral context. We furthermore apply the proposed determinants of public adaptation involvement to the top-down estimates for various European aggregates.[22] The same procedure can also be used for data from the three case studies.

5.2. Governmental intervention in different sectors

5.2.1. Agriculture

The estimates in literature have a wide range. Fischer et al. (2007) propose adaptation costs for irrigation alone amounting to €161 to 966 million p.a. in Western Europe in 2030, based on different scenarios, with rising costs post-2030. Bosello et al. (2009) estimate a much higher amount of €6,274 million p.a. for irrigation in Western Europe in the 2060s, just to name two extremes of the estimates. The case for governmental intervention, especially long-run structural changes, is underpinned by a variety of reasons. The first one to mention is the interaction between mitigation and adaptation. Certain adaptation measures may not be conducive to mitigation. Changing cultivation or livestock production techniques can lead to increasing GHG emissions. Economic efficiency would require a price being set on these emissions. A task of the government is to set frameworks and support adaptation strategies, in which the interactions are taken into account. The second reason for governmental intervention is to facilitate autonomous adaptation. The long-term adaptation measures show that the distribution of information and provision of a regulatory framework are the basis for private adaptation. This primarily includes knowledge about the effectiveness of adaptation measures and the expected impacts of climate change, as well as regulation of property rights and tenancy rules. Another reason for the government to intervene is equity. Adaptation has the potential to become very costly. Especially in countries where agricultural production is a large share of GDP, the adaptation costs could lead to negative effects on national or regional welfare. Also in the EU, where the economic importance of agricultural production is relatively low, there are differences among the member states. Countries with a lower per capita income, particularly new member states, show a higher dependency on agriculture than richer member states. Moreover, the impacts of climate change may benefit northern Europe while the southern member states are rather disadvantaged. Therefore intergovernmental transfers could help to balance the inequalities. Equity aspects also play a role within a country. The provision of emergency relief after extreme weather events by the government can be justified if farmers cannot afford proper insurance or the possible damages are not insurable at all.

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[22] Due to a lack of detailed data, we do not use the adaptation costs in the cross-sectoral impact field of 'extreme weather events'. Admittedly, according to the adaptation cost matrix the highest adaptation costs may be expected there. But as there is no information available in the literature on which actors are affected by these costs and how exactly the costs arise, to date it has not been possible to determine the specific degree of effects on the government. Therefore the methodology used cannot be applied here.

The attempt to quantify the share of public expenditures on climate change adaptation in the agricultural sector is challenging. The majority of adaptation is autonomous. However, taking into account the planned adaptation, equity and security of supply aspects the expenditures are not entirely private. According to global estimations by the IMF (2008), the public share of adaptation expenditures within agriculture, forestry and fishery is around 15%, which can be justified by our theoretical considerations. This translates into absolute values of approximately €940 million p.a. solely for irrigation in Western Europe in the 2060s and €25 to 145 million p.a. in 2030 (again, solely for irrigation in Western Europe), based on different scenarios with rising costs post-2030.

5.2.2. Forestry

There are no specific data available about adaptation costs in the European forestry sector, so cost estimations and public expenditures cannot be numerically presented. Adaptation to the impacts of climate change in forestry mainly involves precautionary measures, such as the implementation of early warning systems, diversification of tree types and transition to other tree types. The central characteristic of adaptation measures in the forest sector is their long anticipatory time horizon. Long growing periods and the relative impossibility of retrofitting call for early action. The government acts as a social planner, providing knowledge transfers and research on issues as well as early warning systems. Furthermore, it takes the positive externalities of forests into account. These are for instance their CO_2 compensation capacities and their positive effects on regional microclimates, on biodiversity and on local recreation. Finally, the state itself is an owner of forests. The average share of total public ownership weighted by the production size is around 40% (own calculations based on Eurostat data). The shares in the different member states vary largely, such that a European mean value (even a weighted one) has to be interpreted with caution. This ownership approach can only serve as a first assessment of the public shares of adaptation expenditures. Together with states actions as a social planner, the actual share of total adaptation costs is somewhat higher than the ownership share. We propose a share applicable in Europe of around 45%.

5.2.3. Flood protection

Summarised, the cost estimates for flood protection measures in Europe amount to annual costs of €281 to 4,022 million for coastal protection in the EU, assuming different scenarios regarding sea level rise. Flood protection is a prime example of a public good. It resembles a form of joint adaptation, which has to be provided by collective action and in most cases will be organised and financed by a governmental entity. Translated into budgetary effects, that means most (if not all) of the adaptation costs will be borne by public budgets. Assuming a public share of 100% of flood protection costs may be slightly overestimated, however, because some EU member states (e.g. the UK and some Scandinavian countries) share the financial burden of flood protection with private actors.

The phenomenon that in some countries the local municipalities and even private landowners are responsible for financing coastal protection is interesting. It rests on the theory that besides global public goods so-called ‘local public goods’ exist. Local public goods only benefit some of the population. According to the theory of fiscal federalism (Oates 1999), it is efficient to assign the task of providing the local public good to the local authorities and taxpayers. For example, the costs and benefits from the construction of a dyke providing shelter to one city only accrue to municipal authorities and local taxpayers. This view of local public goods can be altered by negative externalities. In the case of local public goods, if their provision in one locality has a negative impact on other localities, uncoordinated actions by the localities will be socially inefficient.[23] In that case planning by a central government can ensure the socially efficient outcome.[24] The fact that even private landowners are made responsible for the financing of coastal protection may be reasoned by the low population density in most of the areas where this regulation can be found. If a specific dyke gives shelter to only one specific plot of land, the theory of local public goods would suggest putting the financing responsibility solely on the private landowner. Whether this regulation is also conceivable and feasible in other countries or areas with a higher coastal population density, is nonetheless very questionable. Under the circumstances of a higher population density (which means that there are several beneficiaries of a coastal protection measure), the collective action dilemma explained in PART I, section 2.2 remains.

After a review of the different funding regulations for coastal protection in the EU, we propose a public share of around 98%. That means the yearly public costs amount to €275 million in 2050 (for the EU) and €3,950 million in the 2060s (in Western Europe), depending on the underlying sea-level rise scenarios and assumptions. Given the substantial planned protection of the coast of the Netherlands the lower estimate for 2050 would be underestimated by approximately €2 billion.

