# Chapter 8
# Modeling Macro Scale Disaster Risk: The CATSIM Model

**Stefan Hochrainer-Stigler, Reinhard Mechler, and Georg Pflug**

**Abstract** Developing countries are placing increasing emphasis on improving their preparedness for and management of disaster risk. We discuss the CATSIM (CATastropheSIMulation) model developed at IIASA for assistance in such planning exercises. CATSIM represents a simple but *risk-based* economic framework for evaluating economic disaster impacts, and the costs and benefits of measures for reducing those impacts. CATSIM uses stochastic simulation of disaster risks in a specified region and examines the ability of the government and private sector to finance relief and recovery. The model is interactive in the sense that the user can change parameters and test different assumptions about hazards, exposure, vulnerability, general economic conditions and the government's ability to respond. As a capacity building tool it can illustrate the tradeoffs and choices government authorities are confronted with for increasing their economic resilience to the impacts of catastrophic events. The model can be used for supporting policy planning processes for the allocation of resources between ex-ante spending on disaster risk management (such as prevention, national reserve funds, sovereign insurance) and ex-post spending on relief and reconstruction. Our paper describes key model features and mechanics, and sets the stage for model applications to the Nepal and Hungary/Tisza cases discussed in this volume.

**Keywords** Catastrophe modeling • Economic impacts • Government risk management • Fiscal stability • Development

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## 8.1 Introduction

The number of natural disasters and associated losses has been increasing due to population growth and migratory trends from rural to urban areas as well as increases in the value of exposed assets (IPCC 2011; Munich Re 2009). Although climate change is often ascribed to increase the frequency and severity of extreme events, such evidence still remains limited (Solomon et al. 2007). While more developed countries often are well equipped to cope with the impacts of disasters, in less developed countries a much larger proportion of the population is severely affected in terms of loss of life and physical impairment and a substantial strain is put on a country's resources, which may lead to important limitations in the ability to continue financing important social and economic programs (Linnerooth-Bayer et al. 2005).

Historically, losses in developing countries have been funded by diversions of funds from the national budget, loans and donations by the international community. Yet these sources are often insufficient, and ex-post gaps in necessary financing of disaster losses are frequently encountered. As one example, the earthquake of 2001 in the state of Gujarat, India led to a significant shortfall between planned government expenditure, planned funding and actual funding made available (Fig. 8.1).

When stimulus is most needed, such lack of timely funding can lead to important follow-on effects. Observed empirical effects on macroeconomic variables can be summarized as follows (see Mechler 2004; Hochrainer 2006, 2009):

- Compared to more developed economies, significant longer-lasting disaster impacts may be expected depending on the size of event, economic vulnerability, and prevailing economic and socio-political conditions.
- In developing countries, GDP falls in the year of the event or the year after, but rebounds in successive years due to increased investment and capital inflows.
- The public deficit increases due to increased spending needs and decreased tax revenue.
- The trade balance worsens, as imports rise (need for additional goods) and exports fall (destruction of goods produced and productive capital stock) post-catastrophe.
- The inflow of external aid and capital is decisive for the speed of economic recovery.

Our analysis focuses on some of these issues and discusses the need for proper ex-ante planning using catastrophe risk modeling as an important element of a comprehensive disaster risk management approach (Gurenko 2004; World Bank 2008). The discussion presents the IIASA CATSIM (CATastrophe SIMulation) model, which is a model framework to assess country-wide contingent disaster obligations and potential financing shortfalls as well as the costs and benefits of vulnerability – and risk-reduction options. The first version of the model was originally developed in 2002 to inform the *Regional Policy Dialogue* of the Inter-American Development Bank, where it was applied to a number of case

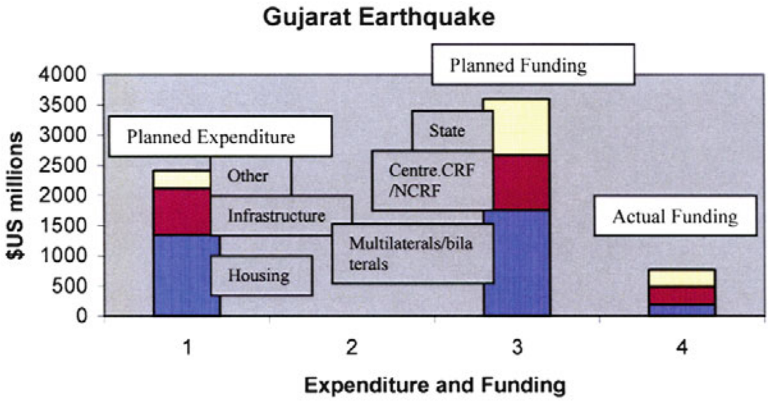



**Fig. 8.1** Resource gap in India after Gujarat earthquake (Source: World Bank 2003)

studies in Latin America (see Mechler et al. 2002 Freeman et al. 2002a; Mechler 2004; Hochrainer et al. 2004). The model has since been revised, extended (including the development of a stand-alone application) and utilized by a number of hazard-exposed countries in other regions such as Asia and Africa (see Hochrainer 2006; Mechler et al. 2006; Hochrainer and Mechler 2009).

The discussion on CATSIM in this chapter is organized as follows: Sect. 8.2 discusses the rationale for financing disaster risk. Section 8.3 describes the CATSIM approach and its modeling steps, and Sect. 8.4 ends with conclusions and an outlook to the future. Applications of the model are further discussed in this book in Chap. 9 for the case of Nepal and Chap. 16 for Hungary and the Tisza region.

## 8.2 The Rationale for Financing Disaster Risk

The rationale for financing disaster risk results from the need of highly exposed countries to protect themselves against resource gaps in dealing with disaster consequences and their associated long-term negative effects. In order to analyze it, one needs first to discuss risk, vulnerability and the exposure of the public sector to disaster risk

### *8.2.1 Defining Risk and Vulnerability*

*Risk* and *vulnerability* are concepts with multiple and ambiguous meanings. As an analytical term, vulnerability has been confusingly used in an array of disciplinary contexts, including geography, risk and hazard, anthropology, engineering and ecology. Vulnerability is commonly defined in the context of climate change (e.g. IPCC 2007) as a function of both potential impacts and society's capacity to adapt to these impacts. A narrower definition that focuses only on the impacted 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 a stressor. In this framework, multiple hazards can be caused or aggravated by global-change phenomena, and risk is a function of the hazard (likelihood and severity) and its potential consequences (exposure, vulnerability), but usually fails to consider the coping capacity and resilience (i.e. the ability to return to pre-disaster conditions) of the exposed system. Risk, vulnerability and resilience are important concepts for the model-based analysis of the economic impacts of disasters within the CATSIM model. In the following, we will focus on the concepts of financial and economic vulnerability as well as risk.

