Assessing long-term socioeconomic adaptation strategies to extreme events in Europe

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Abstract. Natural disaster losses seem to exhibit a rising trend. In Europe extreme events already cause huge financial losses and put a heavy burden on people, business and the public sector. There is a growing concern that losses and impacts due to extreme events could strongly increase in the future due to global and climatic changes. As one means to address these concerns, the European Commission is funding the research project ADAM[2] (Adaptation and Mitigation Strategies: Supporting European Climate Policy), which among others is suggesting and examining adaptation options (in combination with mitigation strategies) for the European Union. Our analysis focusing on extreme events and associated adaptation strategies suggests that adaptation strategies should be risk based and need to include longer-term economic costs in order to help adapt more effectively to extremes and to decrease various forms of vulnerabilities. A key aspect in our analysis is the explicit consideration of several forms of uncertainty. The paper focuses on the public sector (central government) and the way various adaptation strategies impact on direct (immediate) and indirect (longer-term) extreme event risk. Adaptation measures discussed include structural risk reduction measures, financial instruments as well as other policies such as land use planning. Furthermore, we discuss the science-policy interface for translating complex relationships to stakeholders. As one important example, national and European wide disaster financing strategies, for example the European Solidarity fund, are examined.

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1 INTRODUCTION

The increase in disaster losses from floods, droughts, and other climate-related disasters both in developed and developing countries has been a major concern over the last years. While this increase as of today can be largely explained by socio-economic factors, there is mounting evidence of a significant climate-change signal in natural disaster events, for example, increasing extreme precipitation at mid- and high-latitudes (Schönwiese et. al, 2003), extreme floods and droughts in temperate and tropical Asia, severe dry events in the Sahel and southern Africa (Parry et al., 2007), and increases in tropical cyclone activity in the Atlantic and the Pacific region (Emanuel, 2005).

Already today many regions and sectors in Europe seem vulnerable to increasing disaster risks because of a lack of resources to implement cost-effective loss reduction and risk transfer measures, and their consequent inability to recover in a timely way to disaster events. Yet, with important exceptions, there has been little research on economic vulnerability as well as economic and fiscal risks of disasters. Indirect economic risk can be important and exceed the direct monetary risk and in order to provide an adequate basis for adaptation (and mitigation) policies such risk estimates considerations are clearly crucial. Although adaptation to extremes and their impacts is complicated by the inherent uncertainty, and specific weather extremes are unpredictable beyond a few days in the future, they are predictable in a probabilistic manner.

This paper builds on this and suggests that important progress can be made in modeling extremes in a risk-based, more geographically explicit manner. Such analysis is increasingly being made possible due to recent innovations and improvements in modeling techniques and data by the climate change and natural hazards modeling communities. This may lead to a better and more consistent assessment of natural disaster risk as a function of a geophysical signal, socioeconomic drivers and vulnerability accounting for the inherent aleatoric (chance) variability of natural hazards (Kunreuther, 2002; Oberkampf et al., 2004).

The key issue we address in our paper is the economic vulnerability of important agents to monetary disaster losses and risks. Economic vulnerability is defined as the capacity to refinance and absorb losses. High economic vulnerability may lead to serious national or regional economy-wide repercussions. If a government, for example, cannot replace or repair damaged infrastructure, roads and hospitals, nor provide assistance to those in need after a disaster, there will be longer-term consequences (Benson, 1997a,b,c). While these consequences are usually much more drastic in developing countries, the paper argues that there should also be concern in Europe. In order to assess this issue systematically, we utilize the IIASA CatSim (Catastrophe simulation) modeling framework for assessing the probabilistic *economic* impacts of natural disasters within a simple *risk-based* economic framework for accounting for the macroeconomic impacts due to natural disasters as well as allowing to study the costs and benefits of measures for reducing those impacts.

The paper is organized as follows. The second section presents an overview over the past, current and possible future losses due to natural hazard events worldwide and on a European scale. We examine drivers of global losses and increases thereof. The descriptive analysis is used to motivate the need for a more pro-active risk management approach to the issue and for identifying emerging problems in the future. Two case studies on the country and the European level underline the point that natural disasters impose a great risk on all scales. The third section investigates potential adaptation measures for decreasing current and future losses and risk due to natural hazard. We distinguish between adaptation options to current variability and longer-run adaptation that also include qualitative considerations. The main focus is on the economic and financial risk of natural disasters. Section four presents the methodological approach assessing indirect and macroeconomic effects of hazard events. Results on a country and the European scale as well as an approach for identifying hotspot regions are discussed in section five. A key issue in assessing and managing risk is to bridge the gap between scientific assessments and the actual implementation of risk management strategies and policies, which we are also addressing there. Section six summarizes and outlines potential avenues for future work.

2 Natural Disaster Losses on the rise

2.1 Increasing Losses Worldwide

On a global scale natural disaster losses both in human and economic terms exhibit a rising trend. Figure 1 shows the number of natural disaster events and economic losses in the EM-DAT database from 1975 to 2005 (CRED, 2008). A trend line is incorporated to indicate the upward slope. Other natural disaster databases, mainly compiled by reinsurers, also detect an increase in losses over time. Especially the increase in insured losses is a major and growing concern. For example, if one compares the decade from 1996-2006 with the decade starting in 1960, the number of natural disaster events increased by more than 210 percent. Furthermore, the economic damages increased by more than 650 percent and the insured losses by over 2,400 percent (Munich Re, 2006).

The observed increase in losses leads to the question as to the main drivers. Very generally speaking, those drivers can be broken down into global change and climate change drivers. More specifically, the increase can be attributed to the interaction of several variables including, (i) the location of geophysical phenomena, (ii) the increased exposure due to the increased population growth and human activity in disaster-prone areas, (iii) the low use of preventive measures, (iv) regional underdevelopment, (v) limitations of government available resources, (vi) environmental degradation and unsustainable land use policies (Miller and Keipi, 2005) and (vii) a possible increase in intensity and frequency of extreme natural events, thought to be associated with the rise of global surface temperature (Munich Re, 2005).

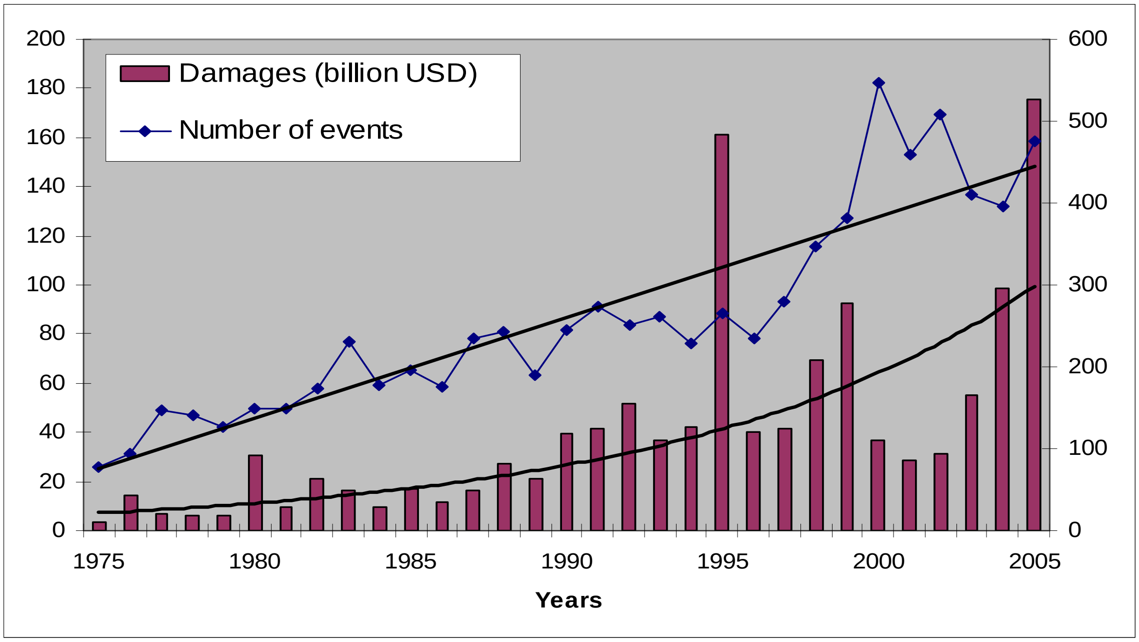

Fig. 1: Number of events and economic damages worldwide from 1975-2005.
Source: CRED, 2008.