5.2.4. Water supply

Adaptation costs in the impact field of water supply are expected to be €251 to 875 million in European OECD countries in 2030 (UNFCCC 2007) and €2,655 million p.a. in Western Europe in the 2060s (Bosello et al. 2009). Governmental intervention in the water supply sector is mainly based on two rationales: first, networks for sewage or water supply create increasing returns to scale and thereby cause market failure. The second is grounded in security-of-supply rationales. Obviously, water is an indispensible good for any economy of the world, which gives a strong case for governments to ensure the secure supply even under new conditions like climate change. For these reasons one can also expect direct governmental action to ensure drinking water supply in times of extreme droughts. Based on these considerations, we propose a public share of adaptation investment costs in the water supply field. Bräuer et al. (2009) assume a share of 25% for Germany, which seems reasonable since great parts of the investment costs are refinanced by usage fees, so ultimately by private actors. Still, public resources are still strained to some extent, for the abovementioned reasons of governmental intervention. Owing to a lack of detailed data for other EU member states, we assume the same portion to be realistic for the entire EU. The budgetary effects of adaptation in water supply and sewage systems will therefore add up to approximately €60 to 220 million p.a. in European OECD countries in 2030, and €665 million p.a. in Western Europe in the 2060s, based on different scenarios.

5.2.5. Health

In Western Europe, global warming could reduce total health expenditure by €563 million p.a. in 2060-2065, as the net result of adverse temperature effects and a decrease of

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[23] For instance, the building of dykes by a local authority in order to prevent river floods upstream may increase the risk of floods down-stream. In a non-cooperative environment, an upstream decision-maker will not take into account the negative externality for the downstream region generated by the dyke.

[24] For a further analysis of the theory of fiscal federalism, see Oates (1999), and with regard to adaptation to climate change, Dannenberg et al. (forthcoming).

expenditures for cold-related diseases (Bosello et al. 2009). In contrast, in Eastern Europe and the former Soviet Union adaptation of the health infrastructure could incur costs in the same order of magnitude in the first half of the century (World Bank 2009). A great part of the adaptation related to health is taken autonomously, for example in cooling homes and other behavioural changes. Collective adaptation tends to entail higher costs, being characterised by, for example, the provision of infrastructure, the dissemination of information, research and the monitoring of climate change-related diseases. The free market normally does not provide these goods, so these measures are mainly taken by the government and hence they involve public expenditures. Furthermore, when it comes to the provision of equal access to health care equity aspects play a role. On the one hand, the geographical distribution of medical care – which means the number and distribution of physicians across the country – is necessary to ensure equal access. On the other hand, guaranteeing that the services are affordable for everyone is essential under equity considerations. Because of the lack of data about specific adaptation expenditures in the health sector we use the current public share of total health care expenditures as a proxy. The EU-wide public share weighted by total expenditures was around 77% in 2005 and 2006. Taking into account an ageing society and growing requests for public infrastructure (e.g. heat-wave early warning systems), we propose a slightly higher public share of around 80%. This means that public budgets in Western Europe are estimated to fall by €450 million p.a. in the 2060s (Bosello et al. 2009), whereas other literature suggests additional public costs in Eastern Europe of the same amount in 2010-2050 (World Bank 2009).

5.2.6. Energy supply

The energy sector plays a central role in the climate change debate. But most of the discussion concerns mitigation in the energy sector. For adaptation, the literature suggests the following cost estimates: €563 million p.a. in the 2060s for undefined adaptation measures in Western Europe up to €1 billion in 2050 for cooling measures in thermal power plants in the EU27 plus Norway and Switzerland. Energy networks have always been regulated in some way because of network externalities. In the EU member states, the regulation itself is currently characterised by two slightly different strategies. In both alternatives the network is operated by a transmission system operator (TSO), which is separated from the generating companies (legally, by management or by ownership, see Sioshansi and Pfaffenberger 2006). TSOs may be private companies, regulated by a governmental authority (e.g. the Federal Network Agency in Germany), which sets price ceilings or return-on-investment ceilings. Moreover, TSOs are legally committed to secure an enduring energy supply. In the other alternative, TSOs are publicly owned companies, as is the case in most EU member states. In both cases TSOs should charge prices that ensure a cost-effective operation of the network, without any cross-subsidies. That means that if budgetary costs rise due to some adaptation of energy networks by state-owned TSOs, these costs should be reflected by higher transmission fees ultimately charged to the consumer. Thus, the end consumers should be affected and not the public purse, regardless of the ownership structure of the TSO.

Another situation arises in the context of security-of-supply considerations. No government would accept an enduring breakdown of power networks or even the danger of such an event. Budgetary effects may possibly arise if TSOs require very high price increases for consumers in order to invest in the necessary grid infrastructure, prompting the state to intervene. For ensuring the security of supply, power plants also have to tackle the problem of insufficient cooling water supply. If governments have a strong interest in the security of supply during large-scale heat waves, they might implement policies ensuring that power generators care for these events, which would possibly accrue expenses.

Equity-related issues may affect the fiscal adaptation costs in the energy sector as well. Vertical equity considerations may call for greater public support of citizens in need if the energy retail prices rise because of climate adaptation. To sum up these aspects of governmental intervention in energy supply, we recognise the significant regulatory interventions, but put the overall budgetary costs of adaptation on the energy supply side at not more than 5% of the total adaptation costs. Note that this guess incorporates the assumption of no cross-subsidising of the regular network operation. Combining this share with the available cost estimates, we conclude the following fiscal costs of adaptation in the energy supply sector: €28 million p.a. in the 2060s in Western Europe and around €50 million in 2050 in the EU27 plus Norway and Switzerland.

5.2.7. Energy demand

Adaptation to climate change (i.e. warming) is likely to result in more demand for cooling and less demand for heating energy. Although this behaviour seems trivial and it could be interpreted as a form of impact, it fulfils the criteria of a *reactive adaptation* measure, as defined by the IPCC (IPCC 2007). Therefore, it is included in this analysis. Tol (2002) estimates a net effect of additional energy costs adding up to over €6 billion p.a. in European OECD countries (Tol 2002). Another study suggests net savings from decreased heating needs of around €28 billion in 2050 in the total EU27 plus Norway and Switzerland (Jochem and Schade 2009). The wide range of these figures highlights the immense uncertainty of available adaptation cost estimates. The various results cannot solely be explained by differences in time horizons, spatial coverage and underlying scenarios; there remains a large amount of scientific and technological uncertainty. The effects are relatively high, compared with other adaptation costs, and vary strongly across regions and among different studies. Budgetary repercussions from this adaptation behaviour may occur to the extent that buildings are owned and maintained (heated and cooled) by governmental entities. Thus, the public share of the effect of demand adjustment hinges on the share of public buildings in the total building stock. Bräuer et al. (2009) use a ratio of public buildings over the stock of total buildings of 10% for Germany. An analysis of Eurostat statistics on fixed assets shows that the German value may serve as an approximation for the EU average (weighted by the total fixed assets), although the differences within Europe are high. For the aggregate of all EU member states, a ratio of 10-15% seems reasonable, which means that 10-15% of the demand adjustment effect will affect the public budgets. Expressed in figures, this means that in the total EU energy costs may rise by €600 million to 1 billion p.a. due to the cooling of public buildings (Tol 2002). In contrast, based on the study by Jochem and Schade (2009), there will be energy cost savings for the public purse amounting to €2.7 to 4.2 billion in 2050. These values, however, entail a high degree of uncertainty with regard to the technological development within the 21st century.