### *8.2.2 Vulnerability and Risk Related to Natural Hazards*

The standard approach in catastrophe modeling is to understand natural disaster risk as a function of the hazard, the exposure and the physical vulnerability. Hazard analysis involves determining the type of hazards affecting a certain area with specific intensity and recurrence. Assessing exposure is concerned with analyzing the relevant elements (population, assets) exposed to relevant hazards in a given area. Vulnerability is a multidimensional concept encompassing a large number of factors that can be grouped into physical, economic, social and environmental factors. The factors affecting and comprising vulnerability can be listed as follows (see GTZ 2004).

- Physical vulnerability: factors relate to the susceptibility to damage of engineering structures such as houses, dams or roads. Factors such as demographic change and population growth may also be subsumed under this category.
- Social vulnerability: this can be defined by the ability to cope with impacts on the individual level as well as referring to the existence and robustness of institutions to deal with and respond to natural disaster.
- Environmental vulnerability: a function of factors such as land and water use, biodiversity and stability of ecosystems.
- Economic vulnerability: determinants relate to economic or financial capacity to refinance losses and recover quickly to a previously planned economic activity path. This may relate to private individuals as well as companies and their savings and asset base, or to governments that often bear a large share of country risk and associated losses.

Combining hazard, exposure and physical vulnerability leads to an estimate of *direct* risk in terms of potential effects and losses to be expected. As explained further below, linking direct risk in terms of losses with economic vulnerability produces indirect risk in terms of macro – or microeconomic risk. Risk

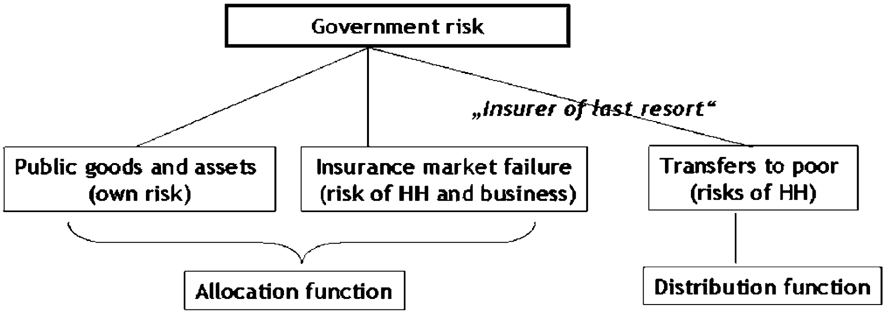



**Fig. 8.2** Government disaster risk

management aims at reducing direct and indirect risks. Benefits of risk management are the reduction in risk estimated by comparing the situation with and without risk management. We denote resilience as the ability to return to pre-disaster conditions; appropriate organizational structures, know-how of prevention, risk reduction and response have a decisive influence on resilience.

### *8.2.3 Fiscal and Economic Implications of Disasters*

From an economic perspective, governments are exposed to natural disaster risk and potential losses due to their two main functions: the allocation of goods and services (security, education, environmental protection) and the distribution of income, Schick et al. (2004), as shown in Fig. 8.2.

According to Schick et al. (2004), Stern (2007), in many cases market forces are unlikely to generate adequate adaptation to disaster risks, broadly because of the following three reasons: (1) uncertainty and imperfect information, (2) missing and misaligned markets and (3) financial constraints. In case of a disaster event, consequently, there may be substantial contingent liabilities as identified in Table 8.1. Should governments insure or purchase alternative risk financing instruments for those liabilities? According to an early theorem by Arrow and Lind (1970) a government may

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

Accordingly governments should behave risk-neutrally and evaluate their investments only through the expected net present (social) value. 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

**Table 8.1** Government liabilities and disaster risk

| | Direct | Contingent |
|---|---|---|
| Liabilities | Obligation in *any* event | Obligation if a *particular* event occurs |
| Explicit<br>Government liability recognized by law or contract | Foreign and domestic sovereign borrowing, expenditureby budget law | State guarantees for non-sovereign borrowing and public and private sector entities, reconstruction of public infrastructure and assets |
| Implicit<br>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 to affected households and business |

Source: Schick and Polackova Brixi (2004)

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 insurance costs of 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. According to Arrow and Lind (1970) governments should thus not insure if they are not averse to risks, i.e. if financial risks faced by a government can be absorbed without major difficulty.

The Arrow and Lind theorem has served 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 (Carpenter et al. 2000). The case against risk aversion, however, may not hold for extreme events. As early as 1991, the Organization of American States' primer on natural disasters stated that the risk neutral proposition is valid only up to certain point and that the reality in developing countries suggests that those 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 should justifiably act as risk-averse agents. This means that the Arrow-Lind theorem may not apply to governments of countries that exhibit some or all of the following characteristics (see Mechler 2004):

- high natural hazard exposure;
- economic activity clustered in a limited number of areas with key public infrastructure exposed to natural hazards (see also Hochrainer and Pflug 2009); and
- constraints on tax revenue and domestic savings, shallow financial markets, and high indebtedness with little access to external finance.

These conditions are fundamental for assessing the financial vulnerability of a state. Governments are financially vulnerable to disasters if they cannot access sufficient funding after a disaster to cover their liabilities with regard to reconstructing public infrastructure and providing assistance to households and businesses (Mechler 2004). As an indicator of financial vulnerability, a *resource gap* measures sovereign financial vulnerability *in terms of the lack of sufficient savings or funding for relief and reconstruction.* The repercussions of large resource gaps can be substantial. An 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.

In 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 undertaking social or infrastructure investments. There are a number of countries like Honduras. Figure 8.3 shows key countries that may need to take a risk averse approach to disaster risk. For this global set of large observed disaster events, losses measured in terms of gross national product are significant for a number of smaller or lower income states, while this ratio becomes smaller for larger and higher income countries.

