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# Assessing the Financial Vulnerability to Climate-Related Natural Hazards

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## Abstract

National governments are key actors in managing the impacts of extreme weather events, yet many highly exposed developing countries—faced with exhausted tax bases, high levels of indebtedness, and limited donor assistance—have been unable to raise sufficient and timely capital to replace or repair damaged infrastructure and restore livelihoods after major disasters. Such financial vulnerability hampers development and exacerbates poverty. Based on the record of the past 30 years, this paper finds many developing countries, in particular small island states, to be highly financially vulnerable, and experiencing a resource gap (net disaster losses exceed all available financing sources) for events that occur with a probability of 2 percent or higher. This has three main implications. First, efforts to reduce risk need to be ramped-up to lessen the serious human and financial burdens. Second, contrary to the well-known Arrow-Lind theorem, there is a case for country risk aversion implying that disaster risks faced by some governments cannot be absorbed without major difficulty. Risk aversion entails the ex ante financing of losses and relief expenditure through calamity funds, regional insurance pools, or contingent credit arrangements. Third, financially vulnerable (and generally poor) countries are unlikely to be able to implement pre-disaster risk financing instruments themselves, and thus require technical and financial assistance from the donor community. The cost estimates of financial vulnerability—based on today's climate—inform the design of "climate insurance funds" to absorb high levels of sovereign risk and are found to be in the lower billions of dollars annually, which represents a baseline for the incremental costs arising from future climate change.


This paper—prepared as a background paper to the World Bank's *World Development Report 2010: Development in a Changing Climate*—is a product of the Development Economics Vice Presidency. The views expressed in this paper are those of the authors and do not reflect the views of the World Bank or its affiliated organizations. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at alotsch@worldbank.org.

# Assessing the Financial Vulnerability to Climate-Related Natural Hazards

*Background paper for the World Development Report 2010*
*"Development and Climate Change"*

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# 1 Introduction

Given increasing empirical evidence on climate change altering intensities and frequencies of natural hazards, the management of extreme event risk has been receiving increasing attention in international climate change policy. In Bali at the 13th Conference of the parties to the UNFCCC, agreement was found regarding the creation of a *Climate Change Adaptation Fund*, which is to sponsor concrete adaptation projects in vulnerable countries. We suggest that one key impediment for finally releasing support from this fund has been a lack of operational methodologies for assessing vulnerability to natural hazards and climate change, which are integrated with the cost implications of supporting efforts to reduce vulnerability. A host of estimates for the adaptation costs, often put together using "hand-waving" methodologies, have been suggested, and the robustness and underlying basis of such estimates has often been difficult to verify.

For weather extremes, which form a subset of the adaptation challenge and are supposed to increase in intensity and frequency with a changing climate, we conduct an assessment of the costs of managing and financing today's public sector risks. National governments have become key actors in managing climate variability and change. Yet, many highly exposed developing countries are faced with exhausted tax bases and high levels of indebtedness and cannot raise sufficient and timely capital to replace or repair damaged assets and restore livelihoods following major disasters, leading to an exacerbation of disaster impacts on poverty and development (Mechler, 2004; Bayer et al., 2005; Hochrainer, 2006; Cummins and Mahul, 2007). Exposed countries often have to rely on donors to "bail" them out after devastating events. However, the evidence regarding ex–post assistance shows that only partial relief and reconstruction funding is usually being made available; furthermore, this support is often associated with substantial time lags (of at a minimum one year); on top of this, such post disaster aid has often not reached those in need effectively.

Over the last few years, there has been a paradigm shift in national and international responses to this problem towards more proactive efforts and upgrading the role of pre disaster risk management (Linnerooth-Bayer, Mechler and Pflug, 2005). Countries, donors and the international community have been working together to devise and implement risk management systems for reducing, pooling and sharing risk. One focus has been on risk financing mechanisms for transferring private and public sector risks from local and national levels to a global scale. Important precedents have been implemented over the last few years as private-public partnerships with donors and governments providing technical assistance, subsidizing or paying premiums, such as the Caribbean Catastrophe Risk Insurance Facility (CCRIF).

This paper focuses on countries' ability to absorb risks within its own limits, or vice versa the need for transferring risks more globally by implementing novel risk sharing mechanisms. Based on an estimate of country-wide risk for the 70+ countries most exposed to weather extremes, we assess countries' current financial vulnerability to climate extremes, which we operationalize as the public sector's ability to pay for relief to the affected population and support the reconstruction of affected public sector assets such as infrastructure. We find a number of countries already highly financially vulnerable for smaller to medium sized events, and suggest that efforts to reduce risk need to be seriously stepped up. In such cases of obvious risk aversion, where disaster risks faced by governments cannot be absorbed without major difficulty, there is also a case for considering to prefinance risks, as the benefits of financing risks can often outweigh their costs. Almost without exception, financially vulnerable countries are highly unlikely to be able to implement pre-disaster risk financing instruments themselves. Thus, there is a need for technical and financial assistance from the donor community. Our estimates may inform decisions pertaining to a “climate insurance fund” absorbing extreme event country risk, which exceeds the ability of any given country to absorb the losses in a given event. We find the costs of such a high risk layer backup fund to be in the lower billions of dollars annually. Our assessment relates to today’s climate, yet we suggest that estimates of today’s climate variability and related risks, although also associated with substantial uncertainty, can be interpreted as a baseline for vey uncertain future projections.

The report proceeds as follows. In section 2, we discuss the developmental challenges imposed by disaster risk and the case for prefinancing disaster risk. In section 3, we present our methodology for assessing country-wide financial vulnerability to extreme events based on the CATSIM model. Section 4 finally presents salient findings and a short discussion of key implications.

# 2 Disasters and development: The financial dimension

Climate-related disaster losses[1] have escalated in recent decades. Although largely driven by socioeconomic change, the increase in monetary losses by an order of magnitude within the last four decades cannot entirely be explained by population or economic growth only (Mills, 2005). The 4th assessment report of the IPCC found increased impacts of extremes such as cyclones and flooding due to altered intensities and frequencies of natural hazards (Parry et al., 2007), many of which are expected to increase in frequency or severity in various places in a future warmer climate (Solomon et al., 2007). Disaster impacts can be devastating, particularly in heavily exposed low- and middle-income countries, and especially the vulnerable within these countries suffer the most. During the 25 year period from 1979 to 2004 over 95% of natural disaster deaths occurred in developing countries and direct economic losses averaged US$54 billion per annum. Not only are there considerable differences in the human and economic burden, but also in insurance cover. In the richest countries average total losses during this period amounted to 3.7% as measured in gross national income with about 30% of the losses insured. In low-income countries, total losses amounted to 12.9% with 99% of these losses uninsured (Munich Re, 2005).[2] It should be emphasized that these disaster statistics do not (for the most part) reflect medium to long-term indirect losses, which can be very significant, particularly in countries with little capacity to cope with extremes, yet are generally very difficult to parcel out from other effects.

There are many ways for absorbing the financial burdens of disasters, with market-based insurance being one, albeit prominent, option. Households often use informal mechanisms relying on family and relatives abroad; governments may simply rely on their tax base or international assistance. Yet, it is a fact that in the face of large and covariate risks, such ad hoc mechanisms often break down and a severe shortfall, a resource gap, remains (see Linnerooth-Bayer and Mechler, 2007).

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[1] The literature does often not clearly distinguish between *losses* and *damages*. We refer to damages as the physical impacts, and losses as the monetized values (direct losses) or the economic follow on effects (indirect losses).

[2] These losses are mostly *direct* losses of productive assets and property (*stocks*); only to a minor extent are *indirect* losses of value added (*flows*), such as business interruption losses, accounted for and insured.

*Financing the resource gap*

The seriousness of the post-disaster resource gap, as well as the emergence of novel insurance instruments for pricing and transferring catastrophe risks to the global financial markets, has motivated developing country governments, as well as development institutions, NGOs and other donor organizations, to consider pre-disaster financial instruments as an important component of disaster risk management (Linnerooth-Bayer et al., 2005). Donor-supported pilot insurance programs are already demonstrating their potential to pool economic losses and smooth incomes of the poor facing weather variability, climate extremes and geophysical disasters. These schemes provide insurance to farmers, property owners and small businesses, as well as transfer the risks facing governments to the global capital markets. Particularly, the latter risk management options, where donors or governments cede risk, are particularly interesting. A few examples shown in box 1 may serve to illustrate the issues.

**Box 1: Novel mechanisms for sharing extreme event risks in developing countries**

- ***The Ethiopian weather derivative***

To supplement and partly replace their traditional food-aid response to famine, the World Food Programme (WFP) designed an index-based insurance system to provide extra capital in the case of extreme drought, the amount being based on contractually specified catastrophic shortfalls in precipitation measured in terms of the Ethiopia Drought Index (EDI). Rainfall data is taken from 26 weather stations representing the various agricultural areas of Ethiopia. In 2006, WFP successfully obtained an insurance contract based on the EDI through AXA Re, a Paris-based reinsurer (Wiseman and Hess, 2007).

- ***The Mexican catastrophe bond***

In 2006, the Mexican government chose to insure its catastrophe reserve fund, FONDEN, against major earthquakes with a mix of reinsurance and a catastrophe bond. The resulting contract is linked to a parametric trigger in terms of magnitude and depth of seismicity for the three-year period 2007-09. The catastrophe bond provides cover of US$160 million out of a total cover of $450 million for a premium/interest totalling $26 million. The major reinsurance company, Swiss Re, issued the bond, which pays an interest of 230 basis points if payment is not triggered. Mexico received substantial technical assistance from the World Bank and Inter American Development Bank over the years, but ,as a middle-income developing country and member of the OECD, it financed the transaction out of its own means. (Cardenas, et al., 2007)

- ***The Caribbean Catastrophe Risk Insurance Facility (CCRIF)***

The *Caribbean Island States* in 2007 formed the world's first multi-country catastrophe insurance pool, reinsured in the capital markets, to provide governments with immediate liquidity in the aftermath of hurricanes or earthquakes. 16 Caribbean countries contribute resources ranging from US$200 thousand to US$ 4 million depending on the exposure of their specific country to earthquakes and hurricanes. This better-diversified portfolio is expected to result in a substantial reduction in premium cost of about 45 – 50% for the participating countries. The fund covers up to 20% of the estimated loss, and claims will be paid depending on an index for hurricanes (wind speed) and earthquakes (ground shaking). Initial funding by donor organizations provided support for start-up costs and helped capitalize the pool. The facility transfers the risks it cannot retain to the international financial markets through reinsurance or through other financial instruments (for example, catastrophe bonds). In addition, donors are adding to the reserves. The governments of Bermuda, Canada, France, the United Kingdom, as well as the Caribbean Development Bank, the World Bank and the EU recently pledged in excess of US $50 million to the CCRIF (Ghesquiere, et al., 2006; World Bank, 2007)

Since many of these and other recent insurance programs are still in the pilot stage, and none have experienced a major and widespread catastrophic event, it is too early to fully assess their effectiveness in reducing economic insecurity. Yet, the need for careful examination of their effectiveness and sustainability, even if based on a short operating history, is underscored by

**Box 2: The MCII proposal**

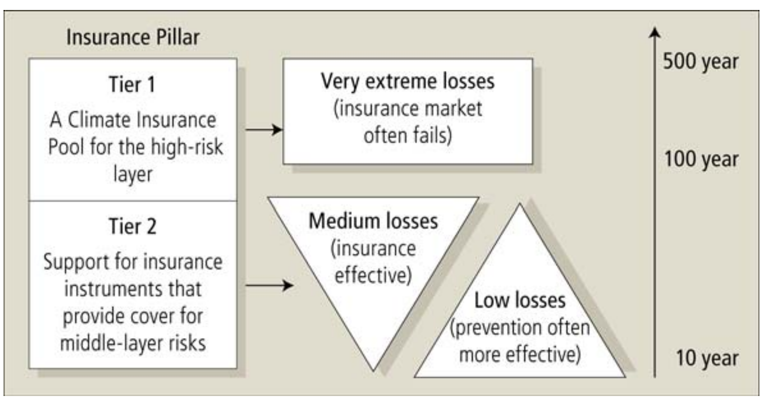
The Munich Climate Insurance Initiative (MCII) insurance proposal suggests a risk management module as part of an international adaptation strategy. As shown on the Figure below, this module includes two pillars, *prevention and insurance*, which would act together to reduce the human and economic burdens on developing countries. The pillars would be fully financed by a post-Copenhagen adaptation fund. The MCII endorses the growing consensus that this fund be financed in accordance with the Convention's principles of common but differentiated responsibilities and respective capabilities of countries (UNFCCC, Art. 3), and that it be disbursed to those who suffer most from climate change.