5.2.8. Tourism

For adaptation measures in the tourism sector, only rare information on adaptation costs is available (moreover, no estimates are available for costs in the total EU). The (direct) budgetary costs of adaptation by the tourism industry depend on the level of governmental intervention in the predominantly private economy. Most adaptation options practised at present constitute private goods. The benefits as well as costs of new tourism opportunities, of the prolongation of the main season and of the exploration of new tourist sites mainly accrue to the (private) decision-makers. Hence, there is no large-scale market failure in the sense of joint adaptation (see section 2.2).

Externalities may occur from private adaptation measures, such as artificial snow-making. The operation of snow-making facilities consumes water and electricity. Although the externalities from electricity production are at least partly internalised through the EU ETS (see section 2.1), externalities from unusually high water consumption may still exist. The use of natural water reservoirs in the vulnerable Alpine region is highly controversial, and the consequences and long-term total costs (including environmental damages) are not fully foreseen. So the economic theory of market failure may justify governmental intervention to restrict excessive use of artificial snow-making, if the total costs are not priced into the production costs. But the budgetary effects of these interventions seem to be low.

Although most of the adaptation options are characterised as private goods, there are also measures that have strong common-good properties and therefore call for collective action. The most evident is the promotion of regional tourism. Regional marketing may become important in relation to adaptation, as some regions may gain recreational attractiveness, but also need to be promoted properly. Other regions may wish to highlight specific features and offers that are attractive even if snowfall is not assured. There are private initiatives by regional tourism associations for regional marketing, but generally they face problems related to the voluntary participation in these projects. An individual provider of tourism services cannot be excluded from the benefits of a marketing campaign for a specific region, even if that provider does not participate in funding. Therefore there may be the case for the provision of regional marketing by the government (on the basis of governmental provision of joint adaptation, see section 2.2).

Alongside negative externalities and public goods there are further aspects that actually serve as arguments for governmental intervention. Tourist regions are frequently located in marginal locations (e.g. Upper Bavaria, north-eastern Germany, Alpine Italy, Wales, Islands in the Mediterranean Sea and coastal regions). The economies of these remote regions tend not to be broadly diversified and they largely depend on local tourist industries, not least in terms of local employment opportunities. If regional (or national) governments value the local economic importance of the tourism sector to a sufficient extent, they can decide to support it even if there are no market failures. A possible trigger for this could be different tax systems in neighbouring countries as is the case in the Alpine region. Recently, the German federal government has reduced the value added tax rates for hotel stays. One of the declared reasons was the threatened competitiveness of German hotels compared with Austrian ones. So at the bottom line of these measures are equity considerations (see section 2.3). First, the need for equal conditions among competitors can necessitate governmental intervention. Second, economically weaker regions need protection from hardships. These aspects also exist without climate change, but they may serve as justifications for supportive governmental intervention in the adaptation processes.

Whether these equity-motivated interventions are advisable or not for policy-makers is not evaluated in this document. We just point out that motivations for government intervention in the absence of market failure exist and that they have their own reasoning in equity considerations. These equity arguments notwithstanding, interventions in free markets may possibly hamper a necessary structural change in the economy and thereby cause inefficiencies. Consequently, the total costs of adaptation borne by society may increase. This is part of the classical trade-off between equity and efficiency, as is analysed in connection with adaptation in Dannenberg et al. (forthcoming). Economists can contribute to this debate mainly by illustrating the consequences of alternative policies (with regard to distributional and efficiency effects) and highlighting the possible inconsistencies of policy instruments. In the end, the actual decision is a political one, bringing together the particular interests of various groups in society.

Quantifying this support in financial terms is not easy. The example of snow-making facilities provides an insight into what can be expected as fiscal costs. The Bavarian state government has announced the co-financing of investment costs in regions that are not eligible for co-funding by the Federal Ministry of Economics and Technology, to provide the possibility of public co-funding to each tourist region in Bavaria. The share funded by the public purse will presumably be in the range of 10-20% of the cost.[25]

Aggregating all private and public adaptation measures, the proposal of a single share of public costs in the tourism industry cannot be more than a first attempt. Great portions of adaptation measures are private, without any direct budgetary effects. The provision of joint adaptation may incur public costs, albeit to a limited amount. Interventions for equity considerations may increase these expenditures to some extent. Summing up, we propose that in future analyses of adaptation costs in the tourism sector the share of public costs in the total adaptation costs be set at around 15%.

5.2.9. Transport

In the transport sector, cost estimates range from €3 to 6 billion for the adaptation of infrastructure in the EU27 plus Norway and Switzerland in 2050 (Jochem and Schade 2009). Besides the impacts on traffic safety, the infrastructure is the most critical issue in the transport sector. Governmental intervention in the transport sector is mainly justified by market failure issues. Road networks that are free of charge and open to the public constitute a public good. While there are roads and other transport infrastructure co-financed by user fees, the bulk of transport networks in Europe (in terms of km) are still free of charge and mostly financed by the public sector. Furthermore, privately owned roads and railways exist. Unfortunately, data on ownership structures are not available at the EU level. Knowledge about the private and public ownerships of the networks would provide a basis for an attempt to estimate the government share of adaptation expenditures. Nevertheless, the share is expected to be high (we assume more than 90%), owing to the high level of public engagement in the transport infrastructure.