As one exemplary case, we discuss the case of Nepal in Chap. 9 of this book. Nepal is a country subject to high natural disaster risk and with minor capacity of spreading or pooling the risks. In such circumstances, the Arrow-Lind theorem may not apply, and the argument concerning the risk spreading capacity of governments – and the resulting individual cost being negligible – becomes debatable. In reality, external aid or loans are in dire need post-disaster. In response to evidence and research on the consequences of disasters, a number of developing and transition countries, such as Mexico and Colombia, have modified their reactive approaches to disaster risk and are actively considering risk management and fiscal planning for risk (Cardenas et al. 2007; Linnerooth-Bayer et al. 2011).

### *8.2.4 Risk Financing Options for Reducing Financial Vulnerability*

Governments can choose among a variety of traditional and novel pre-disaster risk financing instruments for reducing their financial vulnerability. The most common are discussed below:

- A *reserve fund* holds liquid capital to be used in the event of a disaster. Ideally, the fund accumulates in years without catastrophes; however, from experience,

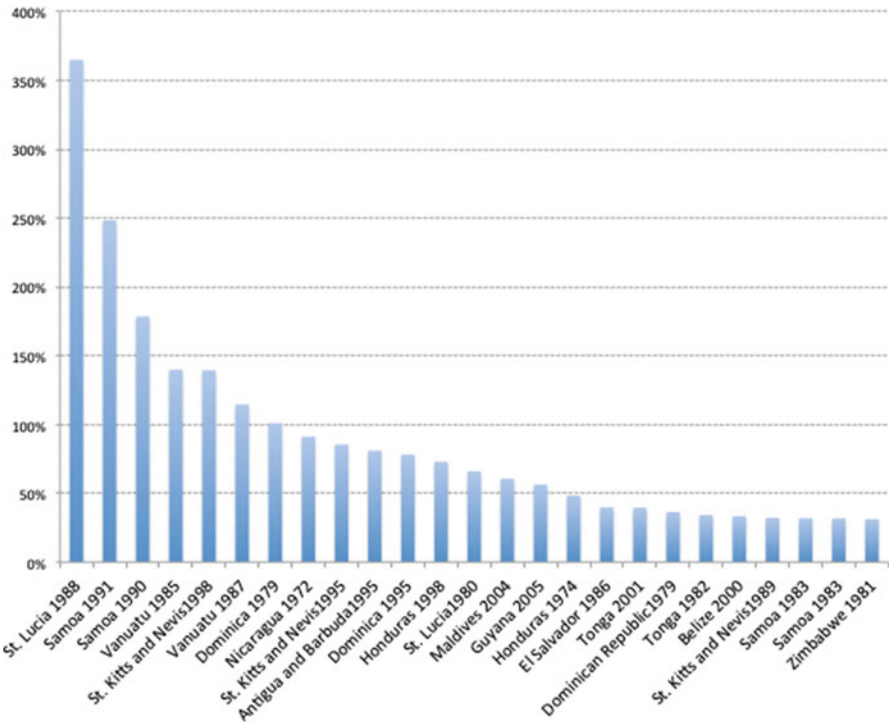



**Fig. 8.3** Risk as measured by observed events vs. Gross National Product for large disaster events (Data Source: Mechler et al. 2009; World Bank 2008)

there is considerable political risk of fund diversions to other pressing government needs, especially after long periods without serious disaster impacts.

- *Insurance and other forms of risk transfer* provide indemnification against losses in exchange for a payment. The most common form of risk transfer is insurance or reinsurance. Insurance is an important pre-disaster, risk-transfer institution in that it distributes disaster losses among a pool of at-risk households, businesses and/or governments and to the reinsurance markets. A catastrophe bond (cat bond) is an alternative risk transfer instrument where the investor receives an above-market return when a specific catastrophe does not occur (e.g. an earthquake of magnitude 7.0 or greater), but shares the insurer's or government's losses by sacrificing interest or principal following the event.
- *Contingent credit* arrangements do not transfer risk spatially, but spread it intertemporally. In exchange for an annual fee, the risk cedent has access to a pre-specified post-event loan that is repaid at contractually fixed conditions. In the case of sovereign risk financing, international finance institutions offer such instruments. Contingent credit options are commonly grouped under alternative risk-transfer instruments.

Due to the extreme nature of the losses and the substantial costs involved in such transactions, disaster insurance and other risk financing instruments generally

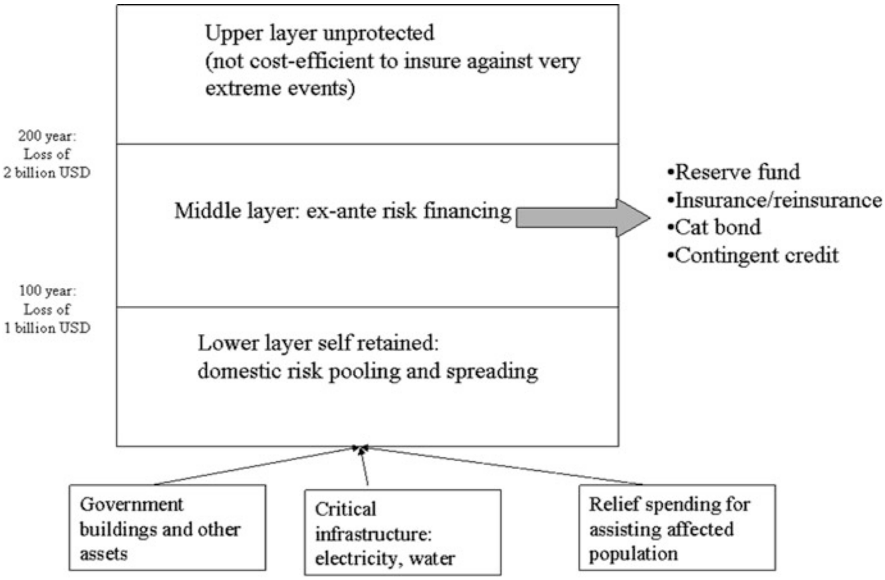



**Fig. 8.4** A structure for financially managing the public sector's disaster risk liabilities

absorb only specified layers of risk, defined by attachment and exit points (or lower and upper thresholds based on the recurrence period of the events, as discussed below). Low layers of risk, for which the risk cedent is able to finance the losses, will typically be retained. Extreme layers of risk will also not be transferred to other agents because of the high and exponentially increasing costs of transfer; one important factor is the uncertainty associated with extreme losses: which necessitates large sums of backup capital "reserved" by the agent accepting the risks in order to fulfill her obligation in case of an event.