**The prevention pillar**

Insurance activities must be viewed as part of a risk management strategy that includes, first and foremost, activities that prevent human and economic losses from climate variability and extremes. The first pillar of the MCII proposal thus calls for comprehensive risk management across vulnerable countries building on detailed risk assessments. Risk assessments can uncover otherwise unforeseen possibilities for risk reduction, and help lay the groundwork for risk transfer systems. The Prevention Pillar would not require developing countries to fully internalize the price of increased climate-related risk; however, qualification for participation in the Insurance Pillar might include progress on a credible risk management strategy with a specific focus on most vulnerable communities and sectors.

**The insurance pillar**

MCII's proposed insurance pillar has two tiers that reflect the different layers of risk that need to be addressed for effective climate adaptation: (1) "high level" risk that exceeds the ability of any given country to pay in the case of an extreme event, and (2) "middle level" risk that is within the ability of any given country to cope if the proper facilitating framework were in place. "Low level" risks can often be more cost effectively addressed with prevention measures, and this risk layer is therefore not addressed in the MCII proposal. As pictured below, the first tier would provide insurance cover to vulnerable countries for a pre-defined high layer of risk (e.g., this might be defined for events that are expected to occur only every 100 or 500 years), and the premiums would be fully paid from an adaptation fund. The second tier would enable risk-pooling and -transfer mechanisms that provide cover for medium-loss events (e.g., this might be defined as events expected to occur less frequently than every 10 years but more frequently than every 100 years). Both tiers would be fully financed by a post-Copenhagen adaptation fund (and thus presumably by Annex 1 countries).




A two-tiered insurance pillar as part of an adaptation fund. Source: MCIII (2008) recent experience with disaster insurance systems in developed countries, especially the widespread inefficiencies of agricultural insurance systems and the insurance controversies following Hurricane Katrina's devastation to poor communities in New Orleans. The question arises whether developing countries should follow the path of the developed world in insuring against catastrophic events, and which insurance instruments and modifications may be appropriate for better tackling the developmental dimensions of natural disasters.

One recent proposal for supporting vulnerable countries with coping with climate-related events was put forward by the Munich Climate Insurance Initiative (MCII) in the context of the UNFCCC negotiations. The proposal suggests a two-pillar (prevention and insurance) international risk-management strategy as part of an adaptation regime (see box 2).

*How much risk reduction and how much insurance?*

How much to invest in risk reduction and how much to use insurance (in a wider sense comprising market-based and other ways of risk financing) is a complex question, depending on the occurrence probability of hazards, the associated size of impacts, the costs, and benefits of both types of activities, as well as on their interaction (keeping in mind that financial instruments, through incentives, influence prevention activities). In figure 1, we illustrate the linkages between effectiveness of instruments and occurrence probability. Since the benefits of measures that reduce risk become less for very low probability, but high consequence events, it is generally the case that prevention is more cost effective for the higher probability events with low to medium-sized losses. For those frequent events (e.g., with return period of 10 years, or annual probability of 10%) prevention and response measures (for instance, constructing levees against floods or retrofitting homes against seismic risks) are likely to have higher benefit/cost ratios than if applied to the less frequent events (meaning non-linear losses as probabilities decrease). Similarly, individuals and governments are generally better able to finance lower consequence events from their own means, for instance, savings or calamity reserve funds, and including international assistance.

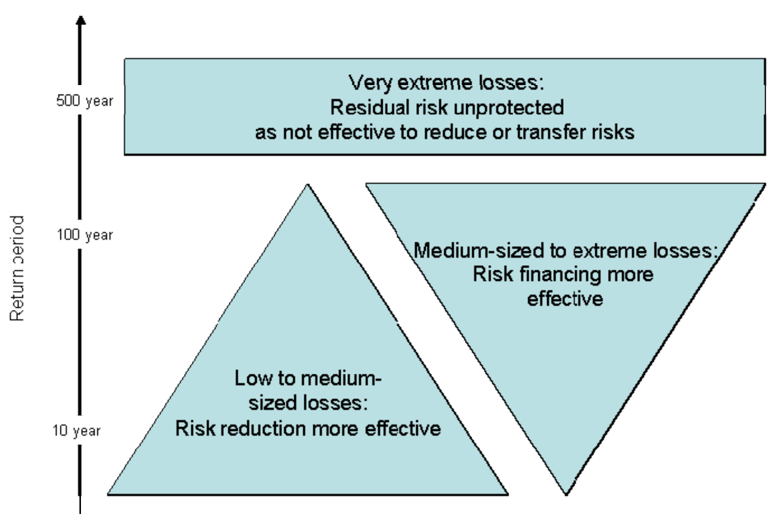



Fig. 1: Efficiency of risk management instruments and occurrence probability

The opposite is generally true for costly risk-financing instruments, like insurance, catastrophe bonds and contingent credit arrangements As catastrophe insurance premiums and the cost of other instruments fluctuate widely and are often substantially higher than the pure risk premium (average expected loss), mainly because the insurer's cost of back-up capital is reflected in the premium, it is generally advisable to use those instruments for lower probability hazards, which may have debilitating consequences. To put it differently, risk financing is generally used to smooth the *variability* of losses, while risk reduction reduces (*expected*) risk. It would not be economically rational to implement insurance for frequent, but low loss events, which may be covered domestically or be reduced easily. Finally, most individuals and governments find it too costly to insure against very extreme risks occurring less frequently than say every 500 years.

*Financial vulnerability and the resource gap: The rationale for financing disaster risk*

According to an early theorem by Arrow and Lind (1970) governments should not insure if they are not averse to risks, i.e. if financial risks faced by the government can be absorbed without major difficulty. According to Arrow and Lind a government may

- Pool risks as it possesses a large number of independent assets and infrastructure so that aggregate risk is negligible, or
- Spread risk over the population base, so that per-capita risk to risk-averse households is negligible.

In theory, thus, governments are not advised to incur the extra costs of transferring their disaster risks if they carry a large portfolio of independent assets and/or they can spread the losses of the disaster over a large population. Because of their ability to spread and diversify risks, Priest (1996) refers to governments as "the most effective insurance instrument of society." Furthermore, the extra costs of insurance can be significant; for example Froot (2001) reports cost up to seven times greater than the expected loss, due to high transaction costs, uncertainties inherent in risk assessment, the limited size of risk transfer markets and the large volatility of losses. Consequently, according to Arrow and Lind governments should behave risk-neutrally and evaluate their investments only through the expected net present (social) value. 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* (Guy Carpenter, 2000*).* The case for sovereign self-insurance, however, may not hold for highly exposed developing country governments, especially those that are not sufficiently diversified or cannot spread losses over the tax-paying public. Already in 1991, the Organization of American States' primer on natural disasters states that the risk neutral proposition is valid only up to certain point and that the reality in developing countries suggests that some governments cannot afford to be risk-neutral:

> The reality of developing countries suggests otherwise. Government decisions should be based on the opportunity costs to society of the resources invested in the project and on the loss of economic assets, functions and products. In view of the responsibility vested in the public sector for the administration of scarce resources, and considering issues such as fiscal debt, trade balances, income distribution, and a wide range of other economic and social, and political concerns, governments should not act risk-neutral (OAS, 1991).

In these cases, governments may justifiably act as risk-averse agents. This means that the Arrow-Lind theorem may not apply to governments of countries that have (see Mechler, 2004; Hochrainer and Pflug, 2009):

- high natural hazard exposure;
- economic activity clustered in a limited number of areas with key public infrastructure exposed to natural hazards; and
- constraints on tax revenue and domestic savings, shallow financial markets, and high indebtedness with little access to external finance.

These conditions are fundamental to determining the financial vulnerability of a country (i.e., the central government), which we will discuss in the following.

# 3 Methodology for determining financial vulnerability

*Risk* and *vulnerability* are concepts with multiple and ambiguous meanings. As an analytical term, vulnerability has been used in a complex array of disciplinary contexts, including geography, risk and hazard, anthropology, engineering and ecology. Vulnerability as commonly defined in the context of climate change (e.g. IPCC, 2001) as a function of both potential impacts and society's capacity to adapt to these impacts (see figure 2).

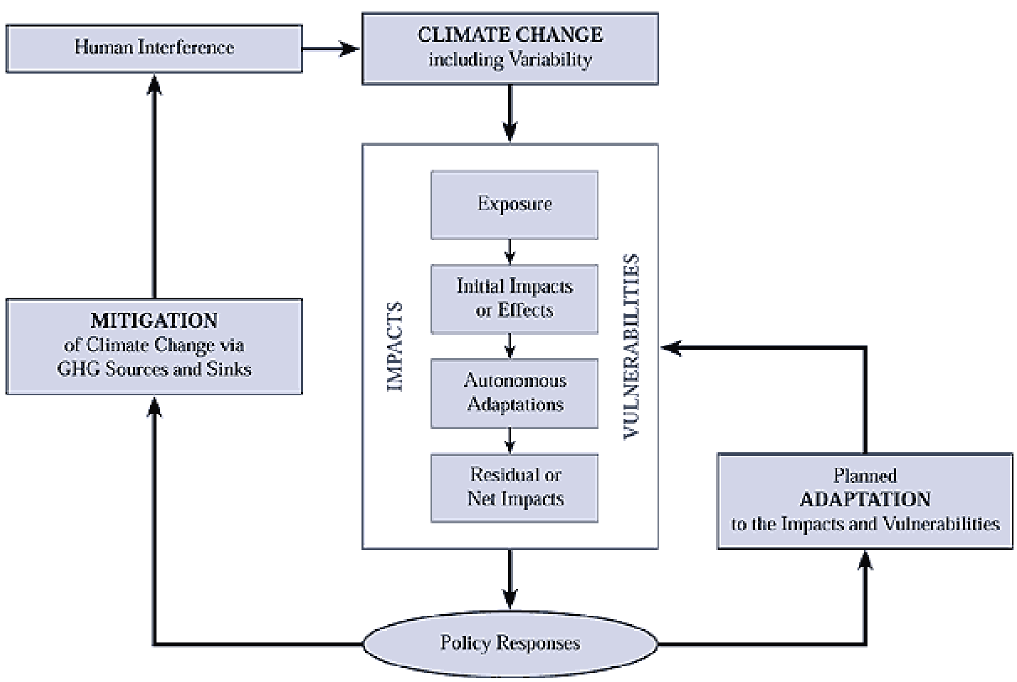



Fig. 2: IPCC's definition of vulnerability to climate change

A narrower definition that focuses only on the affected system is common in the risk/hazards and vulnerability communities. Turner et al. (2003) define vulnerability as the degree to which a system or subsystem is likely to experience harm due to exposure to a hazard, either as a perturbation or stressor. In this framework, multiple hazards can be caused or aggravated by global-change phenomena, where vulnerability is a function of the *exposure, sensitivity and resilience* of the system in question. Risk, alternatively, is a function of the *hazard (likelihood and severity) and its potential consequences (exposure, sensitivity),* but usually stops short of considering the coping capacity and resilience of the exposed system.