Of course, monetary direct losses are not good proxies for determining a country's vulnerability. Although absolute losses are higher in industrialized countries, average losses as a fraction of GDP are higher in middle and highest in low income countries as shown in figure 2.

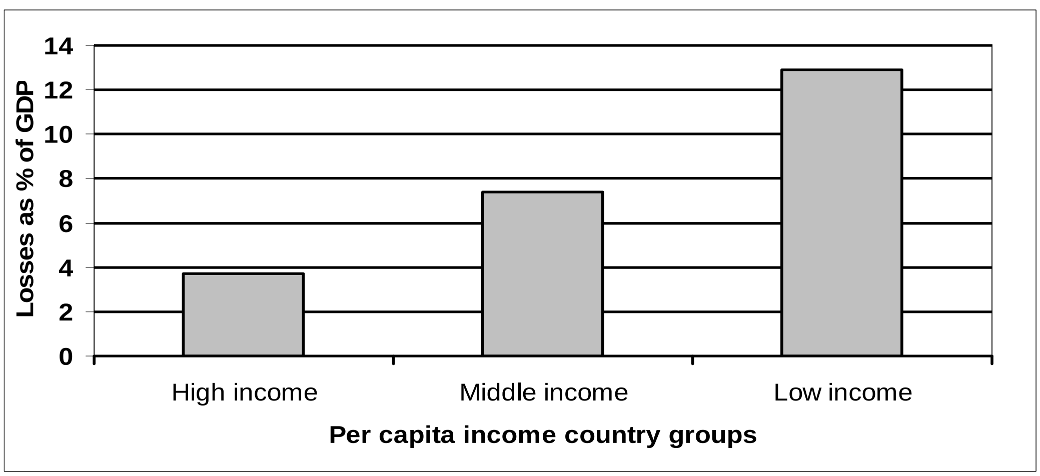

Fig. 2: Average relative losses according to country income groups.
Data Source: Munich Re NatCatService, 2006.

2.2 Natural Disaster Losses in Europe

Also in Europe natural disaster events seem to exhibit a rising trend. Especially, flooding as well as wind storms and extreme temperatures seem to be increasing substantially. This holds also true when economic damages are looked at (see CRED, 2008). It is important to realize that Europe is mostly affected by hazards, which can be altered in its frequency and intensity through climate change (see figure 3). Hence, climate change is an important topic when it comes to determine future impacts of natural extreme phenomena.

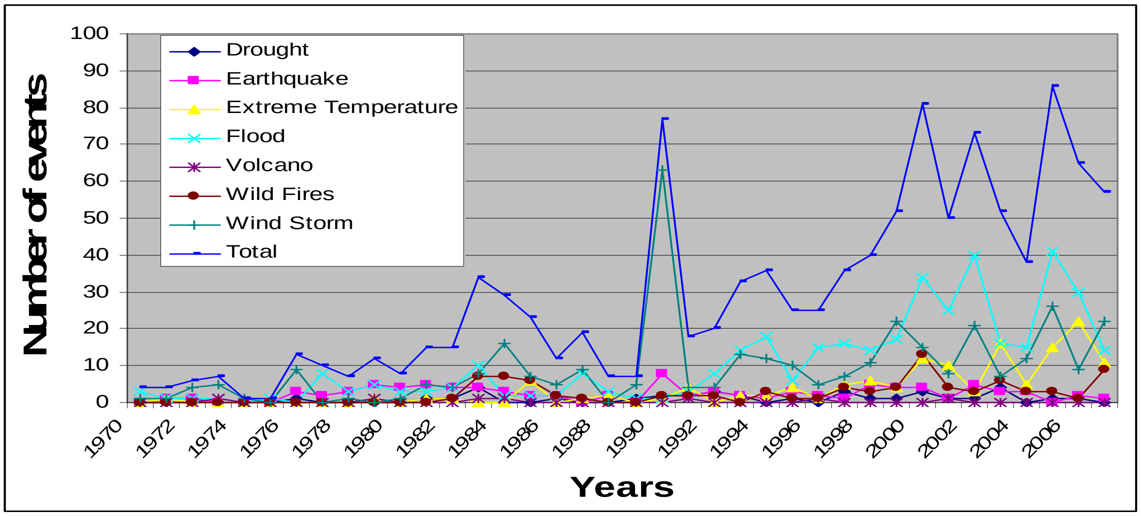

Fig. 3: Number of natural disaster events for different hazards for the time period 1970-2007. Source: CRED, 2008

Furthermore, most of these hazards, especially flooding, have the potential to affect several countries at the same time with even higher losses and damages: The Odra flood in 1997 affected the Czech Republic, Germany, Poland Slovakia, overall causing 100 casualties, economic losses of around 5 billion Euro and insured losses of about 0.8 billion Euro. Furthermore, more than 300.000 people had to be evacuated. Another large scale event in 2002 was the flooding of Austria, Czech Republic, Germany and Slovakia causing 112 casualties, more than 14.4 billion Euro economic losses and more than 3.4 billion Euro insured losses with more than 400.000 evacuations (EEA, 2003).

2.3 The Effects of Climate Change in Europe

There is mounting evidence of a significant climate-change contribution to natural disaster events and losses. For example, the latest IPCC review reports a host of current and future climate change impacts (Parry et al., 2007; Alcamo et al., 2007) and concludes that climate change is likely to magnify regional differences of Europe's natural resources and assets. Furthermore, the review concludes with high confidence that climate change is estimated to pose challenges to many European economic sectors and is expected to alter the distribution of economic activity. Annual maximum temperature is expected to increase more strongly in Southern and Central Europe than in Northern Europe. Large increases are also expected for annual minimum temperature across most of Europe, which at many locations exceeds the average winter warming by a factor of two to three. Also increase in the intensity of daily precipitation events was found and this holds true even for areas with a decrease in mean precipitation. Due to the combined effects of warmer temperatures and reduced mean summer precipitation the occurrence of heatwaves and droughts is enhanced. Agriculture will have to cope with increasing water demand for irrigation especially in southern Europe. Sea-level rise is likely to cause an inland migration of beaches and the loss of up to 20 percent of coastal wetlands. Winter floods increase in maritime regions and flash floods are likely to increase throughout Europe. Coastal flooding related to increasing storminess as well as sea-level rise is likely to threaten up to 1.6 million additional people annually. Warmer, drier conditions will lead to more frequent and prolonged droughts, increased fire risk and longer fire seasons, particularly in the Mediterranean region. Also flooding is expected to increase. Water stress will rise, as well as the number of people living in river basins under high water stress. Areas under high water stress are likely to mount to 35 percent by the 2070s (currently 19 percent). Most affected regions are in southern Europe and some parts of central and eastern Europe, where summer flows may be reduced up to 80 percent. Hydropower potential of Europe is expected to decline on average by 6 percent but by 20 to 50 percent around the Mediterranean by the 2070s. Importantly, the insurance industry should expect increased climate-related claims. However, it is not yet clear where this increase will come from. The impacts will vary substantially from region to region, and from sector to sector within regions. Regions with lower economic development are expected to experience more adverse economic impacts (Benson, 2000). Hence, from a natural disaster management perspective the question is not only where an increase/decrease of frequency or magnitude of natural hazard events will likely occur in the future, but also if the exposed agents are able to cope after events without longer-term negative consequences. It was already indicated that large-scale natural disaster events cause a variety of adverse consequences, including the problem of financing the losses, from the household to the country levels and finally to the European scale. We investigate these issues via taking two perspectives, (i) on the floods in Austria in 2002 on a country level perspective, and (ii) for Europe via assessing the viability of the European Solidarity fund.