An example of a layered risk-transfer portfolio is illustrated in Fig. 8.4. In this case, the lower threshold (attachment point) is illustrated as the 100-year event (an event with an annual probability of less or equal to 1%) with losses of $1 billion. The upper threshold (exit point) is the 200-year event with losses of $2 billion. The lower threshold is in principle determined by the government's *financial vulnerability* since it specifies the disaster risk for which the government is in need of additional financial resources for protecting its portfolio of public assets and providing emergency response and relief.

## 8.3 The CATSIM Model Approach

A number of risk modeling companies are involved in catastrophe risk modeling for insurance and reinsurance companies, to develop adequate financial risk management measures such as estimating required reserve capital or the uptake of reinsurance contracts (Kuzak et al. 2004). In a similar vein, the CATSIM model focuses on the portfolios of governments and outlines the costs and benefits of undertaking risk management options.

### 8.3.1 Methodology and Structure

CATSIM uses stochastic simulation of a disaster in a specified region and examines the ability of governments and private sectors to finance relief and recovery. It is interactive in the sense that the user can change the parameters and test different assumptions about the hazards, exposure, vulnerability, general economic conditions and the government ability to respond. As a capacity building tool, it can be used to illustrate to the authorities the trade-offs and choices they are confronted with to increase resilience to the risks of catastrophic disasters.

From a methodological perspective, CATSIM approaches the decision and modeling problem as a two stage decision problem under uncertainty. Figure 8.5 outlines the logic followed in the modeling approach. The objective is to guarantee the sufficient and timely financing of government post disaster obligations, the provision of relief to the private sector and the reconstruction of public assets.

In the first, ex ante stage, a part of the government's budget can be allocated to undertake risk reduction (e.g. building a dike), or buy insurance and other financial protection instruments for public assets (such as infrastructure and public buildings) and relief obligations to the private sector. This reduces the budget available for investment into regular development-enhancing activities, creating opportunity costs. The second stage, the decision stage after a disaster, is the ex-post stage where budget reallocation and other financial decisions are made in order to finance the funding needs. Yet, financing the losses with ex-post sources also reduces the budget for investment.

The part of the losses that neither ex-ante nor ex-post options can cover is called *resource gap*. This gap in terms of a shortfall of required resources to continue with key socioeconomic priorities affects key macroeconomic outcomes in the future such as GDP, government revenue and the budget position, and therefore it also increases financial vulnerability and consequently future risks.

### 8.3.2 Methodological Steps of CATSIM

CATSIM is operationalized in five major steps as described below and illustrated in Fig. 8.6.

**Step 1:** Risk of direct asset losses (in terms of probability of occurrence and destruction in monetary terms) is modeled as a function of hazards (frequency and intensity), the elements exposed and their physical vulnerability.

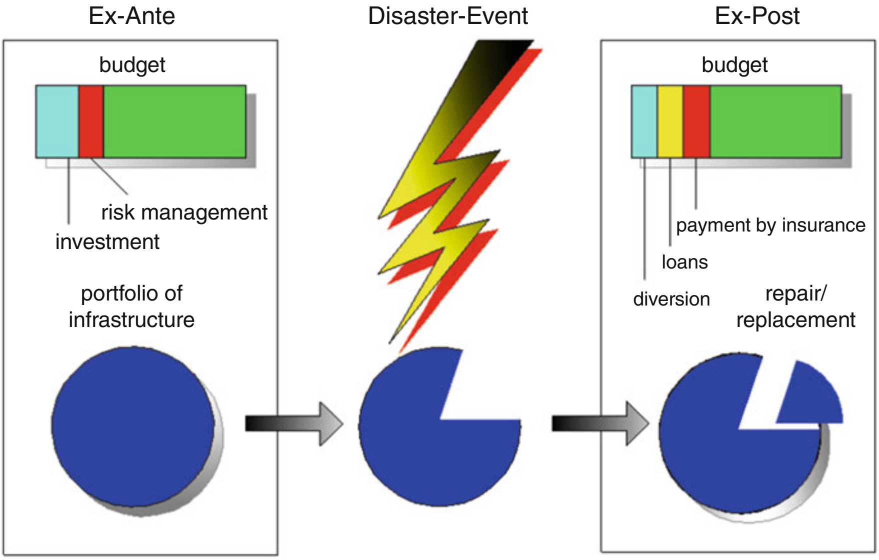



**Fig. 8.5** Modeling logic of CATSIM

**Step 2:** Financial and economic resilience for generally responding to shocks is measured. Resilience is defined as the state or central government's accessibility to savings for financing reconstruction of public infrastructure and providing relief to households and the private sector. Resilience depends heavily on the general prevalent economic conditions of the given country.

**Step 3:** Financial vulnerability, measured in terms of the potential resource gap, is assessed by simulating the risks to the public sector and the financial resilience of the government to cover its post-disaster liabilities following disasters of different magnitudes.

**Step 4:** The consequences of a resource gap on key macro variables such as economic growth or the external debt situation are identified. These indicators represent consequences to economic *flows* as compared to consequences to *stocks* addressed by the asset risk estimation in step 1.

**Step 5:** Strategies can be developed and illustrated that build resilience of the public sector or contribute to the risk management portfolio. The development of risk management strategies has to be understood as an adaptive process where measures are continuously revised after their impact on reducing financial vulnerability and risk has been assessed within the modeling framework.