Even if there are possibilities to exclude users from road services and thereby introduce user fees, governmental intervention may occur owing to security of supply and equity rationales (sections 2.3 and 2.4). If user fee-based road networks fail to provide an adequate quantity (e.g. the distribution of airports or railway stations across the country) and quality (e.g. paved roads) of infrastructure, the government may step in to ensure the access to transport services for each region and each needy member of society. Thereby the public share of total adaptation investments may rise beyond the actual share of the public network infrastructure. But with user fees and privately owned infrastructure, the upper limit is less than 100% for the public share. This results in a range of between 90% and less than 100% for the public

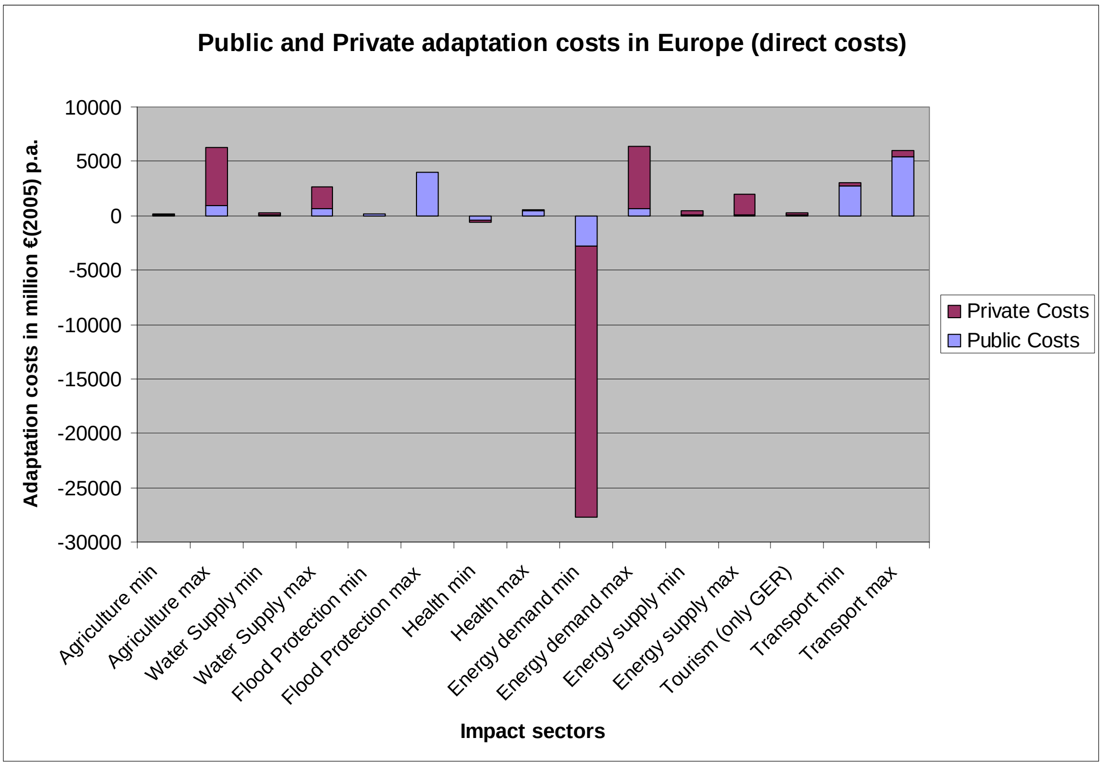
[25] Co-financing shares funded by the Federal Ministry of Economics and Technology for tourism investments in economically weak regions.

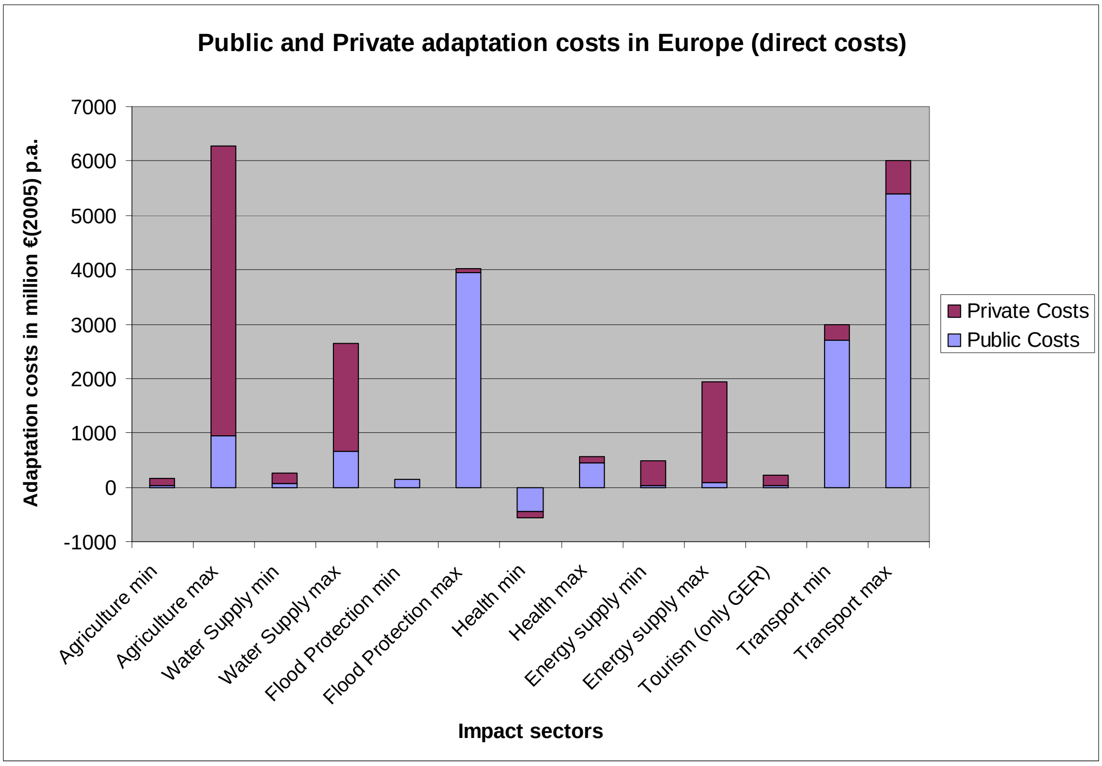
share in the transport sector. Admittedly this is a rough best guess, which can only serve as a first attempt to project the actual public burden. An assumption of a 95% public share (as the middle of the assumed range) would translate into absolute budgetary costs of approximately €2.9 to 5.7 billion for infrastructure in the EU27 plus Norway and Switzerland in 2050.