2.4 The country level perspective: financing flood risk in Austria

To indicate the problems countries may have in financing losses of huge events we take a look at the natural disaster fund in Austria. The Austrian "Katastrophenfond" (National Disaster Fund) was created in 1966 after sever flood events in 1965 and 1966. Its original and main purpose was to finance prevention measures against future floods (50 percent of the fund). The rest should be used to finance damages caused by floods, landslides and avalanches on the municipality and local level (5 percent), the state level (15 percent) and damages of physical and/or legal entities (25 percent). The percentage for loss financing through the disaster fund for physical or legal persons is now at 4.2 percent. While this rate seems to be very low, in reality, due to the low insurance density and low insurance compensation rates for natural disaster events, the disaster fund plays a major role in compensating losses of private and legal persons, ranging from 20 to 50 percent of the total damage (Hinghofer-Szalkay and Koch, 2006).

The fund is funded by taxes, namely income tax ("Einkommensteuer") and corporate income tax ("Körperschaftssteuer"). Hence, the basis for its income is dependent on the current economic situation. The expenses of the catastrophe fund over this time period fluctuated considerable (figure 4). The red line shows the accumulation from 1990 to 2003 (reserves at the year end). As one can see, at the year end of 1995 the fund accumulated 192 million Euros. However, at the end of 1995 the fund was depleted and therefore, the fund started at zero in 1996. Until the year end of 1997 the fund accumulated 65 million Euro but again was decreased to 29 Mio. Since 1998 the level of the fund was restricted to 29 million Euros. All reserves above were taken for other purposes. Because the expenses of the fund were higher than the income and the reserves were too small, the fund became negative in 2002 and 2003. To adjust the fund investments more than 137 million in 2002 and more than 207 million Euros in 2003 were needed.

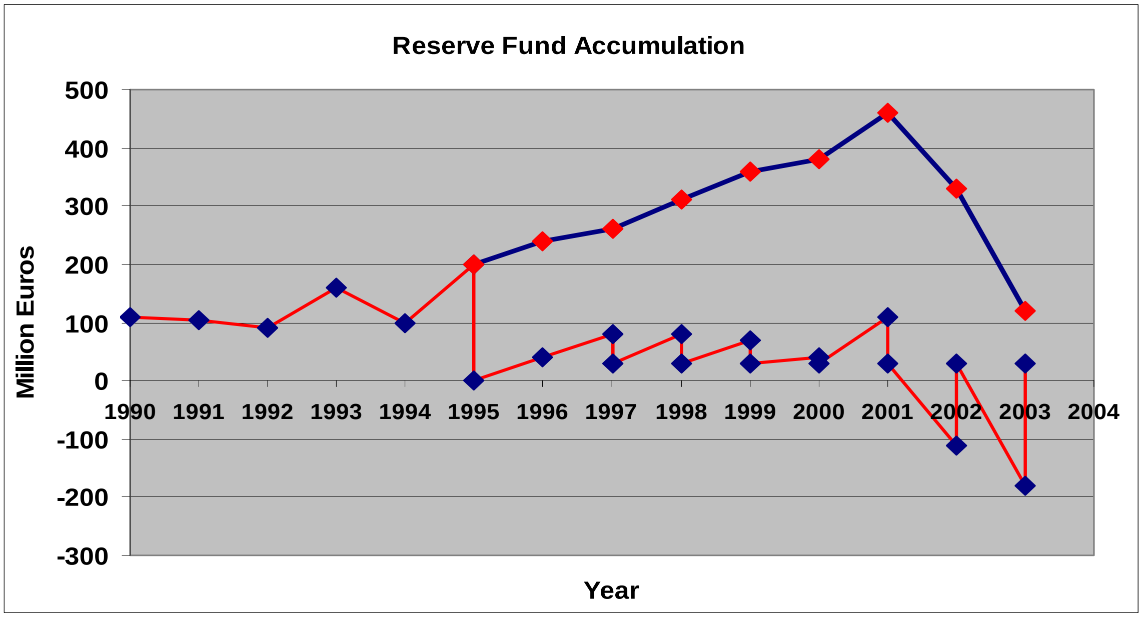

Fig. 4: Reserves of the national disaster fund, hypothetical (blue) and real (red). Data Source: Hyll et al., 2004.

Interestingly, according to the blue line, the fund accumulation since 1995 without restriction and depletion would be have been sufficient for financing the large scale 2002 event. No ex-post measures would have been needed such raising taxes via cancellation of the tax reform (Hyll et al., 2004). This underlines the point that even in wealthier countries loss financing of disasters is a problem, subject to political economy issues and at least in the short run may cause political disruption.

2.5 The European level perspective and the Solidarity Fund

The large-scale central European flooding of the summer 2002 led to financial problems in a number of countries. To address those the European Union Solidarity Fund was created and entered into force on 15 November 2002. Member states and countries which have applied for accession can request aid in the event of a major natural disaster (EUFR, 2002). It provides financial aid for emergency measures in the event of a natural disaster with direct losses above 3 billion Euros (in 2002 prices) or 0.6 percent of the Gross national income (GNI). Furthermore, 25 percent of the fund must be available for allocation during the last quarter of the year (Council Regulation, 2002). The fund can be mobilized even if the threshold is not met, e.g. for a neighboring state that is affected by the same major natural disaster or for extraordinary regional disasters which affects the majority of the population of a region and have serious effects on its economic stability and living conditions. The payments from the fund are limited to finance operations undertaken by the public authorities alleviating non insurable damages (e.g. putting infrastructures back in operation) (Council Regulation, 2002).The European Commission decides the amount of aid and proposes its mobilization. Currently, the maximum annual budget is 1 billion Euros per year 2002 (EUFR, 2004). The amount available annually for extraordinary regional disasters is also limited to 7.5 percent of the EUSF's annual budget (Council Regulation, 2002). However, the actual amount varies from year to year, depending on the occurrence. For example in 2002 it was 728 million compared to only 19.6 million Euros in 2004.[3] Through the GDI threshold level, the aid amount also depends on member countries' income. A country affected by a disaster receives 2.5% for the part of total direct damage below the "major disaster" threshold and 6% for the part of the damage exceeding the threshold (European Commission, 2005).

The total number of applications over the period from 2002 to 2005 is 37, of which 15 (or 41%) were considered major national disasters, 21 (or 57%) were regional disasters and 2 (5%) was dedicated to a neighbouring country. While 21 of the applications were accepted (57%), 15 applications were rejected (40%). Thus, in case of a substantial national disaster event, the EU fund provides a mechanism for assistance and solidarity within the EU and has been accessed frequently over the last years. Although in relative terms the support granted is still small compared (for example, 134 million Euro for the Austria floods in 2002 compared to a total direct damage of 2900 million Euro), the funding is substantial and indicates that risks were not absorbed lightly (as well other additional sources were utilized in Austria to finance the damage toll, such as public and private donations).

Currently, there is a discussion to change the threshold levels to 1 billion Euro and 0.5 percent of GNI as well as widening the definition of events to incorporate industrial disasters, public health emergencies and terrorism,[4] which at constant funding puts the viability of the fund at risk. What is more, the fund may be heavily exposed to one event only, as experienced in 2002 with ¾ of the fund depleted flooding. Given the fact that a number of new member states are very hazard-prone and disaster losses are likely to rise, the Solidarity Fund is likely to be severely under-funded in the future.

3 Adaptation to climate variability and change: Natural Disaster Risk Management

Disaster risks can be reduced or financed. For our focus on the latter, it is important to identify who bears the risk. On an aggregate country level, risk bearers are the government and the private sector (business and households). Additionally, in developing countries international financial institutions (such as the World Bank) are exposed due to their development portfolio, (Miller and Keipi, 2005). Private sector stakeholders include property owners, insurers, reinsurers and the capital market. Each stakeholder mentioned above may implement a wide range of risk management and adaptation strategies,

[3] Due to the length of the table, it is not included here. The full table can be found under the following website: http://www.iiasa.ac.at/~hochrain/

[4] See http://europa.eu.int/rapid/pressReleasesAction.do?reference=MEMO/06/153&format=HTML&aged=0&language=EN&guiLanguage=en

including risk reduction, preparedness and transfer. The most important ones are presented in the next two subsections.