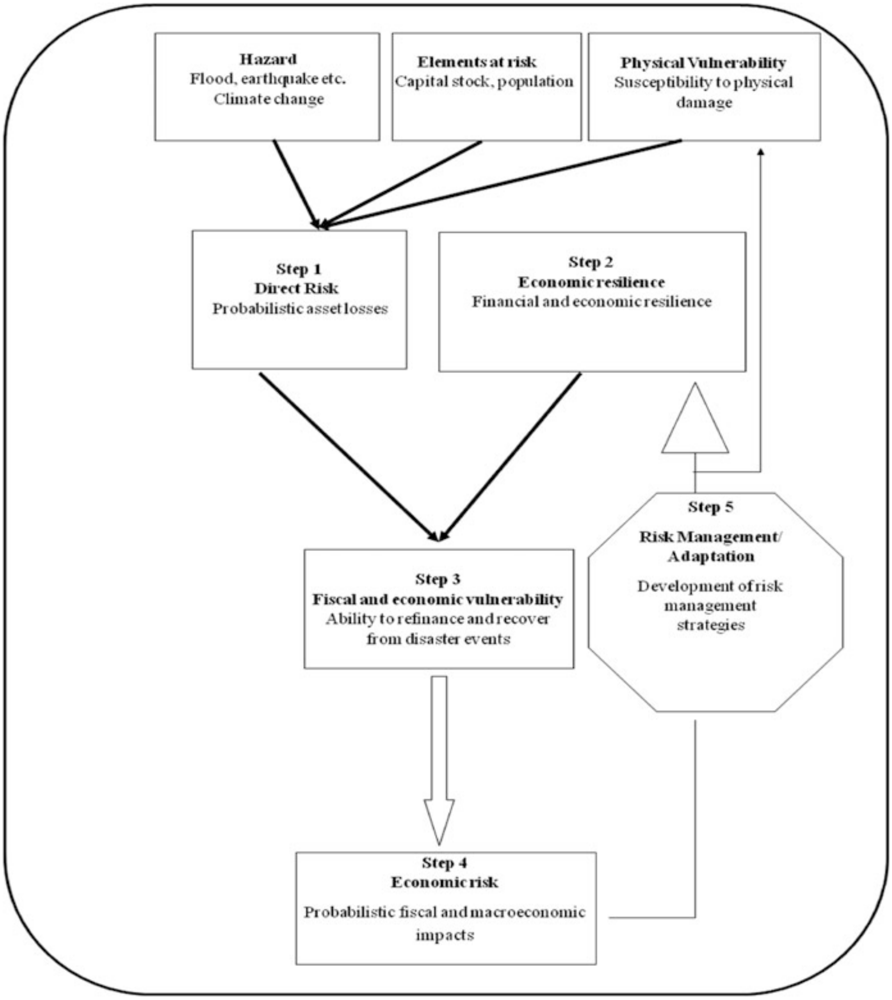



**Fig. 8.6** Flow chart of CATSIM methodology

In the next few paragraphs, we discuss each step in more detail.

*Step 1: Assessing disaster risk*
In the 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). In more detail,

- Natural hazards, such as earthquakes, hurricanes, or floods, are described by their intensity (e.g. peak flows for floods) and recurrence (such as a 1 in 100 year events, i.e. with a probability of 1%).
- Exposure of elements at risk is estimated as total private and public capital stock.

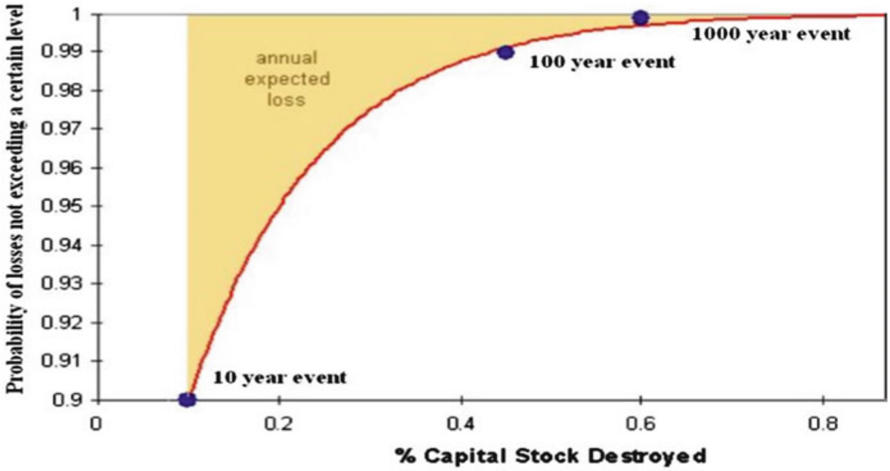



**Fig. 8.7** Risk of losses as measured by a cumulative loss-frequency distribution (Source: Freeman et al. 2002b)

- Physical vulnerability describes the degree of damage to the capital stock due to a natural hazard event. The standard method followed here consists of estimating vulnerability or fragility curves putting the degree of losses in relation to the intensity of a hazard.

Based on such information, potential losses due to destructive events can be established for a country, state or region in terms of per cent of capital stock lost. The data on return periods and losses serve as input to CATSIM for generating loss-frequency distributions, which relate probabilities to assets destroyed. For example, Fig. 8.7 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 of damage. For example, with a probability of 0.9 (90%) flood losses will not exceed 0.1% of capital stock; inversely, there is a 0.1 (10% chance) that such a loss and larger will occur.

Top-down estimates at the aggregate national scale are necessarily rough. Since most disasters are rare events, there is usually insufficient historical data at hand; furthermore, it is difficult to include dynamic changes in the system, e.g. change in exposure and hazards due for instance to population and capital movements and climate change. To improve the robustness of estimates 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 assets at a more detailed scale.

An important summary measure of this distribution is the annual expected loss, the loss to be expected on average every year. The annual expected loss is the sum of all loss weighted by their probability of occurrence. Graphically, the expected losses is represented by the area above the cumulative distribution curve. While the expected loss is an important metric, it should generally be stressed that risk management strategies for extreme events focus strongly on the fat tails of the distribution (the 100 or 200 year events) rather than the average risks.

*Step 2: Assessing public sector financial resilience*
Based on the information on direct risks to a government portfolio, financial resilience can be evaluated by assessing 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 CATSIM 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. For this assessment, it is necessary to examine government's resources including those that can be relied on after the disaster (probably in an ad hoc manner, *ex post* sources) and resources put in place before the disaster (*ex ante* sources). These sources are described below.

*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 international financial institutions and issuing bonds on the international market (Benson 1997a, 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 (Table 8.2). As an example, disaster taxes are not only expensive to administer but may add to recessionary tendencies after large scale disasters (e.g. due to a decrease in consumption).

As a second example, borrowing can also be constrained by 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). These ex post instruments have (often high) associated costs; even budgetary diversions lead to opportunity costs in terms of foregoing other government investments like building health clinics, highways or schools.

*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 the instruments discussed above such as reserve funds, traditional insurance instruments (public or private), alternative insurance instruments, or arranging a contingent credit. These ex-ante options can involve substantial annual payments and opportunity costs; statistically the purchasing government will pay more than the expected losses with a hedging instrument than if it absorbs the loss directly. However,

**Table 8.2** Ex post financing sources for relief and reconstruction

| Type | Source |
|---|---|
| Decreasing government expenditures | Diversion from budget |
| Raising government revenues | Taxation |
| Deficit financing | Central Bank credit |
| Domestic | Foreign reserves |
| | Domestic bonds and credit |
| Deficit financing | Multilateral borrowing |
| External | International borrowing |
| | International Aid |

under the assumption of risk aversion these measures may still be beneficial depending on the size of potential losses and the degree of financial vulnerability and risk aversion.