We consider governments financially vulnerable to disasters if they cannot access sufficient funding after a disaster to cover their liabilities in terms of reconstructing public infrastructure and providing assistance to households and businesses in need. We operationalize this concept by the term *resource gap*, which we define the net loss associated with a disaster event after exhausting all possible ex-pots and ex ante financing sources. Such a *resource gap* is a useful measure of sovereign financial vulnerability. The repercussions of a resource gap can be substantial. The inability of a government to repair infrastructure in a timely manner and provide adequate support to low-income households can result in adverse long-term socio-economic impacts. As a case in point Honduras experienced extreme difficulties in repairing public infrastructure and assisting the recovery of the private sector following Hurricane Mitch in 1998. Five years after Mitch's devastation the GDP of Honduras was 6% below pre-disaster projections.[3] When considering whether Honduras and other highly exposed countries should protect themselves against resource gaps and associated long-term negative consequences, it is important to keep in mind that risk management measures have associated opportunity costs, which means that they can reduce GDP by diverting financial resources from other public sector objectives, such as investments into social or infrastructure projects.

In the following, we outline a methodology based on the CATSIM model (Hochrainer and Mechler, 2009) to calculate this resource gap, and derive a global country-level estimate for the most hazard-exposed countries. Figure 3 shows schematically how we combine risk estimates with financial resilience to lead to an estimate of financial vulnerability.

[3] Own calculations.

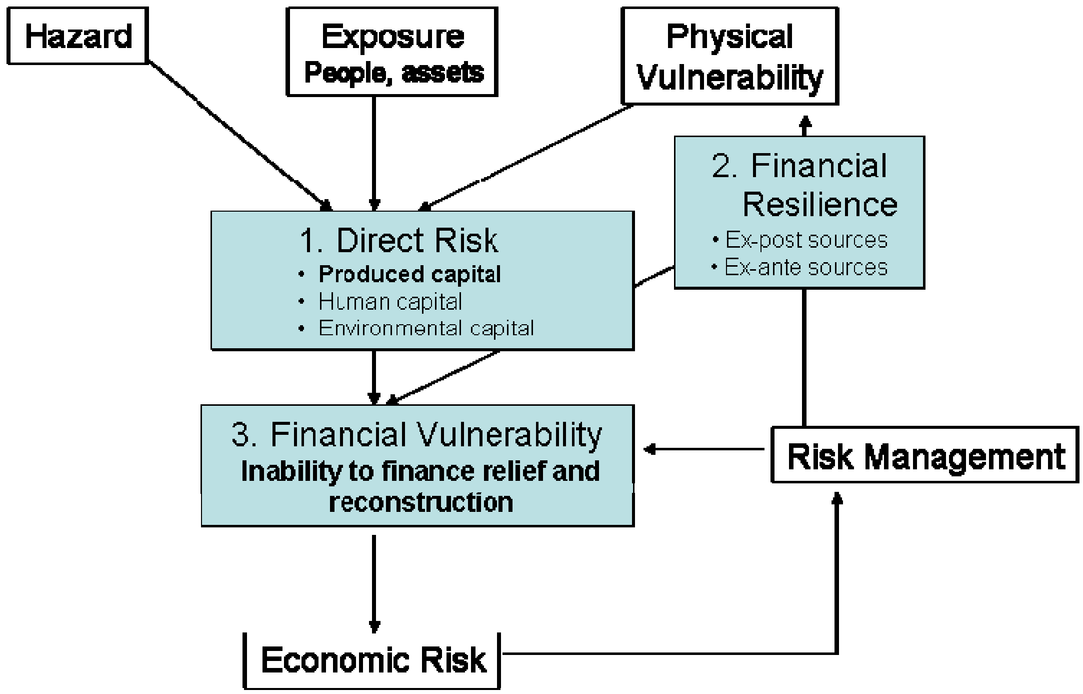



Fig. 3: Illustration for calculating financial vulnerability

The standard approach for estimating natural disaster risk (the probability of potential impacts) is to understand natural disaster risk as a function of hazard, exposure and (physical) vulnerability. We focus on risk to assets, economic and financial vulnerability, with financial vulnerability as a subset of economic vulnerability. Our methodology follows the following steps.

### *3.1 Step 1: Assessment of public sector liabilities*

Disaster risk emanates from explicit and implicit contingent public sector liabilities, classified in table 2. The explicit liability consists of rebuilding damaged or lost infrastructure, which is due to the public sector's allocative role in providing public goods. Implicit liabilities are related to the commitment of providing relief due to the distributive function in reallocating wealth and providing support to the needy (see table 1).

We calculate direct risk (potential losses and their probabilities) accruing to a national government's liabilities for hydrometeorological events. The calculation is done as a function of hazard, exposure (assets) and the physical vulnerability of assets. We only focus on assets (produced capital), and do not account for the risk to human and environmental capital. We calculate loss distributions in terms of 50, 100, 250 and 500 year events.

Table 1: Government liabilities and disaster risk

| **Liabilities** | **Direct:** obligation in any event | **Contingent:** obligation if a particular event occurs |
|---|---|---|
| **Explicit** Government liability recognized by law or contract | Foreign and domestic sovereign borrowing, Expenditures by budget law and budget expenditures | State guarantees for nonsovereign borrowing and public and private sector entities, **reconstruction of public infrastructure** |
| **Implicit** A "moral" obligation of the government | Future recurrent costs of public investment projects, pension and health care expenditure | Default of subnational government and public or private entities, **disaster relief** |

Source: Modified After Schick and Polackova Brixi, 2004

In this first CATSIM step the risk of direct losses is assessed in terms of the probability of asset losses in the relevant country or region. Consistent with general practice, risk is modeled as a function of hazard (frequency and intensity), the elements exposed to those hazards and their physical vulnerability (Burby, 1991; Swiss Re, 2000). [4] In more detail,

1. Natural *hazards*, such as hurricanes, or floods, are described by their intensity (e.g. peak flows for floods) and recurrency (such as a 1 in 100 year events, i.e. with a probability of 1%). We focus on sudden-onset climate-related events only such as tropical cyclones, floods and winterstorms. Generally, for the sudden-onset events analysts generally equate given loss and risk data with asset losses.[5]

Our estimates, i.e. probability of given events and corresponding losses on the country level, are based on available data as reported in Cummins and Mahul (2009) as well as own estimates based on past losses and using extreme value theory. While Cummins and Mahul (2009) present risks based on catastrophe model approaches, for countries where such data were not available, we used reported loss data from CRED (2009) and Munich Re (2009) to estimate a Generalized Pareto distribution using either Maximum likelihood optimization methods if more data points existed (i.e., usually more than 10 observations) or Minimum-Distance methods if only a few data points were available. Based on the estimated parameters the selected loss return periods were calculated. The historically observed cumulated yearly relative losses (losses in percent of GDP) were taken as the basic data. A Generalized Pareto distribution was fitted to the tails (i.e. to the data exceeding the 80%-quantile) by minimizing the integrated square distance between the empirical distribution and the estimated distribution. For countries with more than 25 data points, the maximum likelihood estimates of the parameters were calculated alternatively. The higher quantiles (90%, 95%, 98%, 99%, 99.6%, 99.8%) of the fitted distribution as well as the

[4] In the hazards and risk community, "sensitivity" is referred to as "vulnerability", and often exposure is included in the sensitivity component; thus, risk is defined by hazard and vulnerability. In catastrophe models carried out for insurance purposes, the contract specifications of the underwritten and exposed portfolios are added as a fourth component (eg. Swiss Re, 2000).

[5] An indication that this assumption can be maintained is the fact that loss data are usually relatively quickly available after a catastrophe, which indicates that flow-indirect impacts emanating over months to years, are usually not considered.

probability of first loss (obtained from the empirical distribution) were taken as input to the CATSIM model.

2. Exposure of elements at risk: From an economic perspective, governments are exposed to natural disaster risk and potential losses due to three functions: (i) the allocation of goods and services (security, education, clean environment, (ii) the provision of support to private households and business in the case of market failure, (iii) and the distribution of income as shown on Figure 4 (see Musgrave, 1959).

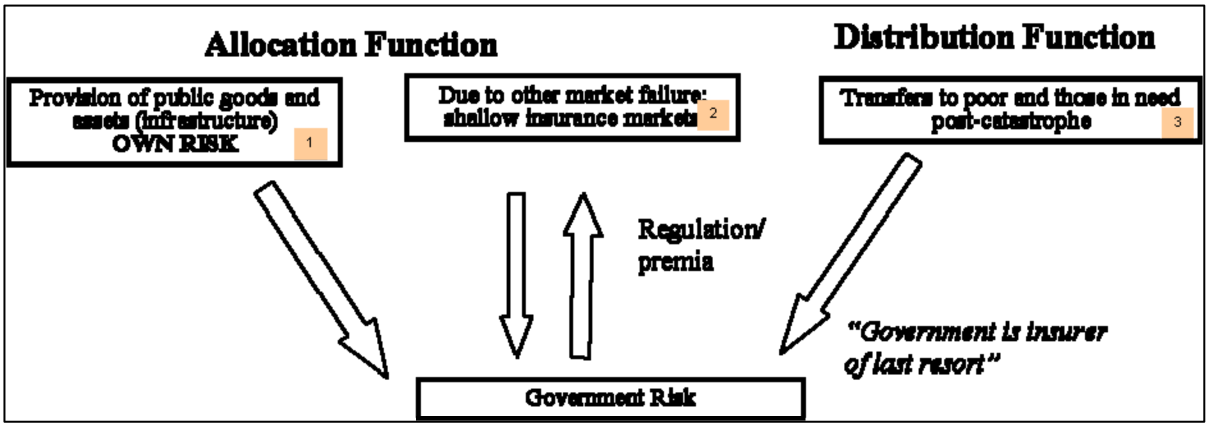



Fig. 4: Sources of government disaster risk

Total capital stock for each country is taken from Sanderson and Striessnig (2009). These estimates are based on a perpetual inventory method using Penn World tables with data on investments starting in 1900 and assuming annual growth and depreciation of 4 percent. To compute public sector liabilities, due to a lack of globally comparable data, we take the following assumptions: (i) Based on World Bank (1994) we use an estimate of 20% of total capital stock as the infrastructure component (category 1 in the chart), and then add another 30% for relief and reconstruction to affected households and business (categories 2 and 3 in the chart). From a normative view, this share a government should be prepared to refinance, can be broadly justified by examining the very limited empirical evidence on actual spending in events (see figure 5).

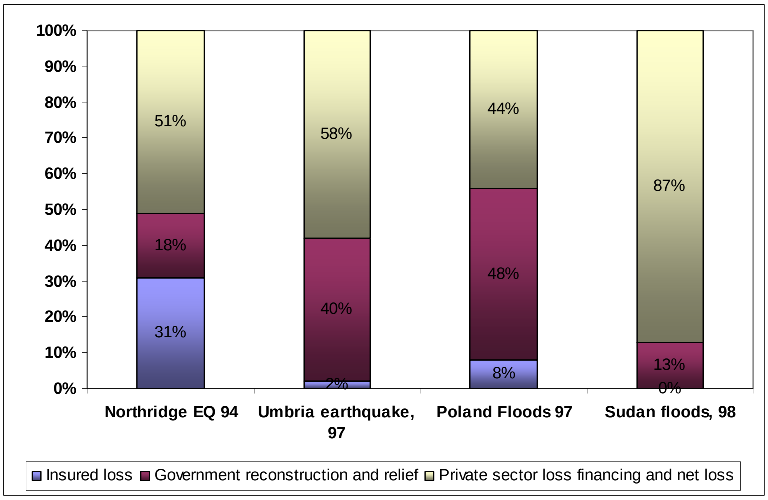



Fig. 5: Insurance and government assistance for selected disasters as a percentage of direct losses (Source: Linnerooth-Bayer and Mechler, 2007)

3. Physical vulnerability describes the degree of damage to the capital stock due to a natural hazard event. The method commonly used here are fragility curves setting the degree of damage in relation to the intensity of a hazard.