5.3. Conclusions: Direct fiscal adaptation costs in Europe

In the previous sections we provided theory- and data-based guesses of the direct fiscal costs of climate change adaptation in the most important impact sectors. The analysis of the fiscal ramifications of the direct adaptation costs provides initial insight into the fiscal implications of adaptation and combines the theoretical background and the results from the literature review and case studies (chapters 2 to 6 in PART II). As noted earlier, the cross-sectoral impacts of extreme weather events could not be integrated into this kind of analysis, due to the lack of data availability (for an explanation see footnote 22). This has to be kept in mind in the discussion of results. Still, the findings highlight certain fields in which the impacts are associated with relatively high public costs, compared with others where the total adaptation costs may be high, but the public burden is expectedly low. Figure 5.2 depicts the public burden in the different impact sectors graphically. The comparability of the bars is limited, as the values are derived from various studies (incorporating different methodologies, models, assumptions, time horizons and climate scenarios). Therefore we have included the lowest and the highest expected costs for each sector, such that a wide range of possible outcomes is illustrated. Detailed information on the underlying scenarios, time horizons and assumptions can be found in the adaptation cost matrix in chapter 7 of PART II. The upper part of the figure shows the projected adaptation costs, divided into public and private costs, as they appear in the matrix. Owing to very high negative costs in energy demand, the other bars are hardly visible. That is why we have included the lower part of the figure, where energy demand is dropped to improve the visibility of the other sectors.

Figure 5.2: Direct public and private adaptation costs (upper part including energy demand, lower part without energy demand)





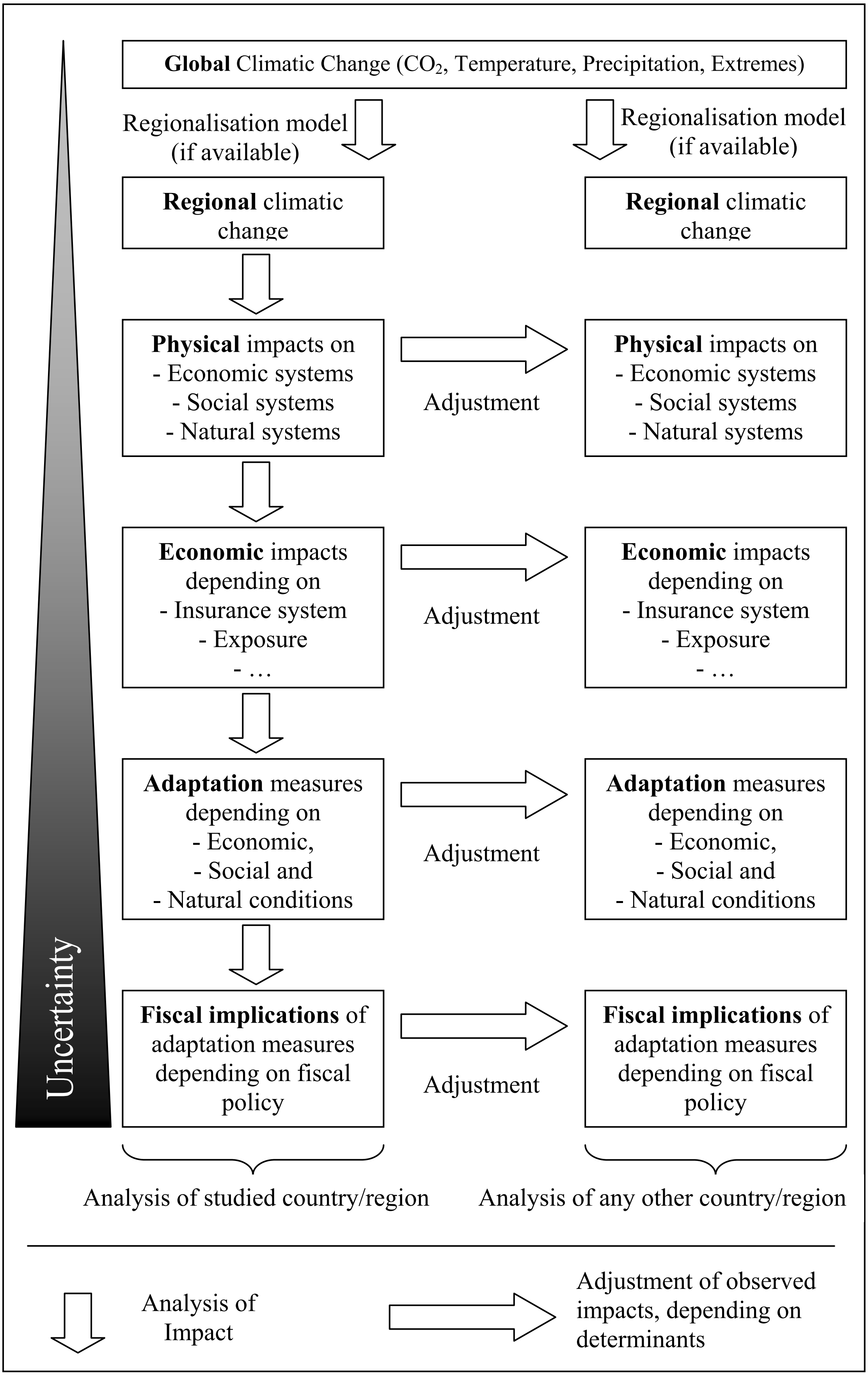
The direct budgetary costs of adaptation are comparably high for transport infrastructure and flood protection. In other impact sectors (e.g. agriculture) adaptation gives rise to higher costs, but these are mainly financed by private actors. Direct effects due to energy demand are highly variable over regions (Jochem and Schade 2009, Eskeland and Mideksa 2009), so the figure for the total EU (savings of up to €28 billion p.a.) has to be interpreted with caution. While northern European countries may significantly gain from saved heating costs, there is a possibility of net public costs owing to cooling needs in Mediterranean countries. All cost projections (including energy demand, transport and flood protection) are subject to a high degree of uncertainty with regard to climatic change scenarios and future socio-economic development. For instance, the budgetary effect of flood adaptation is estimated to be in the range of €137 million p.a. (EC12 without East Germany, by 2100) to €3,950 million p.a. (Western Europe, 2060s), depending on the underlying assumptions and scenarios. Given the Dutch proposals by the Delta Commission (Deltacommissie 2008), the lower estimates are most likely unrealistic. The Delta Commission's recommendations estimate a yearly investment from 2010 of €1.5 to 2 billion to defend the Netherlands from sea surges. Regarding the budgetary effects of adaptation of the health sector, even the sign is not sure. Yet, although the uncertainty ranges are still very high, this analysis can serve as a first, theory-grounded and reasonable insight into what magnitudes of budgetary effects will be triggered by which sectors.