*Step 3: Measuring financial vulnerability by the **resource gap***
Using the information on direct risks to the government portfolio and financial resilience, financial vulnerability can be evaluated. Financial vulnerability is thus defined as the lack of access of a government to domestic and foreign savings for financing reconstruction investment and relief post-disaster. The shortfall in financing is measured by the term *resource gap*. The term resource gap has been defined in the economic growth modeling literature as the difference between required investments and the actual available resources in an economy.

The main policy recommendation consequently has been to fill this gap with foreign aid (Easterly 1999).[1] Here, this tradition is followed and the resource gap is understood as the lack of financial resources necessary to restore lost assets and continue with development as planned. Figure 8.8 illustrates the calculation of this metric for a hypothetical case.

Given losses due to a certain event, such as the 100 year event (in the example associated with a public sector loss of 4 billion USD), 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 would have the least costs associated as these are donations free of cost to the recipient, and thus they would be used first. Second, diversions from the budget could be used, then domestic credit, followed by borrowing from the international institutions (such as World Bank) and the international markets (bonds).

While in this illustration, a 100-year event could be financed, for a 200 year event (public sector loss of 10 billion USD), there would be lack of (ex-post) sources and consequently a resource gap occurs. It is the main objective of CATSIM to illustrate the costs and benefits of closing this government resource gap by ex-ante measures and the consequences of not being able to do so. World

[1] This approach has been criticized among others by Easterly (1999) as generally it lacks considering the role of incentives and institutions in economic growth. Nevertheless, it is without doubt that capital investment plays an important role in economic growth.

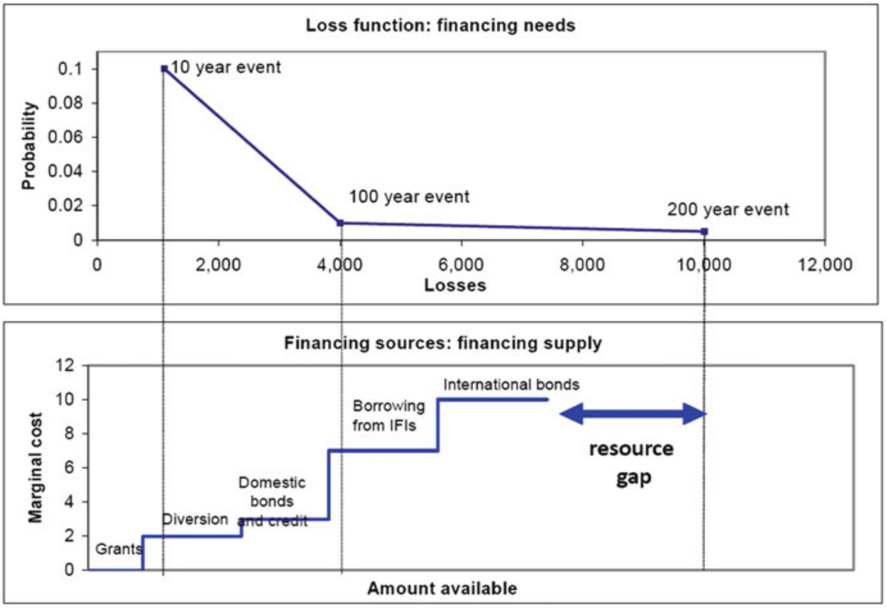



**Fig. 8.8** Illustration of methodology for calculating the disaster resource gap (Million USD)

Bank (2008) added another important dimension to this approach in terms of the timing of resource flows. As illustratively shown on Fig. 8.9, while enough funding may become available over time, there may be a temporary resource gap in the aftermath of a disaster event (here shown to be the first 4 months post event) when urgent expenditure needs are high, but immediately available financial resources are often very limited.

While CATSIM is resolved in annual time steps, it considers the fact that the timing of financial inflows for financing the losses is also important and can differ for different ex-ante and ex-post instruments.

*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 a government can neither replace nor repair damaged infrastructure (for example, roads and hospitals) nor provide assistance to those in need after a disaster, this will have long-term consequences which can be illustrated by CATSIM. Key aggregate flow outcomes measured by the model are on the fiscal position of a government and the ensuing GDP effects resulting from the lack of ability of a government as a key economic agent to act post event. Governments may brace against these adverse outcomes by implementing physical and financial risk management measures, and generally a government' position and the economy are stabilized against disasters if such measures are adopted. Yet, there are important opportunity costs associated with spending on risk management and in the absence of disaster events, economic welfare will be higher if a government

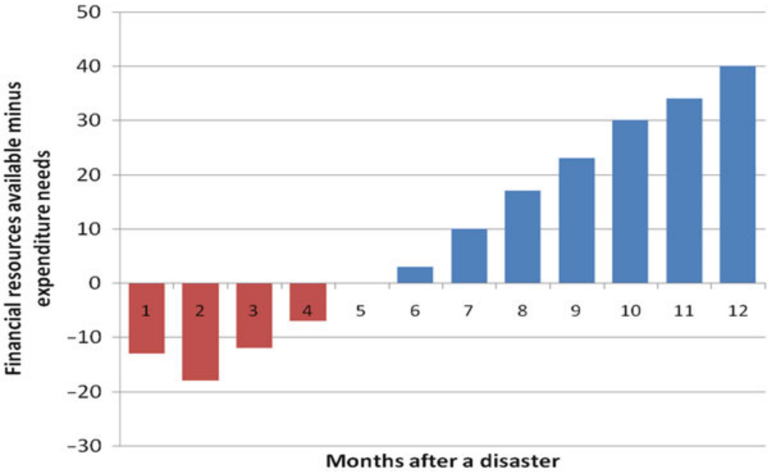



**Fig. 8.9** Government resource gap after a natural disaster (Source: World Bank 2008)

does not allocate resources to catastrophe insurance or other risk management measures. This effect is pronounced for financial measures, such as insurance, where annual premiums have to be paid, whereas for physical measures, such as building dikes, the key costs are investment costs to be paid once only.