Based on data on the return period and losses in percent of capital stock, CATSIM generates loss frequency distributions describing the probability of specified losses occurring, such as a 100-year event causing a loss of 200 million USD, a 50-year event causing a 40 million USD loss, and so on.[6] It should be kept in mind that top-down estimates at this broad scale are necessarily rough. Since most disasters are rare events, there is often little in terms of historical data; furthermore it is difficult to include dynamic changes in the system, for example, population and capital movements and climate change. To improve the data information, bottom-up assessments can be undertaken that involve a detailed analysis of the occurrence of hazards in certain areas, the exposed elements and vulnerabilities of structures on a more microscale level.

As already indicated risk and potential losses are summarized by means of loss-frequency distributions, which relate probabilities of loss to assets destroyed. For example, figure 6 shows a cumulative loss-frequency distribution for flood risk in a hypothetical country. The horizontal axis shows the fraction of capital stock destroyed by a disaster, and the vertical axis represents the probability that losses will *not* exceed a given level. For example, with a probability of 0.9 (90%) flood losses will not exceed 250 million LCU; inversely, there is a 0.1 (10% chance) that such a loss and larger will occur.

[6] It is standard practice to refer to 20-, 50-, 100-, 500- and 1000-year events.

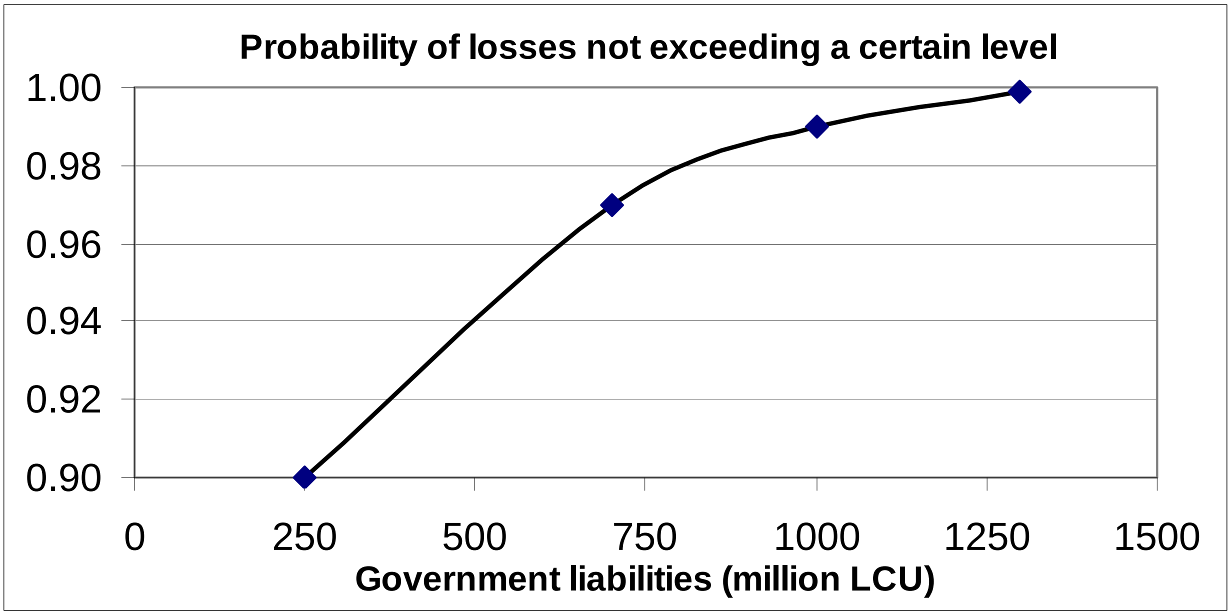



Fig. 6: Risk of losses as measured by a cumulative loss-frequency distribution

An important summary measure of this distribution is the annual expected losses, or the losses to be expected on average every year. The annual expected loss is the sum of all losses weighted by the probability of occurrence. Graphically, the expected losses are represented by the area above the cumulative distribution curve. However, it has to be kept in mind that disasters are not average events, rather they are extreme events occurring very rarely. Over a specified time period, like 100 years, catastrophes may occur, and the losses suffered over this period will be close to the sum of annual expected losses over these years.Based on available information, potential losses due to earthquake events in terms of percent of capital stock lost can be established for a country, state or region.

### *3.2 Step 2: Estimation of the public sector's financial resilience*

Given limited resources to reduce human and economic losses, governments need to be financially resilient, or be able to provide sufficient funds to finance reconstruction of public capital, provide relief to households and support business in their recovery efforts. Sources of funding for reconstruction include aid, budget diversion as well as multilateral and international lending. However, these are not infinite and come at a cost.

Based on the information on direct risks to the government portfolio, financial resilience can be evaluated by assessing the government's ability to finance its obligations for the specified disaster scenarios. Financial resilience is directly affected by the general conditions prevailing in an economy, i.e., changes in tax revenue have important implications on a country's financial capacity to deal with disaster losses. The specific question underlying the CATSIM tool is whether a government is financially prepared to repair damaged infrastructure and provide adequate relief and support to the private sector for the estimated damages of 10- 50- 100- and 200-year events? For this assessment, it is necessary to examine the government's sources, including sources that will be relied on (probably in an ad hoc manner) after the disaster and sources put into place before the disaster (ex ante financing). These sources are described below (based on Mechler, 2004 and Hochrainer, 2006).

*Ex post financing sources*

The government can raise funds *after* a disaster by accessing international assistance, 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, borrowing from the IFIs and issuing bonds on the international market (Benson, 1997 a,b,c; Fisher 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 this CATSIM module (see table 2).

*Aid inflows* from abroad after a catastrophe include private and public donations from private institutions, government agencies and inter-governmental agencies in the form of relief, technical assistance, grants, commodities and money (Albala-Bertrand 1993). The amount of aid is as much dependent on the event as on the will of the donors to grant assistance. Thus there is considerable uncertainty as regards the amount of aid obtained post-catastrophe necessitating a case by case examination. As discussed, a value of 10.4% of direct losses for this parameter was estimated. It is assumed that all aid inflows will be divided up between the public and the private sector in relation to their share of infrastructure (government) and non-infrastructure (private sector) in total capital stock. As there is uncertainty whether aid will in fact be made available, the availability of aid is assumed to be constrained in three scenarios: 0, 50, 100% made available, i.e. 0% of losses are financed by aid, 5.2% and 10.4%. These scenarios will be looked at in combination with the scenarios on the availability of foreign borrowing as is explained below.

Table 2: 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 | x |
| Raising government revenues | Taxation | - |
| Deficit financing *Domestic* | Central Bank credit | - |
| | Foreign reserves | - |
| | Domestic bonds and credit | X |
| Deficit financing *External* | Multilateral borrowing | X |
| | International borrowing | X |
| | Aid | X |
| **Ex-ante sources** | | |
| Reserve funds | | X |
| Insurance | | X |
| Contingent Credit | | X |

*Budget diversion* means using funds that were earmarked for other purposes and thus implies foregoing the returns and benefits of these projects. As well, there is often high political cost to diversion when money is taken from ministries. It is assumed that the government is able to divert some funds from government spending to reconstruction activities. In recent research maximum diversion post-disaster for the four Latin American countries Bolivia, Colombia, Dominican Republic and El Salvador was estimated at 5-10% of current expenditure (government spending) (Freeman et al. 2002b: 35). For this report, we use an average value of 7.5% for both Honduras and Argentina.

Establishing additional *taxes* after a catastrophe will decrease private savings when consumption is to stay constant and exert additional depressionary effects on the economy. Furthermore, disaster taxes are expensive to administer. For this reason, no additional tax revenue is assumed.

Given a budget deficit, *deficit financing* options are accessing credit from the Central Bank or the private sector (commercial banks and private households), tapping into the foreign reserves of the central bank, obtaining loans from IFIs or selling bonds abroad (Benson 1997c).

*Central bank credit* is usually granted by selling government bonds to the Central Bank resulting in money creation which is potentially inflationary if money growth is not held in proportion to real GDP growth (Fischer and Easterley, 1990). Using *foreign exchange reserves* of the central bank creates the potential for a balance-of-payment crisis due to the lack of needed reserves for imports. The sources reserves and central bank credit are generally considered to be particularly problematic, e.g. an assessment of a World Bank and IMF team on reconstruction financing options in El Salvador after the earthquakes in 2001 stated:

> Under any monetary system, a country needs to maintain a strong underlying fiscal position and a sound credit policy, with an adequate cushion of net international reserves, to preserve macroeconomic stability. Expanding the money supply or reducing the central bank's net international reserves are never optional sources of financing for reconstruction costs. (IMF and World Bank, 2001: 5).

Central Bank credit and tapping into reserves are used in practice as deficit financing sources, but from a normative planning point of view, they should not be considered in the case study countries in Latin America where inflation and external debt issues are important policy issues (Ferranti, 2000: 61). For these reasons, these two sources will not be considered as viable sources for ex-post catastrophe finance in this report.

*Borrowing domestically* also incurs costs: domestically, credit may be compressed particularly so in shallow credit markets resulting in a rise of the interest rate and a crowding-out of domestic investment. Borrowing from the private sector via issuing domestic government bonds is another option. However, it is a common characteristic that in developing countries domestic bond or financial markets are rather shallow (Ferranti 2000). We assume 10% additional government borrowing from the private sector, which seems an optimistic assumption given the post disaster crunch and shallow domestic financial markets in most of the disaster vulnerable countries studied.

A major source of a country's ex-post disaster funding is *foreign borrowing*. The importance of (foreign) borrowing for reconstruction is demonstrated by the following statement that also came from the post-earthquake IMF and World Bank mission to El Salvador.

> From the standpoint of macroeconomic policy, the key question is how much and how rapidly can the government afford to borrow to finance the reconstruction costs, while keeping fiscal policy on a sustainable path (IMF and World Bank, 2001).

We consider borrowing to be constrained by the existing country debt. CATSIM assumes that the sum of all loans cannot exceed the so-called *credit buffer* for the country. In the Highly Indebted Poor Countries Initiative (HIPC) the credit buffer is defined as 150% of the typical export value of this country minus the present value of existing loans (HIPC, 2002).

*Ex ante financing sources*

In addition to accessing ex post sources, a government can arrange for financing before a disaster occurs. 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. 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. Insurance and other risk-transfer arrangements provide indemnification against losses in exchange for a premium payment. Risk is transferred from an individual to a (large) pool of risks. 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. While a number of countries have reserve funds implemented (albeit generally with low nominal amounts), insurance and contingent credit options are only currently being considered with prime examples being Mexico, Colombia and the countries participating the in the Caribbean pool. Table 3 graphically shows the ex post and ex ante instruments that can be accessed to finance post-disaster needs. Another critical point suggested in this chart is the time dimension, which generally is in favour of ex ante instruments releasing financing rather quickly.