5.4. Transferring case study results to other member states

The methodology outlined can be used to derive a best guess of the direct budgetary effects of adaptation not only for Europe overall, but also for the three countries examined in the case studies, albeit with an even lower degree of literature availability, reliability and certainty. Still, after gaining initial insight into the direct fiscal costs of adaptation investments in Germany, Finland and Italy, the next step could be to transfer the results to other EU member states. This procedure is highly desirable since it would allow a reasonable estimation of the total EU fiscal implications of adaptation, without actually relying on the extensive work of 27 in-depth country case studies. Moreover, the multitude of empty cells of the matrix in chapter 7 of PART II highlights the potential benefits of applying research results to different contexts.

To perform this transfer reasonably and effectively, a number of aspects have to be considered. Figure 5.3 illustrates the discussion in the next section, which explores the different stages of an adaptation cost assessment by transferring case study results. The figure clarifies which steps are necessary to come to well-grounded estimates of fiscal adaptation costs. On the left-hand side the impact sequence is illustrated for a given country analysed in a case study (comparable to the case studies in PART II); on the right-hand side the same sequence is illustrated for any other country to which the results shall be transferred. Then each of the single steps is explained in more detail.

Figure 5.3: Schematic illustration of multiple stages of a transfer of fiscal adaptation costs



The estimates and results from the literature review and case studies summarised in chapter 4 based on the analysis in PART II are influenced by a multitude of determinants at different levels. The first impact stage is global climate change, quantified for instance in global CO_2 emissions, radiative forcing and average temperature increases. This stage yields uncertainty, which is not negligible, but by nature does not cause any differences within countries or regions.

The next stage looks at changes in the regional climate. Regionalised climate models, like WETTREG or REMO for Germany and FINSKEN for Finland respectively, use dynamic or statistical methods to translate global climate models into regional climate impacts. These models partly provide a very high resolution of expected temperature and precipitation; however, thereby they are also an additional source of uncertainty. For transferring economic climate impacts, the first step therefore would be to apply a regionalised climate model for the target country, in order to determine the regional characteristics of climate change. In cases where a regional climate model is not available one has to revert to global climate projections, which can provide only a fraction of detail. A transfer of regionalisation results is not feasible as regionalisation models by nature depend strongly on site-specific conditions.

Subsequently, a transfer of the physical impacts on the economic, social and natural systems can be attempted. Obviously, these systems differ substantially from country to country. For example, an increase of the mean temperature by 2°C can have significantly different outcomes in the agricultural sector, depending on many physical features, such as current mean temperature, topography and hydrologic parameters. While transferring physical impacts, one has to keep these differences in mind and – if possible – adjust the expected impact to the parameters of the new location. This procedure is more practical and less error-prone if two countries are chosen that are comparable in terms of their climatic parameters, topographies and human activities. In reality, it is very likely that no country is the perfect image of another, even when the analysis is restricted to the physical conditions.

The transfer becomes even more problematic at the stage of economic impacts. The translation of physical into economic impacts hinges on various parameters of the social and economic systems. For example, a river flood may incur huge direct public costs in one country, as the government may feel the need to support many uninsured flood-affected people. In a neighbouring country where the private insurance sector has a higher market penetration, the same flood may strain insurance budgets instead of public budgets. The division of the flood costs would be totally different – in the first case they would have to be borne by all taxpayers, whereas in the second case by private insurance companies and consequently by the collectivity of their customers. Another point is even more relevant – the exposure of economic systems to climate risks differs within countries. A further example illustrates this: while the physical impacts of a 1 m rise in sea level may be the same in two regions with comparable orographical characteristics (i.e. the flooded land area would be the same, in the situation of identical protection levels), the economic impacts are highly dependent on the capital accumulation and population density in the flooded area. Transferring economic impacts thus requires particularly careful consideration of the respective levels of exposure. The complexity of that task is at least as high as in benefit transfer studies.

To analyse the fiscal burden of adaptation to climate change, the next stage would be the transfer of adaptation measures. The nature and intensity of optimal adaptation depends on its expected effectiveness and the expected climate impacts (see section 2.1). That is, the main economic indicators of adaptation requirements are expected climate impacts and adaptation costs (and their marginal values). A simple transfer on the basis of comparable economic impacts can be misleading, however, since differences in natural, social and economic systems may make other adaptation techniques more efficient. For instance, in one country the relocation of residential or industrial areas may be an accepted governmental intervention, while in others it would give rise to massive public protests and would not find any acceptance in public opinion.

Furthermore, countries differ in terms of their values and norms with regard to governmental interference. Whereas in some countries governmental intervention through laws and regulations may be widespread and commonly acknowledged as an appropriate means of policy, in other countries the government is much more prone to use market-based instruments. In those countries strong governmental regulation may be more difficult to implement and enforce. Although the validity of the economic theory of market failure and governmental intervention is not affected by these differences in government perception, it may be put in practice in various ways and with different accentuations.

Another difference can arise from divergent political systems. Even assuming that both countries in the comparison are democratic regimes, the concrete system can differ considerably. The degree of federalism is an important variable in this respect. As an example, in Germany a compulsory insurance scheme for flood damages could not be realised, partly because of unresolved federalism issues (Schwarze and Wagner 2006). Adaptation solutions will most likely look different in federal and centralistic political systems.

In addition to the cultural and political differences that may render some adaptation techniques unfeasible in certain countries, differences in adaptive capacities also have to be tackled. It may be the case that all the physical and economic impacts are comparable, but the efficient adaptation techniques are simply not affordable for one country while they are employed in another.

Finally, even if concrete adaptation costs can be evaluated by transferring case study results, the question remains open about how much of the total adaptation costs have to be borne by the public budgets. The share of public involvement in investment funding is by no means identical. Coastal protection may serve as a first example. Whereas in most EU member countries the public sector is in charge of planning, organising and financing the complete coastal protection measures, in Scandinavian countries and the UK private actors (landowners or other beneficiaries) also have to bear some of the financial burden (Policy Research Corporation 2009). Another illustration is given by the expenditures made in the adaptation of the health sector. Given that additional health expenditures caused by climate change are allocated to private and public budgets in the same ratio as current health expenditures, one can expect great differences in the fiscal burden of health adaptation. (The ratio ranges from 90.6% of total health expenditure in Luxembourg to 42.5% in Greece, with 2006 data, according to the WHO.) These differences, which are actually differences in fiscal policy, have to be studied carefully and taken into account when a transfer of fiscal adaptation costs is attempted.