3.1 Adaptation to Climate Variability

Instruments for managing current and future variability can be used on different levels within the private and the public sector. Our focus is on the public sector as a key for risk management and adaptation to extremes because of its responsibilities for public assets as well as for businesses and households, e.g. as insurer of last resort and/or helping the affected after a disaster. Private sector instruments are only shortly introduced.

Risk management strategies can be separated into risk reduction techniques, risk financing instruments and loss absorption. The later is called an *ex-post* or after-the-fact approach, while the former two are proactive (*ex-ante*) approaches. Risk reduction techniques (also called risk mitigation measures in the disaster community) are methods to lessen the direct impacts of the natural hazard. Mitigation can take place before, during or after the disaster. Measures may be both physical or structural and non-structural (Benson and Twigg, 2004). While structural mitigation measures reduce the physical susceptibility of the exposed elements at risk and include measures such as building codes, non-structural mitigation measures include among others the training of people in response to disasters and land use regulation. Risk financing instruments can be categorized into risk transfer and risk spreading instruments. The dominant risk financing instrument is risk transfer through insurance. Alternative insurance instruments include, catastrophe bonds, contingent surplus notes, exchange traded catastrophe options, catastrophe equity puts, swaps and weather derivatives (Pollner, 2001). There is also the possibility for inter-temporal risk spreading by means of contingent credit arrangements, reserve funds or micro-credit and –savings.

Table 1: Government intervention types.

Intervention type	Beneficiaries
Cash transfers	Poor families, women and children; working poor including informal sector; disabled; poor elderly; other vulnerable groups
Public works	Poor unemployed and underemployed including informal sector; poor agricultural workers during off seasons
Unemployment assistance	Formal sector unemployed
Wage subsidies	Formal sector unemployed, working age youth, usually poor
Commodity price subsidies	Poor and extreme poor families, especially the urban working poor
Targeted human development	Poor students; poor families with access to health services
Service fee waivers	Poor students; poor families with access to health services
Food and nutrition	Small children, pregnant and lactating mothers; children attending schools in poor communities
Microfinance	Poor micro entrepreneurs, poor women
Social funds	Poor families, women and children; poor unemployed and underemployed

Source: Adapted from Blomquist et al., 2002.

Repairing damaged infrastructure and providing assistance to the business sector and households are major responsibilities of a government (see table 1). There are also government catastrophe (insurance) programs, to increase insurance density in the country by supporting insurance companies after hazard events which caused huge losses. The programs differ widely amongst each other and reflect the underlying exposures and the social milieu of the country (see Guy Carpenter, 2003).

In theory governments should behave "risk-neutrally" against catastrophe risk if they can effectively spread or pool the risk. The theoretical basis for this was provided by Arrow and Lind (1970). According to their theorem, a government may (i) pool risks as it possesses a large number of independent assets and infrastructure so that aggregate risk is negligible, or (ii) it can spread risk over the population, so that per-capita risk to risk-averse household is negligible. As a consequence, governments may behave risk-neutral and evaluate their investments only through the expected net present (social) value (Little and Mirrless, 1974). The Arrow and Lind theorem serves as the basis for government strategies for dealing with risk. In practice, most governments neglect catastrophic risks in decision making), thus implicitly or explicitly they behave risk-neutrally. Yet, the Arrow-Lind theorem does not hold for disaster risk generally. Indeed, disaster events can have important economic and financial implications (see Mechler, 2004). This has been established by the relevant literature for smaller, less diversified developing economies. But even for developed countries, there is indication that the theorem implying risk neutrality does not hold perfectly today and may do less so in the future (see section 2).

3.2 Adaptation to climate change and global change in the long run

While the adaptation measures introduced above are important ones to decrease current and near future risk, e.g. up to 10 years, other long term adaptation options are equally important. For example, land use planning is seen as a particularly important option for addressing the flood issue on the long run because decisions in this field involve considering the risks for future generations. It includes so different options like (i) the introduction of changes in land-use planning and management, (ii) the introduction of zoning – delineation of areas where certain land uses are restricted or prohibited, (iii) the development of control of flood hazard areas leaving floodplains with low-value infrastructure, (iv) buy-out of land and property located in floodplains and stimulating relocation, (v) the introduction of flood protection for buildings, flood proofing installations and flood protection devices for cars, (vi) awareness raising , (vii) the building of flood defense infrastructure like dams and flood control reservoirs, flood dikes, diversions, flood ways, improvement of channel capacity to convey a flood wave, enhancing source control via watershed management, (viii) enhancing storage – implementing floodplains and wetlands, polders and washlands, enhancing infiltration – permeable pathways and parking lots, (ix) managing vegetation like afforestation, cropping pattern avoiding bare soil during precipitation season, (x) promoting terracing and contour ploughing as well as (xi) various forms of techniques and options using probabilistic approaches for new insurance schemes. In the case of droughts, which causes losses in agriculture, shape species distributions and abundance in tropical forests, and increases fire risk in temperate, Mediterranean and tropical systems, there are also different options possible. One can differentiate between low-cost, farm level technologies, and economy scale adjustments to droughts. Examples of the former include: choice of crops variety, change of planting date, and local irrigation. Economy scale adjustments include: the availability of new cultivators, large scale expansion of irrigation, widespread fertilizers application, regional/national shift in planting date, and the building of water reservoirs (McEvoy et al., 2008).

It seems evident that the quantification and modeling of long term adaptation instruments within a risk management framework is difficult, because of the dynamic nature of these adaptation measures and the explicit spatial approach which have to be used in this context. However, modeling adaptation to climate variability is less problematic because these measures can be build around other concepts used in other research areas, like extreme value theory (Embrechts et al. 1997), dynamic financial risk analysis (Malevergne and Sornette, 2006) and (probability based) risk functional approaches (Pflug and Römisch, 2007). However, these adaptation measures have to be incorporated within a dynamic macro-economic setting were possible scenarios in the future are path-dependent, e.g. the socio-economic situation of a country in 5 years is different for a scenario where a disaster occurred in year 2 and a scenario where a disaster occurred in year 4. In the later case the loss financing capacity in year 5 could be weaker than in the former scenario, because various adaptation measures are depleted or not restored. This would also affect the macroeconomic performance in a more negative way. To take such considerations of different levels of risks into account a probability based framework is presented next which incorporates indirect and macroeconomic effects in the risk management modeling process.

4 Modeling Impacts and Adaptation

We now turn to describing our modeling approach developed for assessing the immediate monetary risks and medium-longer term fiscal and economic risks in European countries.

4.1 Framework and Modeling Approach

The model framework we use is the IIASA CatSim (Catastrophe Simulation) (see Freeman et al., 2002[5]; Mechler et al., 2006; Hochrainer, 2006), which in a risk-based framework accounts for the macroeconomic impacts due to natural disasters as well as outlines the costs and benefits of measures for reducing those impacts. The innovation of CatSim is that it explicitly models direct and indirect risks as well as the inherent uncertainty of those estimates from a probability based perspective and helps the user to define and analyze risk management strategies on a country level. We start with some definitions of important terms.

Risk and vulnerability are concepts with multiple and ambiguous meanings. Here, *direct risk* is defined as the risk of asset losses in monetary terms. Direct risk is a function of the hazard (likelihood and severity), the exposure (houses, infrastructure) and the physical vulnerability or the susceptibility to physical damage. *Resilience* refers here to the capacity of the system to absorb disturbances and reorganize while undergoing change so as to retain essentially the same function, structure and identity (Walker et al., 2002). *Economic vulnerability* is a function of direct risk and economic resilience and is measured through various indicators. For example, economic vulnerability can be measured via the financing gap. A financing gap occurs if the hazard causes losses which can not be financed. This will create *indirect* losses and at the end also *macroeconomic* consequences, e.g. a drop in the GDP level. The development of risk management

[5] The first version of the model was developed by G. Pflug and R. Mechler.

strategies based on the direct, indirect and macroeconomic risks will increase the economic resilience and decrease the direct risk and therefore ultimately will decrease the economic and financial vulnerability. Figure 5 shows the methodological approach in a nutshell.