Table 3: Ex-post vs. ex ante financing instruments.

| | Immediate hours/days | Short term 1-3 months | Medium term 3-9 months | Long term Over 9 months |
|---|---|---|---|---|
| **Financial needs for post disaster operations** | | | | |
| Relief | | | | |
| Recovery | | | | |
| Reconstruction | | | | |
| Financing tools | | | | |
| Ex-post financing | Budget contingencies | Relief<br>Budget reallocation | Domestic/ external credit | Donor assistance<br>Tax increase |
| Ex-ante financing | Reserve fund | Parametric RT, Contingent debt | Traditional RT | |

Source: Cummins and Mahul, 2009.

## *3.3 Step 3: Assessment of financial vulnerability and the "resource gap"*

Using the information on direct risks to the government portfolio and financial resilience, financial vulnerability can be evaluated. We define financial vulnerability as the (probabilistic) availability of government finances for paying for relief and reconstruction. The resource gap is the difference between the cost of a disaster (step 1), and the funds available to the government to rebuild and provide relief and assistance with recovery efforts.[7] Figure 7 illustrates the calculation of this metric for a hypothetical case.

Given losses due to a certain event, such as the 100 year event (public sector loss of 4,000 local currency units (LCU)), the algorithm evaluates the sources for funding these losses. An implicit ordering of these sources is assumed according to the availability and marginal opportunity costs of the sources: grants from donors and international financial institutions (IFIs) would have the least costs associated as these are donations; thus they would be used first. Second, diversions from the budget could be used, then domestic credit, followed by borrowing from IFIs and the international markets (bonds). While in this illustration a 100 year event could be financed, for a 200 year (public sector loss of 10,000 LCU), there would be lack of (ex-post) sources and consequently a resource gap. Ghesquiere and Mahul (2007) added another important dimension related to the timing of resource flows.

[7] The term resource or financing/resource gap has been heavily used in the economic growth modeling literature as the difference between required investments in an economy and the actual available resources. In this report, this tradition is followed and the financing gap is understood as the lack of financial resources to restore assets lost due to natural disasters and continue with development as planned.

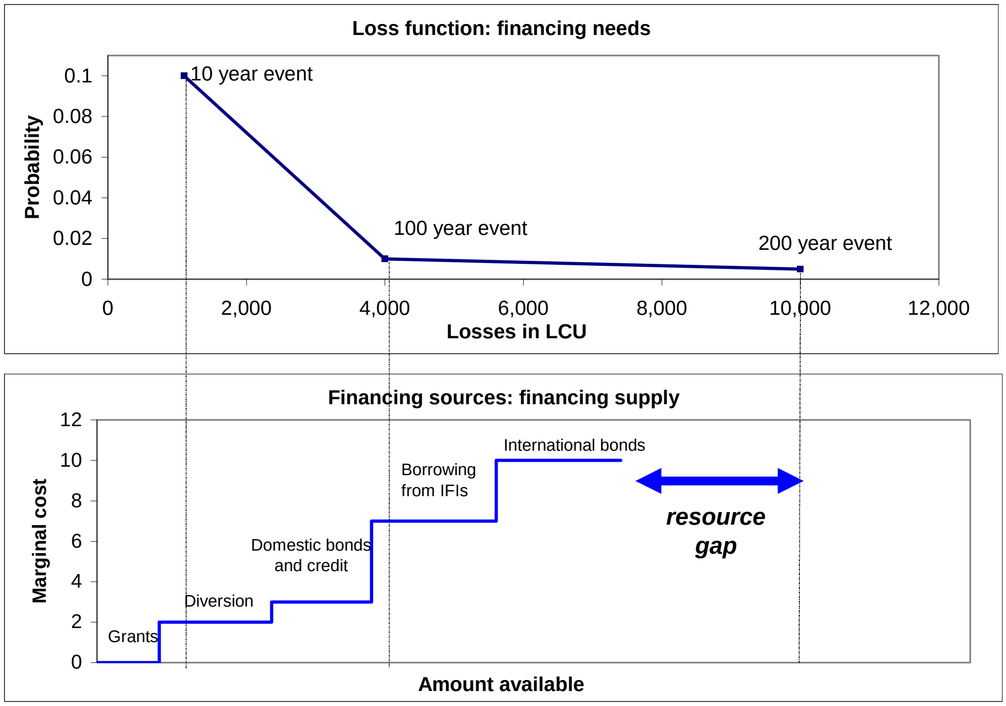



Fig. 7: Illustration for calculating the disaster resource gap

As shown in figure 7, while enough funding may be available over time, yet there may be a sporadic resource gap, as generally in the aftermath of a disaster event, urgent expenditure needs are high and immediately available financial resources often very limited. As an example how the resource gap is calculated here we refer to box 3.

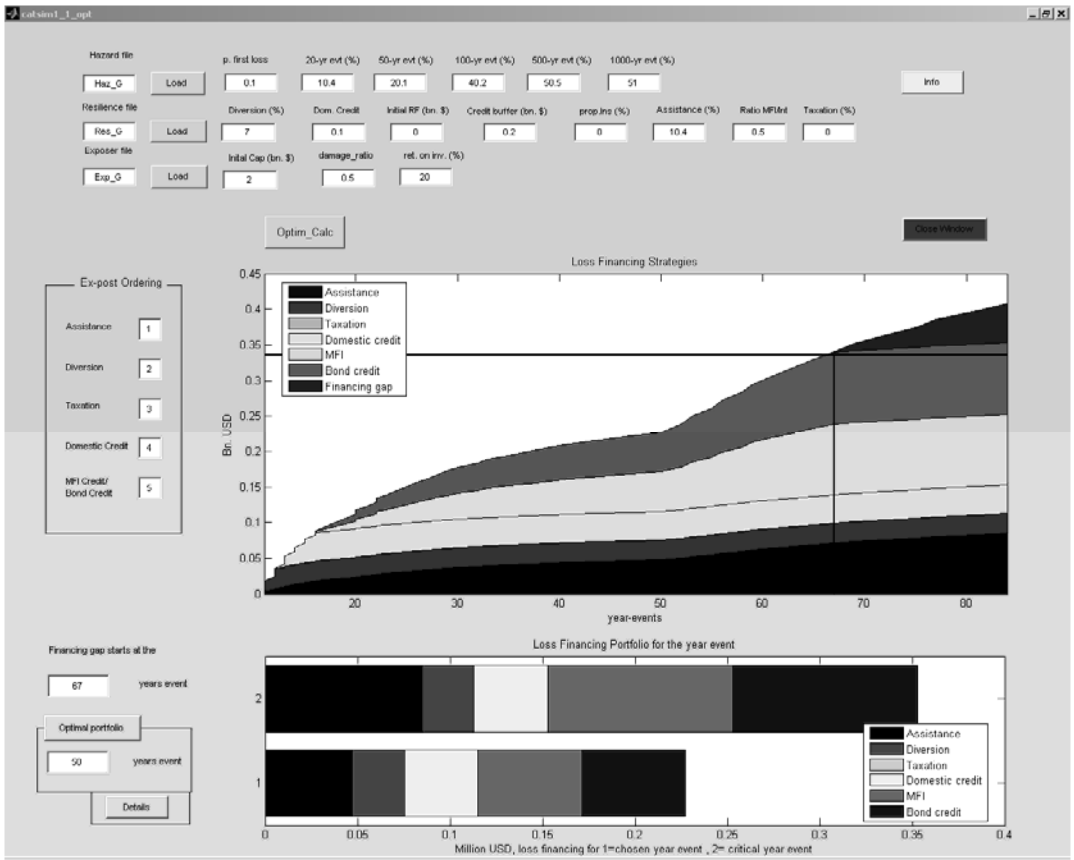
Due to the focus of this work in step 3, we do not go into more detail on steps 4 and 5 in this report but rather present a small overview for the sake of completeness of the CATSIM methodology.

## *3.4 Step 4: Illustrating the developmental consequences of a resource gap*

Financial vulnerability can have serious repercussions on the national or regional economy and the population. If the government cannot replace or repair damaged infrastructure, for example, roads and hospitals, or provide assistance to those in need after a disaster, this will have long-term consequences. The consequences on long-term economic development can be illustrated by the CATSIM tool. Generally, economic welfare will be higher on average if the government does not allocate its resources to catastrophe insurance or other risk management, but the economy has fewer extremes and is more stable with public sector insurance. Investing in the risk financing instruments can thus be viewed as a trade-off between economic growth and stability. Budgetary resources allocated to catastrophe reserve funds, insurance and contingent credit (as well as to preventive loss-reduction measures) reduce the potential resource gap, and thus can ensure a more stable development path. On the other hand, ex ante financing and prevention measures come at a price in terms of other investments foregone and will inevitably have an adverse impact on the growth path of an economy.

Box 3: Calculating the resource gap for Grenada

We show the approach for the case of Grenada. The Figure below shows a user interface of the IIASA CATSIM model for assessing the financial vulnerability of Grenada, a small-island Caribbean country, to cyclone risk (see also Hochrainer and Mechler, 2009).




The year events and corresponding losses can be seen on the x-axis (hazard) and y-axis (losses) of the graph. For each year event, some losses for the government occur, e.g. a 20 year event would cause losses for the government of approximately 120 million USD. The money to finance the losses can be separated into outside assistance, diversion from the budget as well as credit arrangements. However, as the probabilities of disaster events go lower and losses get higher, e.g. the higher the return period, more money is needed till the maximum capacity is reached. In the case of Grenada a 67 year event would cause for the first time a resource gap in the graph. Assuming more restricted credit and diversion possibilities this resource gap would go done to even a 20 year event (the mathematical formulation of the problem can be found in the Appendix A).

### 3.5 Step 5: Reducing financial vulnerability and building resilience

Vulnerability and resilience must be understood as dynamic and can be tackled. There are two types of policy interventions: those that reduce the risks of disasters by reducing exposure and sensitivity and those that build financial resilience of the responding agencies. Based on an assessment of the resource gap and potential economic consequences, CATSIM illustrates the pros and cons of strategies for building financial resilience using ex-ante financial instruments. Below, we suggest how risk financing instruments may be supported. Due to the scope of this report, we here do not go into more detail on steps 4 and 5, which would merit separate discussions (see Mechler et al., 2006, Hochrainer, 2006).

*Uncertainty*

Uncertainty is inherent in every estimation procedure, some of these uncertainties can be quantified some of them not. Also in this report, large uncertainties around the estimates still remain, mostly due to lack of additional data for recalibration and back-testing. This is a quite usual thing for low frequency but high consequence events today and will only get better in the future if loss reports of disaster events are based on a holistic methodological approach which can be applied for in all areas of the world for as much hazard types as possible. In this report, the losses and corresponding probabilities are based on models or past data; in the latter case due to the usually small number of data points, the parameter estimates have large confidence bounds. In this report it was decided to use the mean estimates and neglect the confidence bounds because of violation of some assumptions like minimum amount of data points necessary for variance calculations and so on, which would lead to biases in the uncertainty bounds. Also for the exposure estimates, data were used that were based on simplified versions of capital stock estimation techniques, such as relying on the Penn World tables and selecting a specific depreciation rate. However, for such a large number of countries, and the necessity to have capital stock estimates for all countries, only such approaches can be used. The government liabilities are also taken to be the same in percentage for all countries, an assumption which is not valid if only a country specific approach is taken. However, here it serves well, also because such assumptions can be found empirically in developed as well as developing countries after catastrophe events. Furthermore, the estimation of the resilience of the government is also very difficult, either because data is not there or it is difficult to estimate the different financing sources in each case. Also here, average results are used were appropriate or estimated via econometric methods using databases such as the World Bank. Last but not least, because the loss financing situation for each country is also time dependent, e.g. a disaster within a strong growth period might be less disastrous then in a recession, the loss estimates are only valid for a certain time period. All in all, the numbers presented should be regarded as ballpark numbers and not taken for granted forever or exact without mentioning the uncertainties in it. They numbers however should serve as a starting point at which scale we have a problem and how it could be possibly handled within a generic risk management approach.