*Step 5: Reducing financial vulnerability and building resilience using ex ante risk management options*

Vulnerability and resilience must be understood as dynamic. In contrast to ecological systems, social systems can learn, manage and actively influence their present status quo. There are two types of policy interventions for reducing the financial vulnerability of the public sector: those that reduce disaster risks by reducing exposure and physical vulnerability, and those that build financial resilience of the responding agents. 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. In addition to ex ante financing policy measures (sovereign insurance, contingent credit and reserve funds) one generic option for loss prevention measures has been implemented in order to analyze their linkages with risk financing. Normally, few financial ex-ante options are in place in developing countries, thus the model focuses on analyzing the pros and cons of such new funding sources, which are considered the decision variables.

There are important distinctions between risk reduction and risk financing instruments. While risk financing measures reduce the follow on consequences by transferring risk or sharing risk with others, risk reduction is directed towards decreasing physical vulnerability (Fig. 8.10).

In CATSIM, risk reduction is modeled as an accumulating stock, e.g. similar to a dike used for preventing flooding (see Fig. 8.11). In this representation, there is no

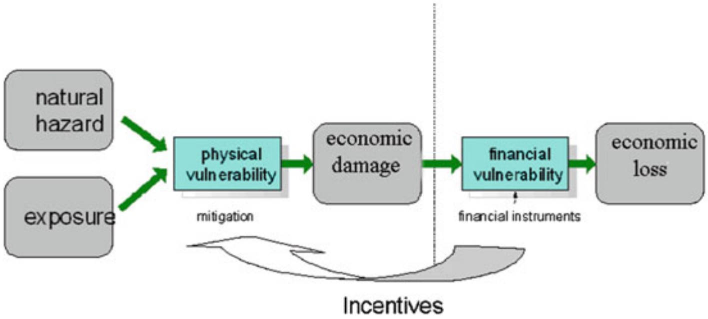
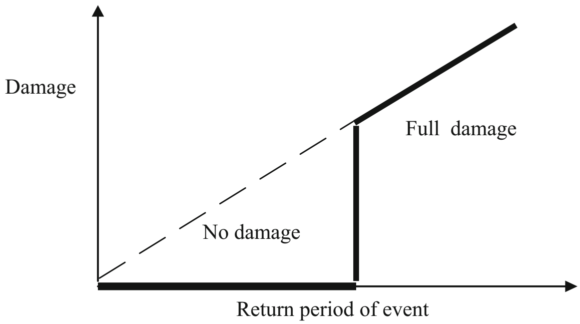



**Fig. 8.10** Reducing and financing risk

**Fig. 8.11** Model representation of risk reduction (Source: Hochrainer 2006)




damage if the accumulated risk reduction is able to withstand the theoretical damages due to an event with a certain return period. In Fig. 8.11 the thick line shows the damage as a function of the "hypothetical" damage without risk reduction. No damage occurs up to a given event magnitude. If the magnitude is larger than this limit, the full "hypothetical" damage occurs.

Furthermore, risk reduction and risk financing options are linked within the model. If risk reduction is in effect, it reduces the costs of insurance and contingent credit payments. Thus, risk reduction has the double effect of reducing damage as well as reducing insurance and contingent credit premiums.

### *8.3.3 Algorithm for Calculating Financing Available from Ex-Ante and Ex-Post Sources*

The physical damage is translated into a financial loss for the government after subtracting all ex ante and ex post sources. The existing options are used to the necessary extent. If all of the physical damage can be covered by ex-ante and ex-post options the financial loss is zero. Otherwise, if after exhausting all ex-ante and

**Table 8.3** Calculation of ex-ante and ex-post sources

| Type of source | Method |
|---|---|
| Ex-ante | |
| *Insurance* | Claim defined by attachment and exit point |
| *Reserve fund* | Reserve fund is depleted to the extent necessary up to full depletion |
| *Contingent credit* | Triggered to the extent necessary and "reserved in advance" due to payment of a fee for the contingent credit; debt is incurred |
| *Risk reduction* | Damages are reduced to zero, if threshold is exceeded full loss occurs and accumulated risk reduction investment is lost |
| Ex-post | |
| *Budget diversion* | Maximum diversion is a fixed percentage of revenue |
| *Aid* | Fixed portion of physical loss, assumed to be 10.4% of losses according to statistical analysis done with historical data (see Freeman et al. 2002a) |
| *Domestic credit* | Maximum domestic credit available is a fixed fraction of the revenue |
| *Foreign credit* | Constrained by external debt sustainability indicator and credit buffer. It is assumed that half of the needed sum comes from multilateral sources and half from issuing international bonds |

ex-post sources, there still is a net loss, a resource gap, a part of lost capital stock will remain unreplaced, affecting GDP and leading to lower revenue in the next period. Table 8.3 shows how ex-ante and ex-post instruments resources are determined.

Methodologically, we use lexicographic preference ordering as follows: Let the (monetary) loss distribution for the government be called F. Furthermore, assume that the government has $k$ instruments (either ex-post and/or ex-ante) available to finance the losses. In case of a disaster event some or all of the instruments are used to a given amount to finance the losses. In the simplest case, there is a strict preference order between the financing instruments, represented by the resource vector $\vec{x} = (x_1, \ldots, x_k)'$ in the following way: the first instrument (with monetary resources$x_1$) is preferred before all others until depletion; afterwards the second instrument (with resources $x_2$) is preferred before all others until depletion, and so on. Let $\vec{x}_m = (x_{m1}, \ldots, x_{mk})'$ be the maximal (monetary) amount available for each instrument for a given loss event. Then the loss financing scheme for a given event with return period $1/y$ (e.g., for a 100 year event y would be 0.01) is the solution of depleting resources in the respective order till the losses ($F^{-1}(1-y)$) are fully financed. In case that $\sum_{i=1}^{k} x_{mi} < F^{-1}(1-y)$ is fulfilled, a resource gap occurs, and the return period of the event where this happens for the first time (i.e., all events with lower return periods satisfying equation $\sum_{i=1}^{k} x_{mi} = F^{-1}(1-y)$) is called *the critical return period*. As indicated, resource gaps will have (possibly long-term) economic consequences, which are assessed by the economic module discussed next.