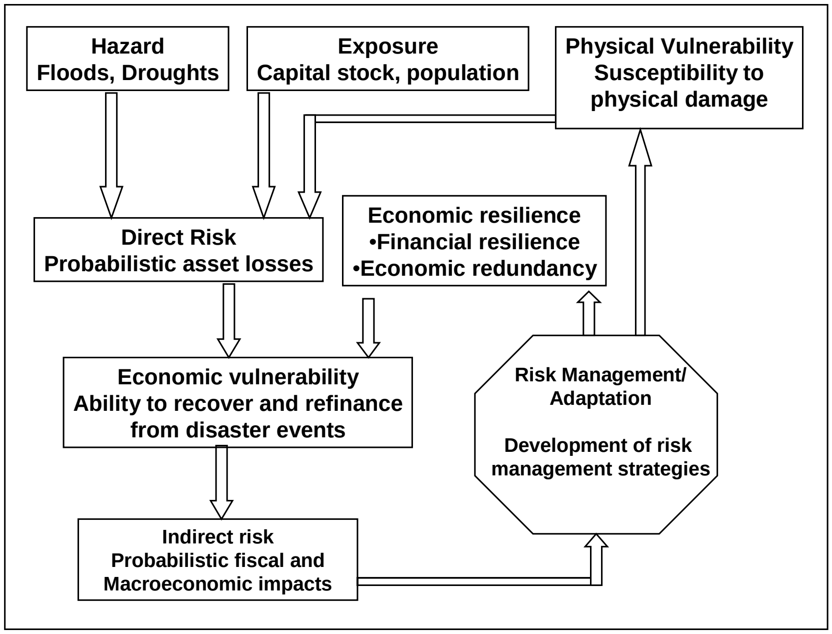

Fig. 5: CatSim modeling approach

Direct monetary risks to public and private sector assets are estimated as a function of the frequency and intensity of hazards (floods or droughts), the assets exposed and their physical vulnerability. Economic vulnerability is a function of economic resilience and direct risk and relates the susceptibility of the economic system to potential disaster damage in terms of monetary losses and return periods. A key indicator is the financing gap, which is the difference between the contingent post-disaster liabilities of the private and public sectors (for repairing lost assets and providing relief to the private sector) and the sources of funding available. It can be assessed by simulating asset risks and estimating the government's and private sector ability to finance these risks. We define resilience as the general financial and economic capacity of a system to cope with shocks of any kind in terms of refinancing losses as well as providing economic redundancy. In the model, disaster risk is mainstreamed into national development planning by incorporating direct disaster risk and potential financing gaps for funding these losses into macroeconomic projections of the country. These consequences can be analyzed on variables, such as on the budget or on economic growth, which are *flow* indicators as compared to impacts on *stocks* addressed by the direct asset risk estimation. The macroeconomic specifications are based on a simple Solow-type growth framework and the model's focus is on the potential for medium to longer term growth and development of aggregate economic variables given the explicit consideration of disaster risks.[6]

[6] The Solow-Swan model is considered the workhorse of economic growth research for studying the longer term potential development of an economy (see Barro and Sala-i- Martin, 2004 for a discussion of economic growth literature). In the simple exogenous savings version, economic growth is driven by the

4.2 Modeling financial and economic vulnerability

One key aspect in our approach is the operationalisation of risk, vulnerability and resilience into the natural disaster context. As discussed, economic vulnerability is here understood as the susceptibility of the economic system to potential disaster damage (direct risk) and is determined by direct risk and economic resilience. Economic resilience is determined by the following set of elements (see table 2). The adaptation options are separated into ex-post or after the event instruments and ex-ante or pro-active instruments. They determine financial resilience. From the government perspective the following ex-post and ex-ante instruments are looked and parameters based on past loss experiences are estimated (table 2).

Table 2: Operationalisation of economic vulnerability

Element	**Description**	**Operationalisation in model**
Financial vulnerability	Ability to share risks	Financial vulnerability algorithm for determining internal and external savings for reconstruction, relief and recovery given direct disaster losses
Economic redundancy	Ability to pool risks: geographic and economic diversification	CES function specification: input factors are not perfectly substitutable (not fully implemented)

The government can raise funds *after* a disaster by diverting funds from other budget items, imposing or raising taxes, taking a credit from the Central Bank (which either prints money or depletes its foreign currency reserves), borrowing by issuing domestic bonds, issuing bonds on the international market or hope for outside assistance (Benson, 1997 a,b,c; Fischer and Easterly, 1990). Each of these financing sources can be characterized by costs to the government as well as factors that constrain its availability, which are assessed by the model (table 3). Yet, ex post financing can be severely constrained. As an example, disaster taxes are expensive to administer and generally not part of the public sector financing portfolio. As a second example, borrowing can also be constrained by the existing country debt, the model assumes that the sum of all loans cannot exceed the so-called *credit buffer* for the country. Ex post instruments may have high costs; even budgetary diversions have associated opportunity costs in terms of foregoing other government investments like building highways or schools.

accumulation of capital via the savings-investment relationship and the rate of depreciation. Modeling economic growth only as a function of capital stock and the availability of new investment into capital stock has to be regarded as a limitation of the model. Solow and others have shown in the 1950s that in advanced countries more than 50% of economic growth can be explained by productivity increases. This number may not be as large for developing countries, but suggests that a considerable amount of growth is not purely driven by the amount of capital but rather its quality (Dinwiddy and Teal 1996). Also, today economic theory generally stresses the importance of incentives, the role of human and social capital and the importance of robust institutions for economic development (Meier 1995). On the other hand, it is generally acknowledged that capital investment plays a major role as a driver of economic growth.

Table 3: Public sector ex post and ex ante financing sources for relief and reconstruction

Type	Source	Considered in model
Ex-post sources		
Decreasing government expenditures	Diversion from budget	yes
Raising government revenues	Taxation	-
Deficit financing *Domestic*	Central Bank credit	-
	Foreign reserves	-
	Domestic bonds and credit	yes
Deficit financing *External*	International borrowing	yes
	Outside support, e.g. from EU solidarity funds	yes
Ex-ante sources		
	Insurance	yes
	Reserve fund	yes
	Contingent credit	yes

Ex ante financing options include reserve funds, traditional insurance instruments (public or private), alternative insurance instruments, such as catastrophe bonds, or arranging a contingent credit. The government can create a reserve fund, which accumulates in years without catastrophes. In the case of an event, the accumulated funds can be used to finance reconstruction and relief. Insurance and other risk-transfer arrangements provide indemnification against losses in exchange for a premium payment. A catastrophe bond (cat bond) is an instrument whereby the investor receives an above-market return when a specific catastrophe does not occur, but shares the insurer's or government's losses by sacrificing interest or principal following the event. Contingent credit arrangements call for the payment of a fee for the option of securing a loan with pre-arranged conditions after a disaster. These ex-ante options can involve substantial annual payments and opportunity costs; statistically the purchasing government will pay more with a hedging instrument than if it absorbs the loss directly.

4.3 Assessing Uncertainty

Another important issue which is explicitly considered within our approach is the analysis of uncertainty. Generally speaking, in the literature two different types of uncertainty can be distinguished: aleatoric and epistemic (Oberkampf et al., 2004). While aleatoric uncertainty is the uncertainty that arises due to the unpredictable variation in the performance of a variable or, in other words, of the inherent randomness of the system observed, epistemic uncertainty is the uncertainty attributable to incomplete knowledge of the system. Aleatoric uncertainty is immanent in a nondeterministic (stochastic) phenomenon and hence cannot be reduced, yet better quantification of this uncertainty is possible. For example, earthquakes cannot be predicted with certainty but the probability that it will happen can be estimated. One way to represent this uncertainty is via probability distributions. Epistemic uncertainty can be reduced over time as more data is collected and knowledge gathered. If all epistemic uncertainty is eliminated, only aleatoric uncertainty would remain, yet it can be readily seen that the distinction between aleatoric and epistemic uncertainty to some extent is arbitrary. As Hanks and Cornell (1994) point out, aleatoric uncertainty in the present time may be cast into epistemic uncertainty at a later time, which raises the question if there is only one kind of uncertainty, namely that resulting from a lack of knowledge. However, from a practical point of view this question is less problematic. Usually, the system under study is not fully understood or has to be simulated for other purposes and therefore needs to be analyzed, for which the distinction between the two types of uncertainty provide a helpful approach, for example by trying to reduce epistemic uncertainty first.