## 3.6 The data sample

We calculate financial vulnerability for the 73 most weather prone, vulnerable countries that have had at least one large sudden-onset natural disaster event over the last 30 years but also selected some countries where it was feasible to estimate risks based on observed losses. A large event is defined by a threshold of a ratio of (asset) losses expressed per GDP of larger than 1%. For those countries we define risk, loss distributions and financial exposure. As a next step, we assess financial vulnerability. Financial vulnerability is indicated in terms of resource gap recurrence, i.e. it indicates an event and recurrence of this event, for which government financial funds would be insufficient to cover government disaster liabilities caused by the event. Table 1 lists data sources employed for our estimation.

Table 4: Data used in the assessment

| **Variable** | **Data source** |
|---|---|
| Disaster losses (USD) | EMDAT, Munich Re databases |
| Risk estimates | 1. Cummins and Mahul (2009) based on various sources.<br>2. IIASA estimates |
| Capital stock data | Sanderson and Striessnig (2009) |
| Socioeconomic data | World Bank, 2009 |

The disaster loss sample is based on information from two databases and was compiled by Okuyama (2009) with the threshold for a large event defined arbitrarily by a loss exceeding 1 percent of GDP.[8] One database is the open-source EMDAT disaster database (CRED, 2009) maintained by the Centre for Research on the Epidemiology of Disasters at the Université Catholique de Louvain. The other database is the proprietary Munich Re NatCat Service database, which mainly serves to inform insurance and reinsurance pricing. Probabilistic risk estimates are based on two sources: (i) a recent report by Cummins and Mahul (2009), who report such estimates from various sources for a number of countries, (ii) IIASA estimates of risk using extreme value statistics. Capital stock data were used from a new global database also generated IIASA by Sanderson and Striessnig (2009). Finally, other socioeconomic data were taken from the World Development Indicators (World Bank, 2009).

[8] In order to define the "event set" the threshold of stock losses is set as a share (1%) of flow effects (GDP). It would have been more systematic to define an asset based threshold, yet we responded to the larger intuitive appeal of using GDP as a denominator.

# 4 Findings and discussion

We find that a number of countries are highly financially vulnerable. As shown in Figure 8, the majority of the disaster prone countries in our sample experience a disaster financing problem, a resource gap, below a 50 year event.

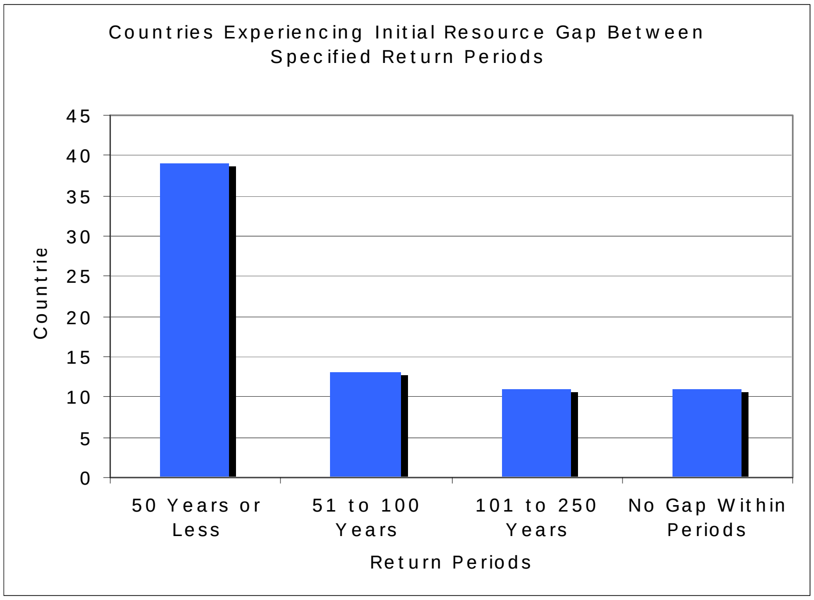



Fig. 8: Number of countries experiencing a resource gap for some return periods

Figure 9 shows how risk as measured in expected losses translates into an estimate of financial vulnerability based on assessments of financial and economic resilience. No clear relationship is discernible between the losses as percent of GDP and the resource gap (in terms of a probabilistic return period) and the resource gap for a 100 year event, which shows that the translation is a more complex one and GDP as a mere indicator of vulnerability may not suffice.

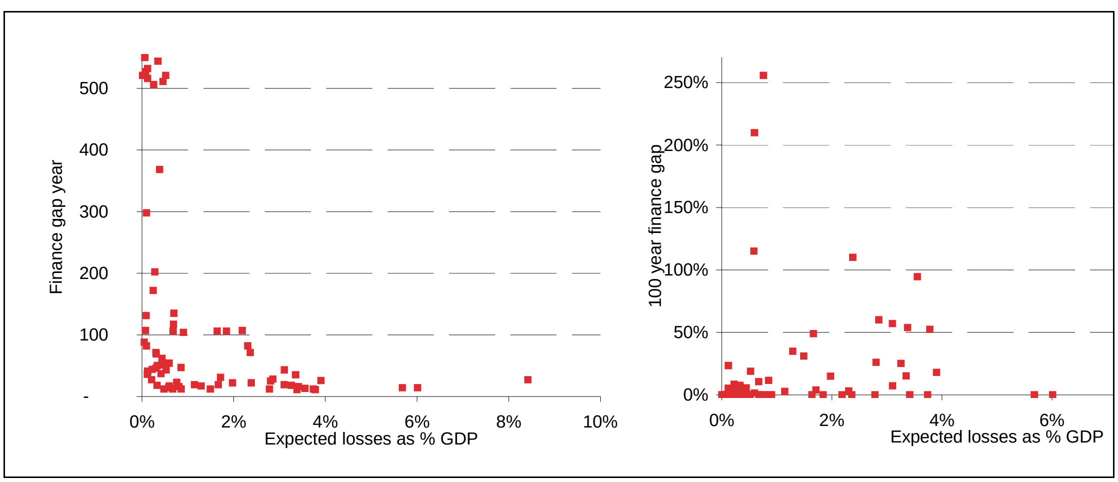



Fig. 9: Risk vs. financial vulnerability

In figure 10 the countries' resource gap year events are shown. We find the following countries to be particularly financially vulnerable

- Small Island Development States (SIDS), such as the Caribbean and Pacific Islands.
- Highly indebted and hazard prone countries, such as in Central America (Honduras, Nicaragua, El Salvador), Africa (Madagascar, Mozambique) and Asia (Nepal).

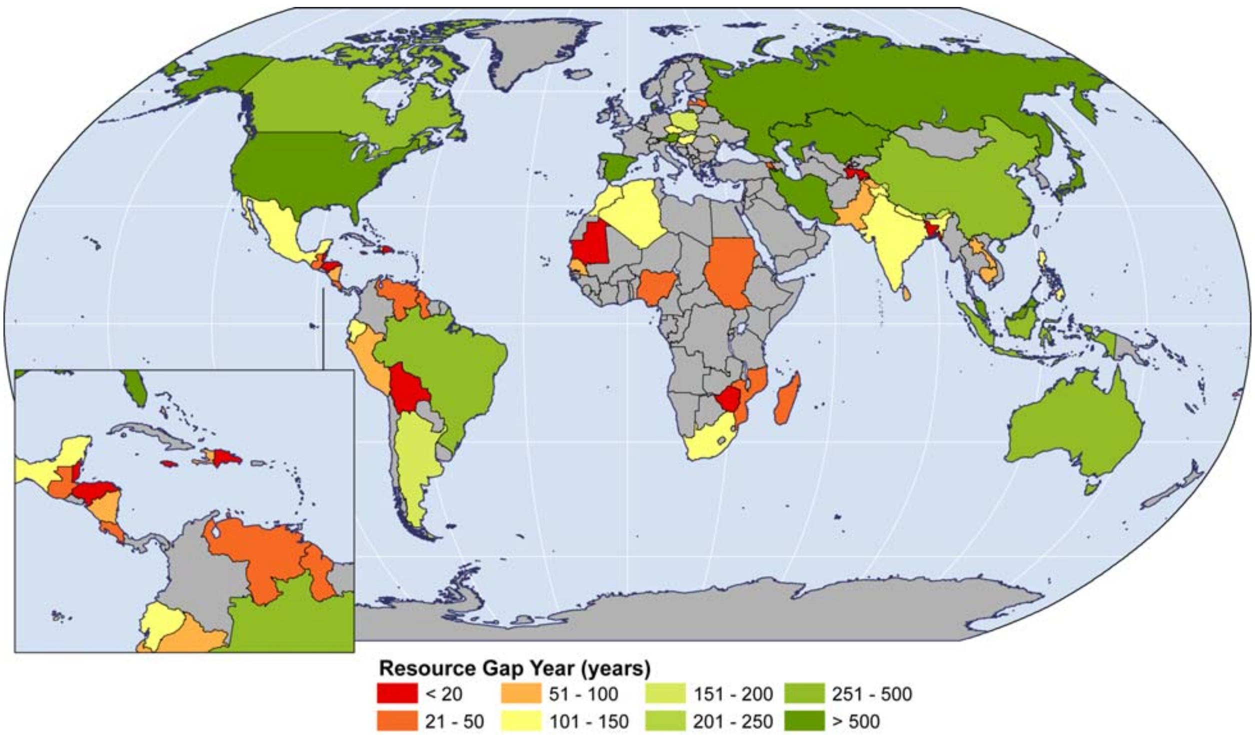



Fig. 10: Global map exhibiting calculations of the resource gap year

What does this mean in terms of implications for financing losses and risks? To answer this question, we calculate losses and gaps for the 50, 100, and 250-year events (see figures 11, 12 and 13), and discuss implications of these estimates in the following.