In all these stages, from global climate change to the fiscal implications of adaptation, the uncertainty of the analysis increases. Of course this does not mean that the uncertainty in the first stage, i.e. global climate change, can be interpreted as low. Indeed, the global climate projections with all their scenarios involve a large degree of uncertainty. Any other analysis based on these projections increases the uncertainty of the outcomes. This is illustrated by the triangle on the left-hand side of Figure 5.3. Consequently, one has to trade the knowledge gain of transferring case study results for the growing uncertainty of the results. The efforts needed for a reasonable and comprehensive transfer study should not be underestimated either, considering all the aspects mentioned above.

Finally, we want to mention an interesting alternative to single country case studies. The case of Italy shows clearly that countries can comprise very different climatic zones and thus climate impacts, which makes it difficult to come to country-wide conclusions or specify policy measures. Instead, studies focusing on coherent vulnerable regions (e.g. the Alps, the North Sea or the Mediterranean) have the potential to yield detailed and reasonable impact estimates, and possibly to result in well-grounded policy advice. Of course, the abovementioned cross-country problems will arise here, too. The socio-economic conditions of Upper Bavaria in Germany and Tyrol in Alpine Italy are very different indeed, which will challenge this kind of study as well. In the case of the Mediterranean, as a vulnerable region the complexity increases because many of the countries bordering the Mediterranean Sea are not even EU member states. So at the stage of socio-economic impacts (and all the following stages of a fiscal effects analysis), cross-country studies face particular problems. Eventually, a stronger combination of vulnerable-site studies for the evaluation of physical impacts and national studies for estimating the resulting socio-economic impacts and policy measures is a promising strategy for the future.

6. Knowledge gaps

This chapter provides a description of the main knowledge gaps derived from the literature review, the case studies and the matrix in PART II. For this purpose, the coverage of the five aspects – time horizon, scenarios, methods, sectors and regions/countries – have been taken into account.

The *time horizon* of the different studies refers to past data or a future perspective. Furthermore, just a point in time or a period of time can be covered. There are also studies where no time horizon is mentioned (e.g. Liebermann and Zimmermann 2000). The majority of the literature concentrates on 'point in time' predictions, where a single study can deal with several points in time in the future. The focus of the existing literature is on a medium-term perspective, which means future predictions for the 2030s to the 2080s. Estimations for the near future are lacking. The maximum time frame is the year 2100. There is only one exception with a longer time perspective, up to the year 2155 (de Bruin et al. 2009). As also stressed in the literature review (PART II, section 2), the long-term effects should not be neglected in future research.

Regarding *scenarios*, the core of the studies is based on the IPCC scenarios, where mainly the A2[26] scenario is used. In addition to the IPCC socio-economic scenarios, explicit temperature and sea-level rise scenarios are used. Estimates for the best as well as worst case scenarios are currently neglected. For example, a melting of the Greenland ice sheet (improbable, but

[26] The A2 scenario depicts a heterogeneous world, in which increases in global population, economic growth and technological change are fragmented and slower than in other scenarios.

possible) would result in a sea level rise of several meters – a scenario not looked at in terms of adaptation costs.

There are several completely different *methods* for estimating the fiscal implications of climate change adaptation. The most frequently used approaches are estimates or simulations based on a literature review. Case studies are also commonly used and consulted as part of the methodology. Besides these approaches, computable general equilibrium models are often used. They are based on different models such as the DIVA model (Costa et al. 2009) or the WIAGEM model (Kemfert 2007). Econometric analysis (Lis and Nickel 2009) based on past data and surveys are rare. Especially with progress in the collection of data, more econometric analysis might be provided in the future. In the literature review in PART II (section 2.1), the difference between top-down and bottom-up approaches and their advantages and disadvantages are explained. Accordingly, mainly top-down analyses are performed.

The case studies and the matrix concentrate on nine different topics or *sectors*: agriculture, water supply, inland floods, coastal floods, health, tourism, energy, transport and weather extremes. These are not covered equally. The topic of 'coastal floods' is the one examined the most, followed by the agricultural sector. Some literature can also be found on the health and energy sectors. Yet transport and water supply are only scarcely covered, while for the tourism sector almost no literature seems to be available. The reason might be that this sector is hardly aggregated as one economic sector, but is mostly treated as a cross-sectional industry and therefore specific data are rare. In addition, the topic of weather extremes, which overlaps with other issues and affects various sectors, lacks specific data. Not only is the coverage of the various subjects insufficient but also the coverage of the different time perspectives and alternate scenarios for each one is unsatisfactory.

The *regional/country* perspective shows significant differences. Among the case studies (PART II) Germany is the most studied country followed by Finland, with the least coverage given to Italy. One reason for this sparse literature backing of the Italian case study is that data are sometimes only available in native languages. In the literature review (PART II) it is pointed out that the estimates for the European level are not as extensive as for the global level. In addition, for Europe different regional separations were found in the literature: Europe, EU27 (plus Norway and Switzerland), Western Europe, Eastern Europe (plus the former Soviet Union) and the European OECD. The most thoroughly covered and therefore most often discussed region is Western Europe. Especially for Eastern Europe estimates are missing. Moreover, cross-country analyses are scarce and are limited to specific regions (e.g. the Mediterranean).

The main knowledge gaps that need addressing and research according to our analysis are the following ones:

- There is still a lack of data with regard to regional differences in climate change impacts, not only *between* countries but also *within* countries.
- The existing literature has focused mainly on autonomous and reactive adaptation. Future research should therefore aim at including planned and anticipative adaptation.
- There is a lack of short-term (up to 2050) and long-term perspectives (from 2100 onwards). Research on the near future might help the planning and design of appropriate policy responses.

- There is a need to integrate more thorough sensitivity analyses into studies. There is also a need to show a range of possibilities with the best and worst case scenarios and their probability of occurrence.
- More econometric analyses should be performed as data availability improves.
- Comprehensive overviews of climate change impacts and adaptation options exist only for a few sectors. Other sectors, for example ecosystems and landscapes, demand more attention.
- Some impacts – such as non-market ones, those from extreme weather events or low-probability events – are often excluded and should be included in future research.
- Cross-sectional data (e.g. weather extremes) estimates are needed.
- Eastern European countries have been neglected so far and need to be studied more thoroughly. Many face serious economic and fiscal challenges.
- Cross-country analysis should be provided.
- The indirect effects on the wider economy need to be researched more thoroughly. In this regard, macroeconomic models dealing with direct and indirect effects should play an important role in future research.
- The costs of adaptation are rarely considered and estimated. There is a need to research further the indirect economic and fiscal effects of climate change.