### 8.3.4 The Economic Module

Financial resilience is part and parcel of the general conditions of the modeled economy and is analyzed independently of disaster risk. In CATSIM, the macroeconomic module is currently set out as a simple Solow-type growth framework with the focus on the potential for medium to longer term growth and development of aggregate economic variables given explicit consideration of disaster risks (see Barro and Sala-I-Martin 2004 for a discussion of the economic growth literature). The Solow model (more correctly *Solow-Swan model*) is considered the workhorse of economic growth research for studying the longer term potential development of an economy. In the simple exogenous savings version, economic growth is driven by the 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's 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. CATSIM makes a number of important modifications to the model:

- The main focus is on the public sector (national or state government), its fiscal liabilities and risk management strategies; the model is solved accordingly.
- Capital can be destroyed by natural disasters. As the occurrence of disasters is modeled stochastically, stocks and flows such as assets, budget and GDP become stochastic variables (labor is currently fixed).
- The private and public sector investment budget can be used for investing in new capital stock (or maintaining existing), replacing destroyed stocks or for protecting these assets by the ex-ante risk reduction measures or risk financing.
- There is a fixed government budget to be used for consumption and investment. Reconstruction of destroyed stocks has to be financed from the budget as well. Also debt service payments (e.g. due to incurring new debt for purposes of reconstruction) have to be paid from this budget.
- The investment budget can be used for investing in new capital stock (or maintaining existing) or for protecting these assets by the ex-ante risk management measures risk reduction or risk financing.

Table 8.4 gives an overview of important model components as part of the modeling approach.

The purpose of the economic module is not to develop estimates for the main economic variables, but to contrast a baseline to a case with additional ex-ante

**Table 8.4** Overview of important model features of CATSIM approach

| Model feature | Description |
|---|---|
| Assumed government objectives | Provide relief post-disaster and rebuild infrastructure quickly while maintaining growth |
| GDP growth | Endogenous, GDP falls in year of event, in subsequent years GDP is determined by investment in previous year |
| Reconstruction investment | Government undertakes reconstruction investment for infrastructure, private sector undertakes reconstruction investment for private capital |
| Domestic savings | Limited supply, decrease after event, as income falls |
| Government consumption | Constant except for year of catastrophe |
| Private consumption | Constant, as low per capita income households increase their propensity to consume to maintain life-sustaining level of spending |
| Production function | Cobb-Douglas with inputs capital and labor |
| Treatment of capital | Catastrophe destroys capital |
| Treatment of labor | Labor force decreased in year of event |
| Imports and exports | Closed economy assumption |

protection for disaster risk and study the associated effects over a certain time horizon. We use a production function approach which seems most suitable for this purpose. Currently, in order to represent the production of goods (supply) a simple Cobb-Douglas function is used with inputs capital and labor.

$$GDP = AK^{\alpha}L^{\beta}$$

where K represents capital stock, L effective labor force, A is a technological efficiency parameter, alpha and beta represent the production elasticity of capital stock and labor.

### 8.3.5 *Representing Uncertainty*

Another key issue for CATSIM is the analysis of uncertainty (see also Compton et al. 2009 and Chap. 2 in this book). Three types of uncertainties are considered: *aleatoric* uncertainty, *parametric* uncertainty and *model* uncertainty. While model uncertainty (the uncertainty that the model appropriately represents the actual system) is more difficult to tackle and based on modeler's choices (see also Chap. 9 in this book for the case of Nepal), aleatoric uncertainty (natural variability) is considered by the above mentioned loss-frequency distributions. Because of the simulation approach used, response variables are expected values and it is important to determine the parametric uncertainty around these estimates. Confidence intervals are used to reflect this uncertainty.

Another type of uncertainty, *epistemic* uncertainty (for a discussion of uncertainties see Chap. 2 by Compton et al. in this book), is harder to treat mathematically. Usually,

**Fig. 8.12** CATSIM in use to inform planning for disasters with officials from Caribbean countries, Barbados, June 2006

the mathematical treatment of *epistemic* uncertainties requires encoding and aggregation of expert opinions. Different approaches for aggregation exist, however, various problems arise due to the issues involved in the weighting process (Pate-Cornell 1996), and thus cannot be seen as very reliable proxies for this kind of uncertainty. In our approach, this kind of uncertainty is dealt with more broadly by involving key stakeholders from finance ministries, disaster management authorities or civil society in deliberative processes organized around workshops. These workshop are facilitated by a standalone software version of CATSIM, which is equipped with a graphical user interface making it possible to systematically assess expert opinions (Fig. 8.12).

This approach allows users to change important parameters and assumptions and study the consequences. Furthermore, as we understand the problem of government risk financing as a trade-off, this setup allows the user to decide which trade-off he/she is willing to commit to and which indicators he/she considers most useful for analyzing the trade-off. The case study on Nepal presented in the Chap. 9 gives some insight into these modeling and decision structuring elements.

## 8.4 Conclusions

Governments of developing and transition countries frequently face post – disaster resource gaps in financing response, relief, and reconstruction, which can have serious effects on longer-term socioeconomic development prospects. The potential for a resource gap and associated adverse consequences provides a rationale for these countries – overriding the Arrow-Lind theorem – to behave as risk-averse agents and consider risk financing options for their contingent disaster liabilities. Risk financing may be implemented using instruments such as catastrophe reserve funds, sovereign insurance, catastrophe bonds or contingent credit contracts. CATSIM informs this decision problem, and we suggest, its modeling approach focusing specifically on risk as well as the translation of direct to indirect risk can be useful input for informing planning decisions related to sovereign disaster risks. Also, while in this paper different risk management options were assessed separately, more realistic, as well as mixed, strategies can be analyzed with CATSIM, e.g. spending a portion of the budget on risk reduction and insurance. For such an analysis, additional information on the preferences and strategies of decision makers are necessary. To elicit those in interaction with potential stakeholders, the model has been used for a number of applications and workshops sponsored by international organizations involved in disaster risk management, which confirmed the validity of the assumptions and its usefulness for developing sound risk management strategies. Due to the user interface and its philosophy of using simulation rather than optimization analysis, the flexibility to consider multiple aspects in informing decisions constitutes a very important feature of the model. For example, for the case of Mexico, which insured its liabilities in 2006, CATSIM provided information on the different layers of seismic risk to the public finances and helped identify which risks could be transferred to the international markets at an acceptable cost (Cardenas et al. 2007). Yet, finally, the government insured its potential post-disaster relief expenditure based on the fact that congress appropriations for a national reserve trust fund had been volatile and subject to political intervention. Thus, beyond economic efficiency, timing and equity considerations, the key objective of the transaction was to achieve security for the planning process. Clearly, any decision making process will depend on such and many other factors, including expert as well as subjectively constructed information, and we propose to embed CATSIM in deliberative processes involving workshops with both stakeholders and experts leading to mutual learning and hopefully improved decisions.

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