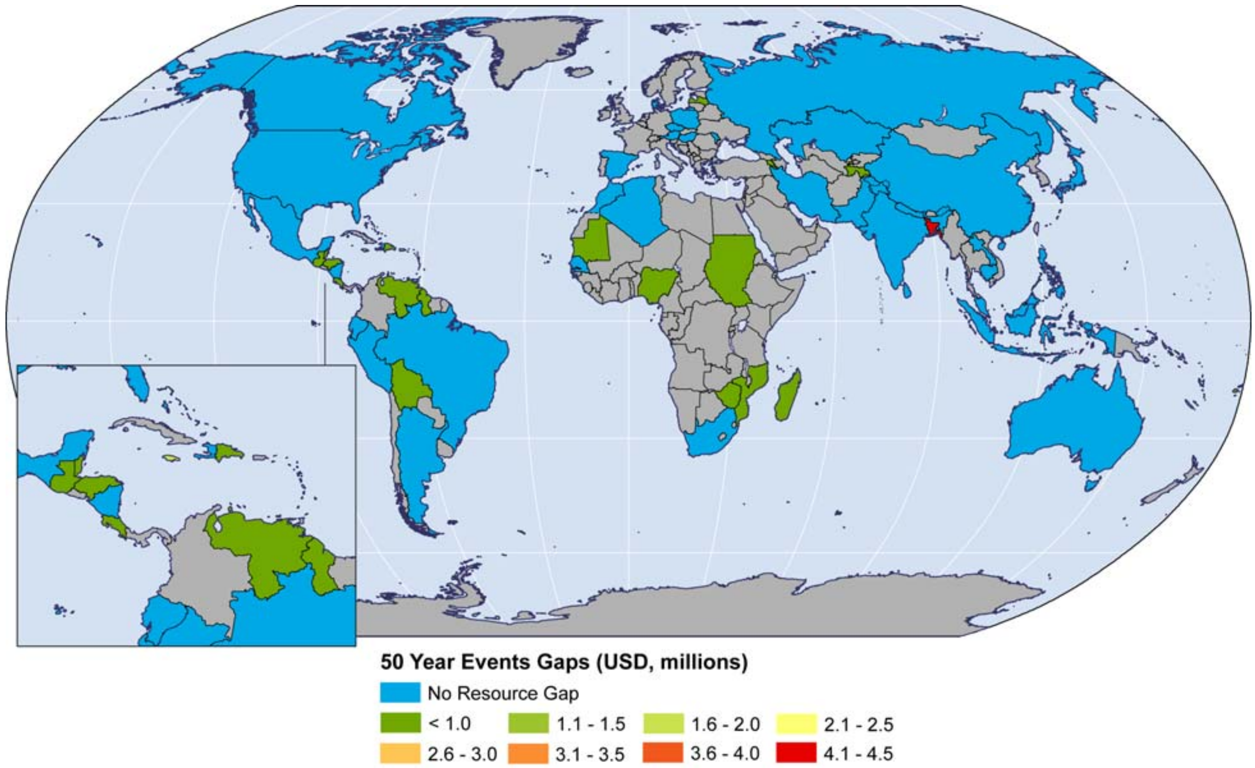



Fig. 11: 50 year resource gap estimates

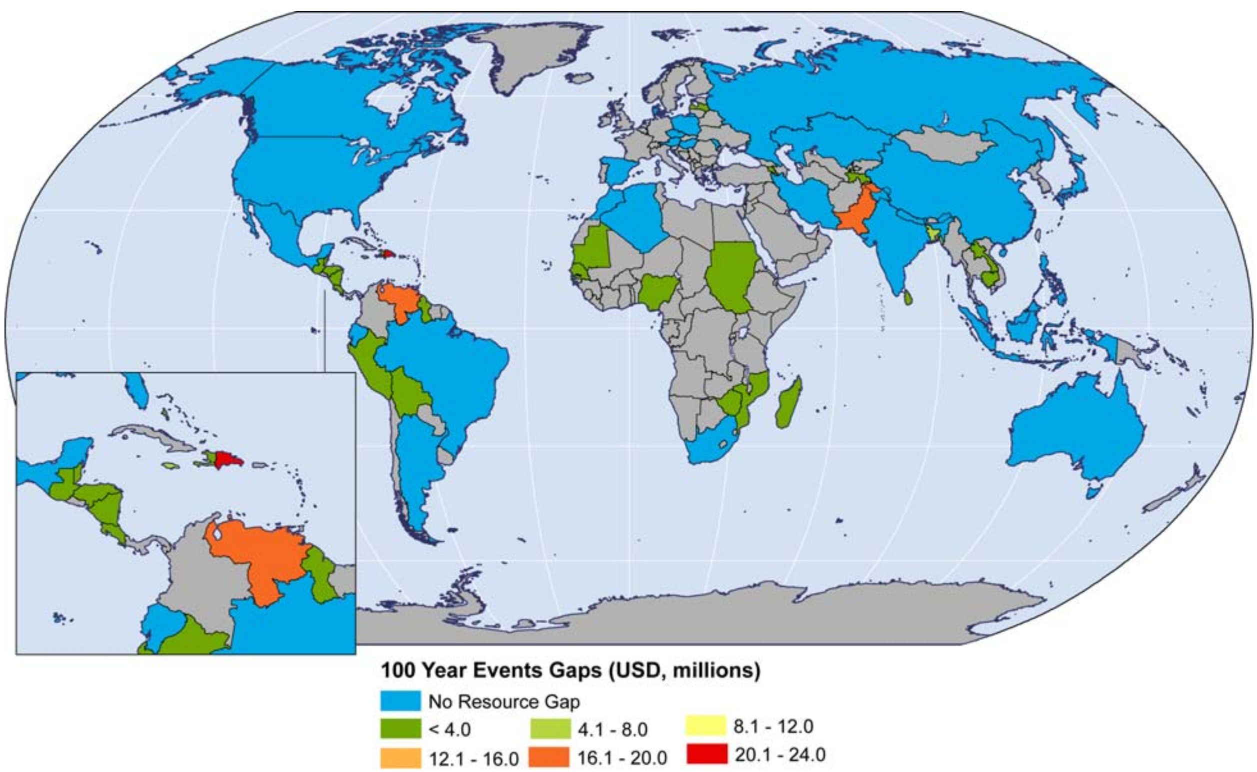



Fig. 12: 100 year resource gap estimates

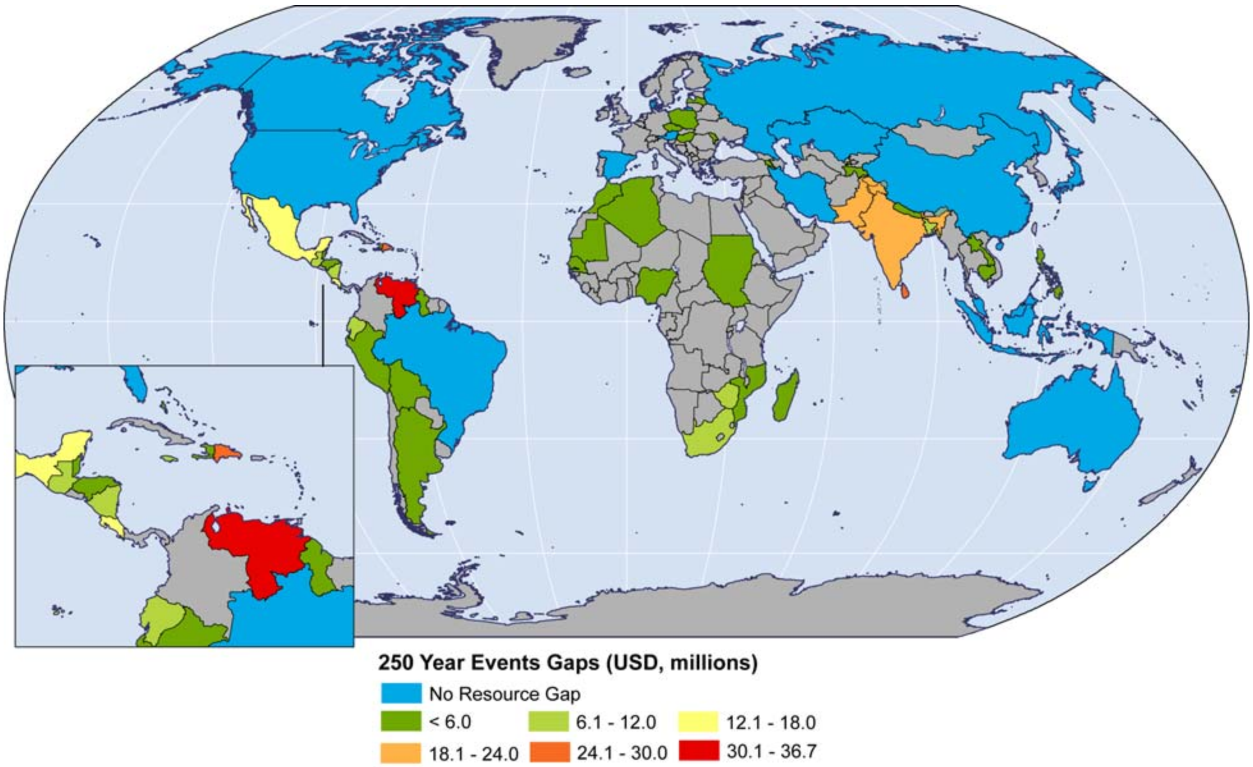



Fig. 13: 250 year resource gap estimates

*Implications for supporting the management of climate variability and change in exposed countries*

For financially vulnerable countries, we see three main implications.

1. In such countries, efforts to reduce risk need to be seriously stepped up in order to reduce the serious human and financial burdens to the affected population, business and fiscal stance.
2. The second implication is that in case of high financial vulnerability, contrary to the Arrow Lind Theorem (1970), there is a case for country risk aversion; this means, that financial disaster risks faced by the government cannot be absorbed without major difficulty. Risk aversion calls for deliberating to prefinance losses and relief expenditure by way of risk financing instruments, such as calamity funds, regional insurance pools or contingent credit arrangements. In fact, some of the countries found financially vulnerable are exactly doing this already and the Caribbean Catastrophe Insurance Pool is probably the best known example.
3. The third implication is that, without exception, all financially vulnerable countries due to their development status are very unlikely to be able to implement pre-disaster risk financing instruments themselves in order to reduce their financial vulnerability out of their own means and require technical and financial assistance from the donor community. There are important precedents such as
   - The World Food Programme (WFP) with USAID funding sponsored an index-based drought insurance scheme for government relief expenditure in Ethiopia.
   - In the Caribbean case mentioned above, where island states have recently formed the world's first multi-country and index-based catastrophe insurance pool for providing

governments with immediate liquidity in the aftermath of hurricanes or earthquakes, donors and IFIs have provided significant capital to the extent of 50 million USD. This funding helps to back up the pool in its early years when accumulated country contributions are insufficient to render this scheme robust to withstand major events such as hurricanes.

***How much money would a pool require to fill the funding gap post-disaster for all disaster prone countries?***

Our estimates may also inform decisions pertaining to a "climate insurance fund," which would fund "high level" country losses that exceed the ability of any given country to pay in the case of an extreme event. Figure 14 shows the funding requirement for different layers of disaster event recurrence. If for example, funding would be set aside to cover resource gaps for more frequent events with a return period of 50 to the 100 year events, than about 1.4 billion USD would be required annually. Covering more infrequent losses as well (such as up to a 250 year event), would mean that more funding would be required, up to 2.6 billion USD. Also, other layers, such as 100-250 year resource gap layers, could be considered to be covered with associated funding requirements. Bundling many risks in a portfolio leads to a diversification effect and thus lower funding requirements. We took the simplifying assumption that risks would be independent. Thus the estimates of the funding requirements have to be considered a lower bound. Furthermore, we only looked at average costs. However, it would be important to consider the whole range of possible costs and associated probabilities, i.e. a global cost curve would be needed. Hence, one research direction for the future is to come up with such a cost curve to incorporate the variability in more detail and accordingly to introduce risk functionals (Pflug and Römisch, 2007).