In our approach parametric as well as simulation form uncertainties are measured. While parametric uncertainty can be entirely aleatoric in nature, model form uncertainty is fundamentally epistemic in nature (Oberkampf et al., 2004). Aleatoric uncertainty is represented by distribution functions or exceedance curves. Furthermore, it is possible to use confidence intervals around these curves to reflect the epistemic uncertainty (Kunreuther, 2002). Because of the simulation approach used, the response variables are expected values, hence, it is also important to determine the uncertainty around these estimates too. Again, confidence intervals can be used to reflect the uncertainty around the point estimates. Last, note that epistemic uncertainty is harder to treat mathematically than aleatory uncertainty, as it often requires the use of expert opinions, which leads to various problems due to the subjective component involved in the weighting process (Pate-Cornell, 1996); for this reason we omit epistemic uncertainty in the analysis.

5 Application of the Model Framework

In the next two sections, we present first results of our analysis on fiscal and economic risks. Furthermore, in section three an approach how to bridge the gap between the scientific assessment and risk management strategies, as well as policy-relevant and more practical issues is presented. The analysis is based on the modeling framework presented in section 4 and is used for identifying possible hotspots in Europe and for the European Solidarity Fund and for examining fiscal, economic and financial planning strategies on the country level.

5.1 The European perspective: Identification of "Hotspots"

Losses in relation to GDP could be used as an indicator for determining the relative impact of the event on the economy. Hence, we use the average annual losses in terms of percent to GDP (Data from JRC, 2007) to group the different countries according to their average percentage losses. The grouping is based on empirical analysis on macroeconomic effects in developing countries which suggested measurable effects above 4 percent and dependent on the economic development also between 1 and 3 percent. No effects are usually found for losses below 1 percent of GDP (Hochrainer, 2006).

- First group: maximum losses below 1 percent
- Second group: maximum losses between 1 and 4 percent
- Third group: Maximum losses above 4 percent

We are interested at the beginning only in the third group which includes the following countries: Bulgaria, Hungary, Lithuania, Romania, Slovakia and Finland. The group consists of eastern European countries, and except of Finland all countries applied successfully for the European Solidarity fund since 2002, which indicates that they had problems of financing the losses by themselves.

A different approach which is very valuable for further research can be taken here too. First, the losses in terms of capital stock are determined using the capital stock estimates from Kamps (2005). Then it is assumed that on average 30 percent of the assets in the private sector which are destroyed by natural disaster events are insured. This is based on Munich Re NatCatService (2006) time series and probably the insurance density in lower income countries in the EU leading to a conservative estimate. It is further assumed that another 40 percent (non insured) of the total losses the private sector is responsible for and these losses will be financed without any help from the government, which will leave 30 percent of loss financing to the government, including public sector loss financing and disaster relief. This is a value which seems plausible if a literature review on losses in developed countries is looked at (Hochrainer, 2006). Figure 6 summarizes the results by showing the losses in percent of total capital stock the government on average is responsible for.

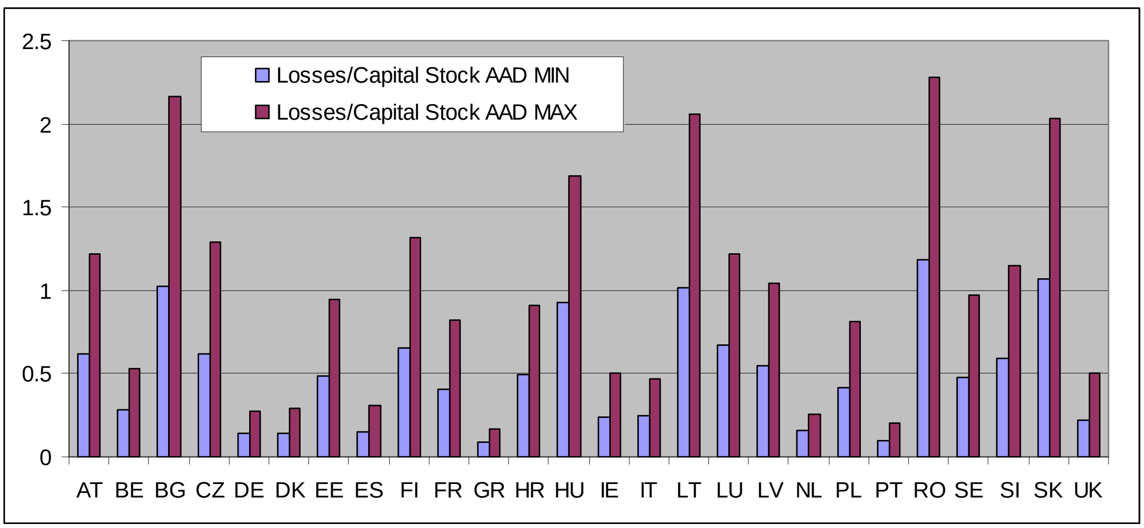

Fig. 6: Average losses of governments in percentage of capital stock due to flooding. Source: Based on JRC, 2007.

Further, we link losses with the ability of the government to refinance the losses. One method to roughly estimate this economic resilience is by looking at the different financing mechanisms each country has available. A key source of funding is borrowing which is however limited by the level indebtedness. Possible debt indicators include (i) the ratio of the net present value of debt to exports which should be below 150 percent or (ii) the debt service to exports ratio which should be below 20 percent (HIPC, 2002).

We use the debts service to exports ratio variable taken from the World Bank Development Indicators (World Bank, 2007) here. If the threshold level is reached by one of the countries which has average losses above 1 percent then this country qualifies as a potential hotspot. Using such an approach this would lead to the following hotspots, all of which are Eastern European countries: **Bulgaria**, **Romania**, **Croatia**, **Hungary**, **Czech Republic**, **Slovakia**, and **Poland** (figure 7)

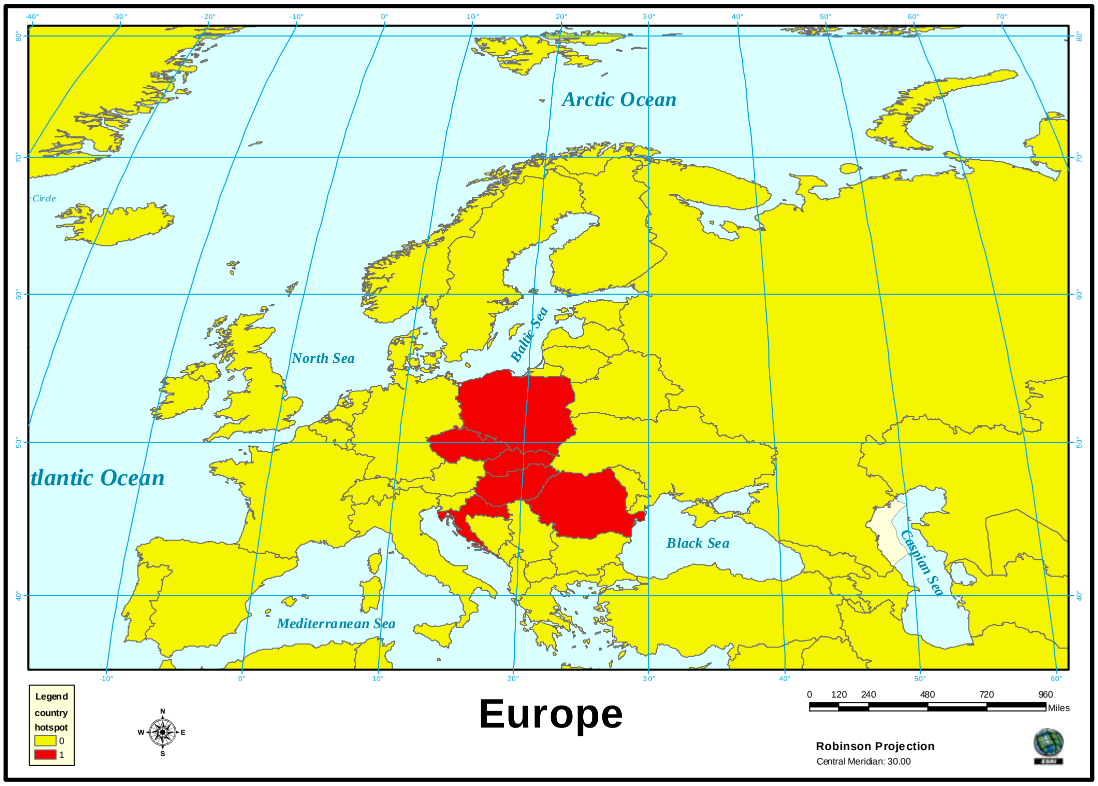

Fig. 7: Flood disaster hotspots regions in Europe.