7. Summary and conclusions

Climate change will have an effect on the European Union. The repercussions will be regionally varied, with impacts on several sectors of the economy. Yet current knowledge about their size, their timing and the precise form of the impacts is very limited. For policy-makers, this is a very problematic situation, in particular concerning decisions that may affect infrastructures and the behaviour of individuals in the long term. The member states' public finances are also strained, and thus the fiscal consequences are important to estimate and the worst case scenarios need to be avoided.

The fiscal consequences have until now rarely been studied rigorously, and there is a lack of understanding about the origin and magnitude of the fiscal effects. The literature review and the three case studies for Italy, Germany and Finland in PART II attempt to determine the causes and magnitude of the fiscal implications and present the knowledge gaps in this field. The lack of relevant research is clearly identified in the reviews performed and graphically presented in a matrix in PART II. The matrix plainly identifies the large gaps in our understanding of the potential economic implications of climate change.

It has been possible to estimate to a certain extent the direct costs to the state budget of gradual climate change (approximately €5 to 15 billion a year), but the far more serious impacts from extreme events and indirect effects through ramifications on the economy are missing. Based on just one estimation for Germany by Bräuer et al. (2009), the indirect effects of climate change on public costs will amount to 87% of all public costs. Thus there is a clear signal that yearly average costs can treble to around €60 billion a year, i.e. 1% of total public expenditure for the EU, and not be evenly distributed territorially. For extreme events, there are very few indications of the expected costs, but studies by Costa et al. (2009), the IMF (2008) and the Dutch Deltacommissie (2008) on the protection of the Dutch coast give some flavour of the serious costs of damages from flood events in the event of insufficient adaptation.

In the face of rising fiscal pressures caused by population ageing, the negative economic and fiscal costs need to be minimised. This study also reveals a number of areas where planned adaptation actions can intervene to reduce the fiscal implications and increase welfare. Many of these actions represent win-win situations and are beneficial without climate change, while increasing the resilience against negative climate impacts in the future.

To identify the areas of action, this study presents a list of the main fiscal drivers behind direct and indirect costs:

1) the degree of exposure to gradual and extreme climate events;
2) the level of protection already in place in areas at risk, i.e. preparedness;
3) the state's liability for damages;
4) the potential and impacts of autonomous adaptation and remedial actions;
5) the cross-border effects of climate change; and
6) the fiscal capacity of the member states and the role of the EU.

There has not yet been any study that satisfactorily addresses the way these factors affect the state budget and particularly its stability. This study offers a first attempt at classifying the fiscal risks. From the case studies and other literature reviews, it is evident that the fiscal consequences are not negligible. A number of predicted climate changes and extreme events could severely impair the fiscal stability of some member states.

In general, the gradual changes caused by climate change are considered manageable from the point of view of direct budgetary costs. But in relation to the costs of extreme events and related indirect effects on growth and thus government revenues, the impacts are not necessarily manageable. Furthermore, the indirect effects of gradual climate change and consequences in other countries can also threaten fiscal stability. A few impacts have been identified as having especially strong, negative fiscal implications. These are primarily related to the risks of floods due to rises in sea levels, increases in sea surges and changes in river flows. In the case of river floods alone, the annual costs of maintaining the necessary protective infrastructure and reacting to damages from extreme events has been calculated to exceed 1% of GDP in several member states. This being an average, the cost in any given specific year could be much higher.

To mitigate the economic as well as fiscal impacts, the study has in the following recommendations:

- Select the right level of protection using appropriate cost-benefit analysis tools.
- Invest in research and development.
- Provide a high level of public information.
- Limit the state's liability through innovative public–private partnerships with the insurance industry.
- Adopt appropriate regulations on land use and on the use of other natural resources.

- Use appropriate mixtures of legal and fiscal instruments to guide autonomous adaptation.
- Reinforce coordinated action across Europe.
- Ensure that appropriate assistance is provided to countries whose internal fiscal resources are insufficient to undertake the necessary adaptation measures or react to catastrophic events.

It is clear that to be able to address the issues presented here, there is a need to improve the level of knowledge on climate impacts using bottom-up studies, such as those performed in PART II, with the aim of devising cost-effective and efficient planned adaptation actions, while taking into account the findings from the theoretical framework. The knowledge gaps are very wide while the few studies undertaken use very different assumptions, which make it difficult to compare them and even more so to aggregate their results. One need that has been identified is for different regions – especially those that can influence each other through their adaptation actions – to coordinate their responses and to use the same working assumptions. At present, even regions within the same country use diverse impact assumptions.

Of course planned adaptation should not only be directed at averting the negative welfare effects and budgetary costs caused by climate change, but also policy adjustments may be needed to take advantage of new opportunities created by climate change. While some land may need to be taken out of use because of drought and flood risks, other regions can be opened to exploitation for the opposite reasons. It is thus important that research on climate impacts and varying conditions is deepened. This study shows that the knowledge gaps are large and while implementation of initial adaptation policies can start today, many require more detailed knowledge of regional impacts.

According to our analysis, research on the economic and fiscal impacts is very scarce and where it exists it is not sufficiently well developed. We list a large number of weaknesses and needs. Generally there is an absence of proper analysis with a unified methodology across regions and countries. Studies lack appropriate sensitivity analyses and econometric studies are scarce, with studies often concentrating on average impacts. Extreme events and increased weather variability are often ignored, while positive impacts and best-case scenarios are absent. The focus of studies is mainly on the direct costs, but the much higher indirect costs are often neglected. The timescales applied by the analyses tend to make the studies difficult to use for any policy design. Many countries have not undertaken any studies on climate impacts.

Thus, more bottom-up studies are required to understand the risks, opportunities, needs and potential at the national, regional or local levels and thus determine the appropriate actions with some level of confidence. With the increasing realisation that there is a need to develop adaptation strategies today, it is important that policy-relevant background research is properly undertaken. A methodological baseline allowing for cross-regional comparisons and coordinated action across the EU is also highly recommended. Guidelines could be developed by the JRC. Studies could then be financed by EU R&D funding.

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