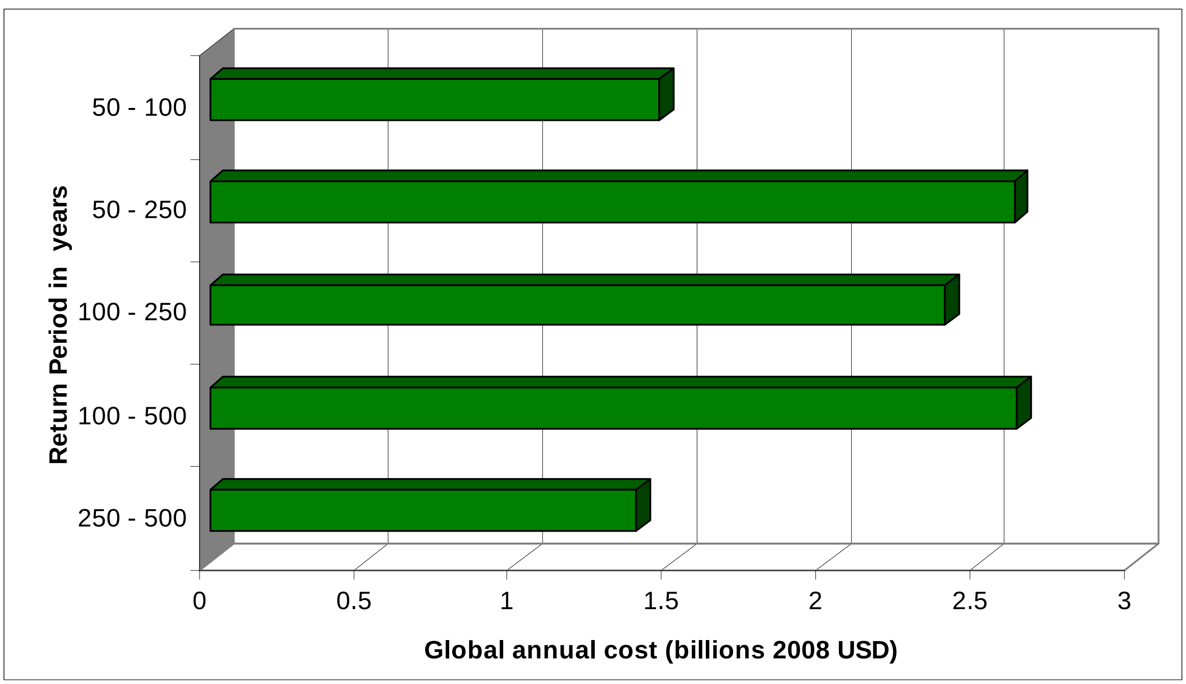



Fig. 14: Funding requirements to cover resource gaps for different layers of return periods

Our estimates can be used to gauge the support needed by vulnerable countries to buffer against extremes and the scale of funding necessary when implementing a global fund for this purpose.

Our findings may also be used for identifying the scope of the problem of managing climate variability today and in the future, and may thus be interpreted as a sort of baseline estimate for what may be to come, if we do not manage emission reductions and adaptation to climatic risks better. Comparing our estimates of the costs of financing high loss layers of sudden onset events with the at least as uncertain numbers currently available regarding the costs of adaptation to both slow and sudden onset climate variability and change, we arrive at the lower end of the estimates of the prominent UNFCCC (2007) report. For example, for adapting infrastructure alone to climate change impacts (including extreme events), the UNFCCC calculates a broad range of 8 –130 billion USD necessary in 2030 (in 2030 values) (UNFCCC, 2007). Others have even put their estimates a magnitude higher, yet essentially these, as well as our numbers are associated with uncertainty, and remain imprecise. However, as societies have found many ways for coping with uncertainty, such quantitative estimates may be sufficiently precise to at least start a process for thinking about appropriate options and courses of action for absorbing current and future extreme event risks.

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**Appendix A: Calculating the resource gap (Hochrainer, 2006):**

Assume that there is a strict order between financing instruments, represented lexicographically by the vector $\vec{x}_p = (x_{p1},...,x_{pk})'$, so that the first entry (instrument) would be preferred until depletion of the other instruments. Let $\vec{b}_p = (x_1,...,x_k)'$ be the maximal amount for each instrument for a given event. Then the loss financing scheme $\vec{x}_p = (x_{p1},...,x_{pk})'$ for a given event with return period $1/y$ is the solution of:

$$
\begin{aligned}
x_{p1} + ... + x_{pk} \quad &= \quad F^{-1}(y) \qquad \text{with } 0 \leq y \leq 1 \\
& \quad\ \ \text{s.t } \vec{x}_p \leq \vec{b}_p \\
\text{where} & \\
& \quad\ \ x_p = \begin{pmatrix} x_{p1} \\ \vdots \\ x_{pk} \end{pmatrix}, b_p = \begin{pmatrix} b_1 \\ \vdots \\ b_k \end{pmatrix}, \\
& \quad\ \ x_{p2}(b_1 - x_{p1}) = 0 \\
& \quad\ \ \vdots \\
& \quad\ \ x_{pk}(b_{k-1} - x_{pk-1}) = 0 \\
& \quad\ \ x_{pi} \geq 0 \qquad i = 1, ..., k.
\end{aligned}
$$

where $1/y$ is the critical return period if $\vec{x}_p = \vec{b}_p$. Since $\vec{b}_p$ is nonlinearly dependent on the return period, the relative composition of $\vec{x}_p$ is different for every event size.

## Appendix B: Additional tables

Table B1: Resource gaps

| Country | Resource gap year event | Resource gap (in bn 2008 USD) | | | | |
|---|---|---|---|---|---|---|
| | | 20 year event | 50 year event | 100 year event | 250 year event | 500 year event |
| Algeria | 144 | 0.000 | 0.000 | 0.000 | 0.423 | 0.705 |
| Anguilla | 122 | 0.000 | 0.000 | 0.000 | 0.029 | 0.043 |
| Antigua and Barbuda | 19 | 0.004 | 0.035 | 0.220 | 0.447 | 0.522 |
| Argentina | 153 | 0.000 | 0.000 | 0.000 | 0.208 | 0.367 |
| Armenia | 50 | 0.000 | 0.001 | 0.256 | 3.263 | 4.265 |
| Australia | 447 | 0.000 | 0.000 | 0.000 | 0.000 | 0.260 |
| Austria | 550 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Bahamas, The | 51 | 0.000 | 0.000 | 1.192 | 2.399 | 2.802 |
| Bangladesh | 14 | 2.635 | 4.209 | 5.189 | 6.864 | 7.422 |
| Barbados | 124 | 0.000 | 0.000 | 0.000 | 0.181 | 0.269 |
| Belize | 16 | 0.044 | 0.082 | 0.246 | 0.453 | 0.522 |
| Bermuda | 93 | 0.000 | 0.000 | 0.017 | 0.348 | 0.458 |
| Bolivia | 19 | 0.006 | 0.056 | 0.257 | 4.192 | 5.504 |
| Brazil | 358 | 0.000 | 0.000 | 0.000 | 0.000 | 2.467 |
| Cambodia | 53 | 0.000 | 0.000 | 0.045 | 0.236 | 0.300 |
| Canada | 417 | 0.000 | 0.000 | 0.000 | 0.000 | 1.056 |
| Cayman Islands | 23 | 0.000 | 0.050 | 0.906 | 2.095 | 2.492 |
| China | 368 | 0.000 | 0.000 | 0.000 | 0.000 | 5.476 |
| Comoros | 15 | 0.008 | 0.143 | 0.622 | 0.623 | 0.624 |
| Costa Rica | 36 | 0.000 | 0.072 | 1.438 | 12.505 | 16.194 |
| Czech Republic | 115 | 0.000 | 0.000 | 0.000 | 2.800 | 3.973 |
| Denmark | 550 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Dominica | 85 | 0.000 | 0.000 | 0.015 | 0.128 | 0.166 |
| Dominican Republic | 18 | 0.131 | 0.386 | 21.512 | 24.786 | 25.877 |
| Ecuador | 106 | 0.000 | 0.000 | 0.000 | 6.299 | 8.550 |
| Fiji | 22 | 0.000 | 0.043 | 0.093 | 0.229 | 0.275 |
| Grenada | 60 | 0.000 | 0.000 | 0.080 | 0.292 | 0.363 |
| Grenadines | 19 | 0.001 | 0.017 | 0.162 | 0.372 | 0.442 |
| Guatemala | 48 | 0.000 | 0.015 | 0.701 | 6.318 | 8.191 |
| Guyana | 25 | 0.000 | 0.059 | 0.192 | 0.911 | 1.151 |
| Haiti | 81 | 0.000 | 0.000 | 0.023 | 0.162 | 0.208 |
| Honduras | 16 | 0.056 | 0.633 | 1.813 | 4.049 | 4.794 |
| Hungary | 113 | 0.000 | 0.000 | 0.000 | 1.570 | 2.206 |
| India | 116 | 0.000 | 0.000 | 0.000 | 20.370 | 29.131 |
| Indonesia | 305 | 0.000 | 0.000 | 0.000 | 0.000 | 0.836 |
| Iran, Islamic Rep. | 550 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Jamaica | 13 | 1.027 | 1.386 | 4.075 | 7.390 | 8.495 |
| Japan | 550 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Kazakhstan | 544 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Lao PDR | 60 | 0.000 | 0.000 | 0.084 | 1.953 | 2.576 |
| Latvia | 48 | 0.000 | 0.003 | 0.185 | 0.311 | 0.353 |
| Madagascar | 36 | 0.000 | 0.005 | 0.227 | 0.548 | 0.654 |
| Malaysia | 550 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Maldives | 61 | 0.000 | 0.000 | 0.027 | 0.235 | 0.304 |
| Mauritania | 13 | 0.041 | 0.682 | 0.682 | 0.687 | 0.689 |
| Mauritius | 25 | 0.000 | 0.706 | 5.818 | 7.344 | 7.853 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Mexico | 135 | 0.000 | 0.000 | 0.000 | 16.909 | 26.657 |
| Moldova | 141 | 0.000 | 0.000 | 0.000 | 0.052 | 0.084 |
| Montserrat | 22 | 0.000 | 0.002 | 0.016 | 0.038 | 0.045 |
| Morocco | 127 | 0.000 | 0.000 | 0.000 | 0.321 | 0.481 |
| Mozambique | 30 | 0.000 | 0.049 | 0.530 | 3.916 | 5.044 |
| Nepal | 108 | 0.000 | 0.000 | 0.000 | 0.867 | 1.190 |
| Nicaragua | 52 | 0.000 | 0.000 | 2.394 | 6.150 | 7.402 |
| Nigeria | 39 | 0.000 | 0.003 | 0.032 | 0.183 | 0.234 |
| Pakistan | 52 | 0.000 | 0.000 | 19.953 | 20.332 | 20.458 |
| Peru | 84 | 0.000 | 0.000 | 0.054 | 0.058 | 0.060 |
| Philippines | 123 | 0.000 | 0.000 | 0.000 | 2.286 | 3.374 |
| Poland | 179 | 0.000 | 0.000 | 0.000 | 1.924 | 4.223 |
| Russia | 550 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Samoa | 11 | 0.083 | 0.211 | 0.367 | 0.631 | 0.719 |
| Senegal | 71 | 0.000 | 0.000 | 0.004 | 0.048 | 0.063 |
| South Africa | 133 | 0.000 | 0.000 | 0.000 | 11.077 | 17.323 |
| Spain | 550 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Sri Lanka | 62 | 0.000 | 0.000 | 0.823 | 24.558 | 32.469 |
| St. Kitts and Nevis | 63 | 0.000 | 0.000 | 0.097 | 0.328 | 0.406 |
| St. Lucia | 117 | 0.000 | 0.000 | 0.000 | 0.055 | 0.078 |
| Sudan | 22 | 0.000 | 0.351 | 0.801 | 2.250 | 2.733 |
| Tajikistan | 14 | 0.061 | 0.269 | 0.575 | 2.162 | 2.690 |
| Tonga | 13 | 0.005 | 0.020 | 0.043 | 0.158 | 0.196 |
| Turks and Caicos Islands | 68 | 0.000 | 0.000 | 0.053 | 0.226 | 0.283 |
| United States | 550 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Vanuatu | 13 | 0.011 | 0.064 | 0.182 | 0.000 | 0.182 |
| Venezuela, RB | 40 | 0.000 | 0.541 | 19.528 | 36.708 | 42.435 |
| Zimbabwe | 19 | 0.004 | 0.279 | 0.868 | 6.450 | 8.310 |

Table B2: Funding requirements to cover resource gaps for different layers of return periods

| Layer from event year to event year | Annual cost (bn 2008 USD) |
|---|---|
| 50 - 100 | 1.4 |
| 50 - 250 | 2.6 |
| 100 - 250 | 2.4 |
| 100 - 500 | 2.6 |
| 250 - 500 | 1.4 |