Additionally, by way of this analysis we can also draw some conclusions for risk instruments on the European level, e.g. by means of the Solidarity Fund. When taking average losses in each country and using the Solidarity Fund criteria to calculate the average annual amount the Fund is depleted by each year, we arrive around 0.4 billion Euros with a standard deviation of around 0.3 billion.

5.2 The country perspective: Fiscal and economic consequences

The prior analysis has to be considered as approximate as it is based on average loss values. Yet, particularly the occurrence of very extreme events cannot be handled in this manner, and the full distribution has to be used when such effects also should be incorporated in simulations. Hence, a more detailed approach using the CatSim model is a necessity. In section 2.4 the problem of Austria's disaster fund was already discussed. While Austria is among the wealthiest countries in Europe and therefore, at least in theory (Arrow and Lind, 1970), should not be vulnerable to disaster events, it has experienced financing problems at least in the short run in the past, for example in 2002. For this event, additional sources of funding had to be sought, and a tax reform was implemented; furthermore, a discussion ensued in Austria on the need and government's ability in light of this calamity to continue with certain large-scale investment projects such as the upgrading of the country's defensive air shield by means of the purchase of additional aircraft. Eventually, frictions within the government become so large, that the coalition fell apart and the total amount of the aircraft project was reduced substantially. If we assume that the disaster fund should be the main financing instrument after extreme events one can use the methodology and model explained in section 4.

As a starting point, the direct risk is considered through the loss distribution. We use a loss exceedance distribution which is based on observed losses in Austria due to flooding (see figure 8)

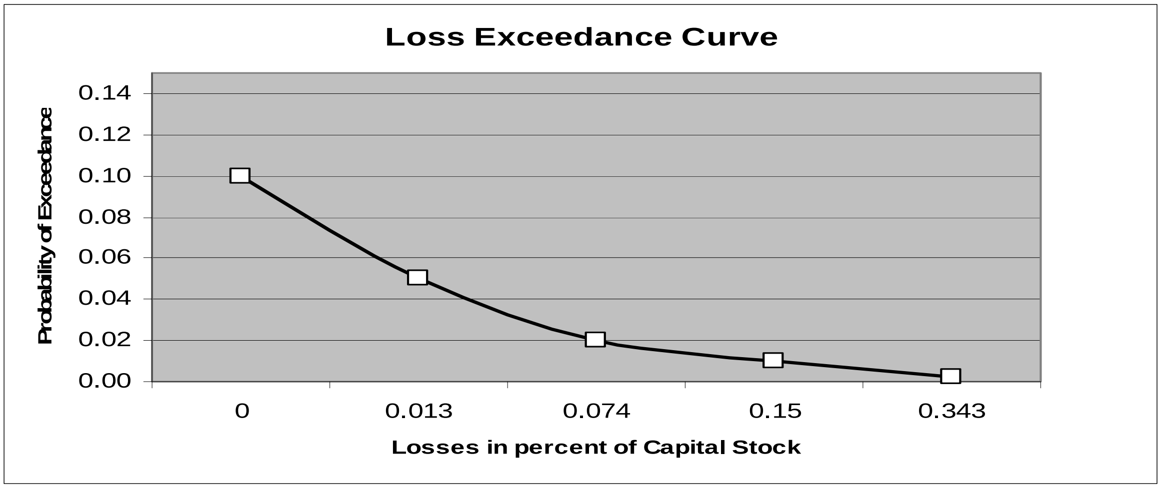

Fig. 8: Loss exceedance curve for Austria based on observed losses

For the case of Austria and in order to determine the economic vulnerability of the government to natural disaster losses some assumptions have to be made. First, it is assumed that the government has to finance 30 percent of the total asset losses, of which 20 percent of the losses come from the public sector (infrastructure etc.) and 10 percent from the private sector. These numbers are based on estimates of the August 2002 flood loss financing. The financial resilience is determined by the ex-post instruments which are used to finance the losses. The following parameters are chosen based on past experience on loss financing:

- 2.5 percent of the direct losses of the public sector are financed from outside assistance, namely the European Solidarity fund for losses higher than 3 billion Euros or 0.6 percent of GDP.
- For the baseline case, the disaster fund is set to 30 million Euros each year.
- The credit buffer, e.g. the maximum amount of credit from abroad the government can or may use is set to 5 billion Euro.[7]

To get a first glimpse at the problem the parameters, especially the credit buffer which determines how much the government can borrow, are restricted. It is assumed that with these parameter settings, the losses until the financing gap year event, e.g. the year event when for the first time a financing gap starts, can be financed without any significant opportunity costs. With these assumptions a financing gap would start at the 172 year

[7] Actually, in reality it would be much higher, e.g. 30 billion Euro, however this number was set as the maximum amount the government can take for natural loss financing from credits because the national disaster fund should be the main instrument for loss financing.

event. It should be mentioned that the disaster fund is restricted with 30 million Euros here, but in reality, like in the year 2002, the reserve fund is used nearly completely to finance the losses (e.g. over 500 million Euros in 2002 and 2003).

The next step consists in incorporating financial disaster risk and potential financing gaps for funding these losses into macroeconomic projections of the country so as to determine economic consequences. The consequences on long-term economic growth, fiscal effects and other macroeconomic variables can be illustrated then. For example in figure 9 one can see the trajectories, e.g. possible futures, over the next 10 years of the percentage of discretionary budget to total budget, e.g. the percentage of the budget which could be used for new projects

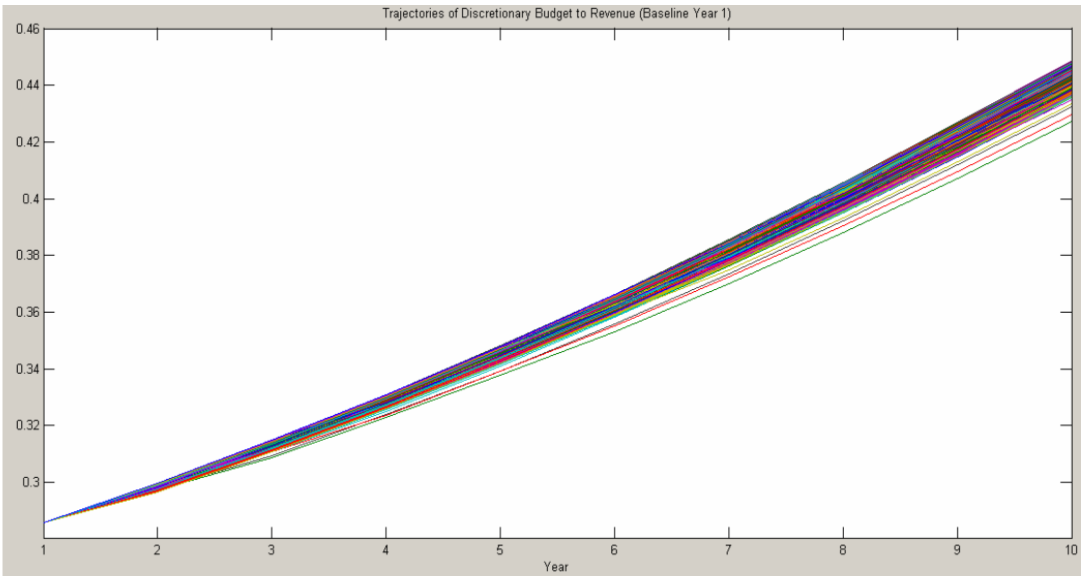

Fig. 9: Trajectories of percentage of discretionary budget to total budget for Austria.

Next, we discuss uncertainty issues. Clearly, parameter estimations are necessarily uncertain due to various reasons, including data scarcity and modeling uncertainty. One way to handle some of the uncertainties is by the use of confidence regions. For example, there could be confidence regions for each of the return periods, e.g. on a 95 percent level.[8] Just to outline our approach, we assume for the moment that for the upper 95 percent confidence interval the value is 20 percent higher than the ones shown in figure 8. With these uncertainty estimates other curves could be fitted reflecting the uncertainty for the estimated loss return periods.

In a next step, sensitivity of financial vulnerability to these uncertainties can be analyzed, e.g. by choosing the worst and best case scenarios. For example, with the upper confidence estimates a financing gap would start now at the 133 year event instead of a 172 year event. On the other side using the lower confidence interval the financing gap would start at the 330 years event. While before it was explained how to deal with input uncertainty there is also the important issue of modeling uncertainty. Because simulations are used the estimated variables are also a function of the number of runs. To deal with

[8] Once national-level data are made available from JRC within the ADAM project we will take these input uncertainties into account in our research.

that, confidence regions can be used to determine the uncertainty. The results are summarized in table 4. It is certainly true that not all uncertainties can be quantified however, in cases were it is possible they will be assessed in such a manner.

Table 4: Probability of a financing gap in the next 10 years with confidence intervals for various input and modeling uncertainties.

	Output uncertainty			
		Upper Confidence int.	Estimated	Lower Confidence int.
Input uncertainty	Upper confidence int.	6.4	6.8	7.2
	Estimated	4.1	4.5	5.0
	Lower confidence int.	2..0	2.2	2.5

5.3 Science-Policy Interface

An additional challenge in modeling and communicating model results is to bridge the gap between the scientific assessment and risk management strategies, as well as policy-relevant and more practical issues. For this purpose, CatSim also has a graphical user interface and can be used as a stand-alone application which makes it possible to assess expert opinions within the model approach.

The results and interrelationships of important variables such as probability, losses and risk financing are used to express complex ideas in an understandable way (Fishkin, 2006; Tufte, 2001). Figure 10 may serve as an example, which shows the user interface for assessing the financial vulnerability. The parameters which can be changed are listed on the top, while the graphical results are shown in the main part of the window. Without using any terminologies and modeling explanation, the user can easily understand the relationship between loss financing and the probability level of the disasters, if he knows that the x-axis is the graphical representation of the impact level of the disasters and the y-axis are the damages due to disasters separated into different financing resources available. In the second picture, one can look at loss financing strategies with all financial resources available and can compare those two types of events. Issues of global and climate change can be assessed in this manner too, e.g. by shifting loss distributions or increasing the exposure over time. Yet, it is important to keep in mind that the model shows one dimension of the threat only, namely the financial vulnerability of the government and the implications for the future via a set of indicators. It is clear, that other dimensions in the context of extreme events and global changes are equally important, e.g. environmental effects or protection of human lives to name but a few, and in the process of assessing the financial vulnerability, such questions of adapting to global *and* climate change naturally arises because of the interrelationship of the different dimensions.

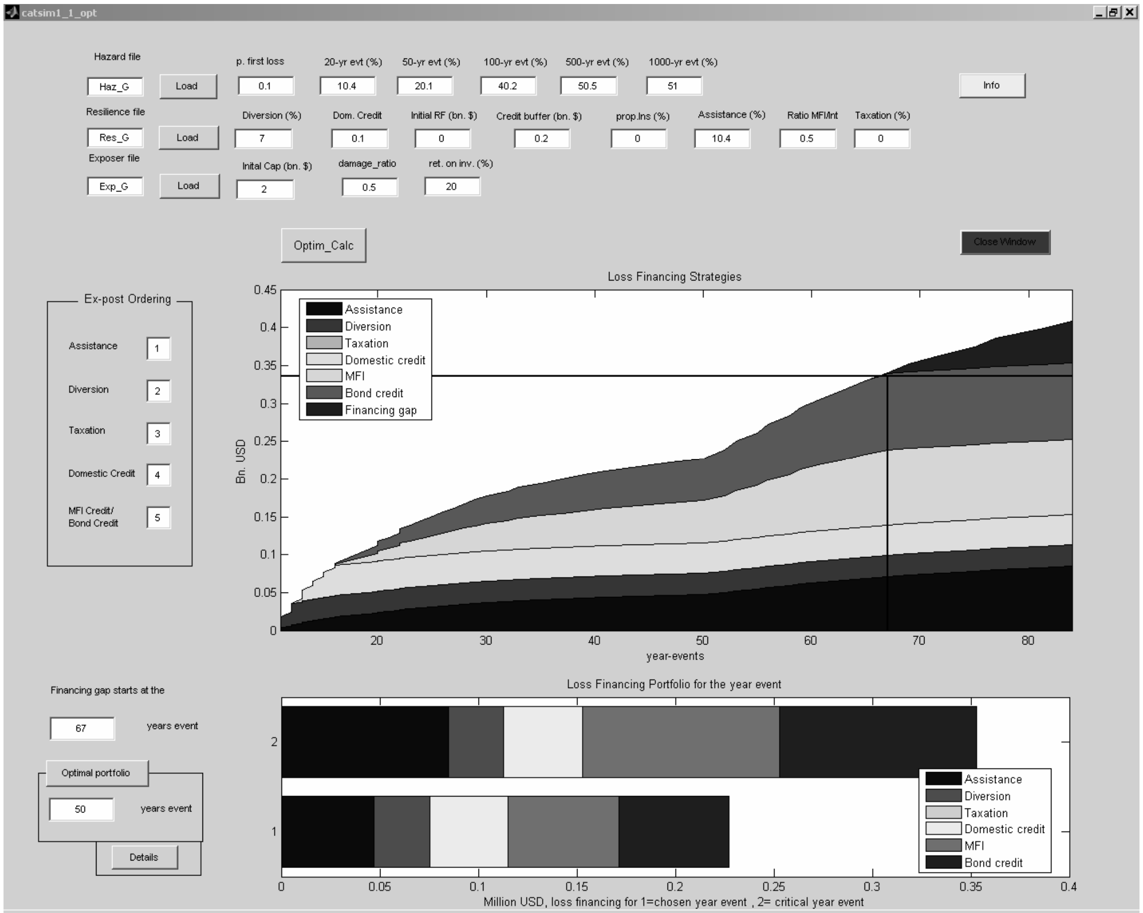

Fig. 10: CatSim user interface to determine the financial vulnerability.

The model can assist policy makers in assessing one piece of the problem, but results are not optimal in the sense that they solve the problems for all dimensions. Hence, an open process and discussion is always required when it comes to *decision making* (Hochrainer and Mechler, 2008).

6 CONCLUSIONS

Natural disaster losses are increasing also in Europe due to a variety of reasons. Although it is commonly held, that European countries due to their level of development can efficiently deal with disaster risk and are risk-neutral towards such risk (as opposed to a number of risk-averse developing countries) as they are well able to pool and spread risks and therefore would not need to account for disaster risks in their economic planning decisions as specified in the Arrow-Lind theorem, empirical indications are found evidence to the contrary. We suggest to tackle the problem from a risk management perspective on a country or even European wide level, and to also include indirect and possible macroeconomic effects as well. Our results indicate that there is need to think over the funding provided under the EU solidarity fund and change this fund to a more risk-based mechanism. This will help addressing likely increases in losses and funding needs both due to global and climatic changes.

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