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Using Probabilistic Models to Appraise and Decide on Sovereign Disaster Risk Financing and Insurance

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Abstract

This paper presents an overview of the structure of probabilistic catastrophe risk models, discusses their importance for appraising sovereign disaster risk financing and insurance instruments and strategy, and puts forward a model and a process for improving decision making on the linked disaster risk management strategy and sovereign disaster risk financing and insurance strategy. The paper discusses governments' use of probabilistic catastrophe models to inform sovereign disaster risk financing decision making and describes the ex ante and ex post financing instruments available for responding to extreme natural events. It also discusses the challenge of appraising sovereign disaster risk financing and insurance instruments, including a review of the multiple dimensions of disaster risks and the value that probabilistic catastrophe risk models provide. The decision making framework for sovereign disaster risk financing and insurance put forward by the paper includes the use of a decision model (an influence diagram) as a rigorous representation of the relationships between the decisions, uncertain events, and consequences relevant to sovereign disaster risk financing and insurance decision making. The framework also includes a process for generating high-quality customized components for the decision model, and a tool for designing coherent sovereign disaster risk financing and insurance strategies. The paper ends with suggestions for improving catastrophe risk models to facilitate sovereign disaster risk financing and insurance decision making.

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Using Probabilistic Models to Appraise and Decide on Sovereign Disaster Risk Financing and Insurance[1]

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Introduction

The 2005 United Nations World Conference on Disaster Reduction and the resulting Hyogo Framework for Action highlighted the need for pro-active disaster management, including cost-effective risk reduction investments and, where this is not possible or as a complement, financial risk transfer through (re)insurance and capital market instrumentation.

Sovereign disaster risk financing and insurance (SDRFI) instruments are among the main resources that states can use for disaster risk reduction (DRR); however, appraising SDRFI instruments can be a challenging task. Deciding on SDRFI instruments requires taking into consideration the different types of disaster risks the state faces; the variety of their economic, social and environmental consequences; and the uncertainty on the occurrence, magnitude, and impact of severe natural events, in addition to the cost, timing, and availability of a wide range of SDRFI instruments.

Probabilistic catastrophe risk models provide a coherent framework for appraising the multiple elements related to SDRFI instruments and they are especially useful for valuing the consequences of uncertain events; it is worth exploring how to get the most value from them.

This paper presents an overview of catastrophe risk models and their use for appraising SDRFI instruments, and suggests a model and a process for improving decision making on sovereign disaster financial instruments. The first section describes probabilistic catastrophe models in terms of their inputs and outputs, and discusses their use by governments to inform sovereign disaster risk financing decision making. The second section describes the financing and insurance instruments available for responding to extreme natural events and the design of strategies that take into consideration the cost and timing of the available financing instruments, in many cases combining ex-ante and ex-post instruments. The third section discusses the challenge of appraising SDRFI instruments, including a review of the multiple dimensions of disaster risks; it highlights the value of probabilistic catastrophe risk models for appraising SDRFI instruments. The fourth section puts forward a decision making framework for SDRFI that includes the use of a decision model (an influence diagram) as a rigorous representation of the relationships between the decisions, uncertain events and consequences relevant to SDRFI decision making. The framework also includes a process for generating high quality components for the model (components tailored to the circumstances of the individual country) and a tool for designing coherent SDRFI strategies. Finally, suggestions for enriching catastrophe risk models in order to facilitate SDRFI decision making are presented.

1. Probabilistic Catastrophe Models

Catastrophe risk models have been developed and used by participants in the private international (re)insurance community since the late 1980s. Functionally, these models attempt to represent the likely direct economic impact of natural hazards (e.g., hurricanes) on a portfolio of physical assets at risks (e.g., a selection of hotels in Miami) and provide outputs that can be used by decision makers to inform their risk management strategies. There are two distinct types of catastrophe modeling analysis that can be performed: deterministic and probabilistic. Deterministic (or "what if") analyses represent the impact of a defined scenario event, e.g., the 2010 Chile earthquake; whereas probabilistic analyses attempt to capture the impact of all of the possible natural hazard events that could affect a given region. While deterministic event analyses can provide valuable information to risk decision makers, they inherently contain no information about the likelihood that the given event could happen (only its potential impact); however probabilistic analyses allow decision makers to understand the likelihood of the full range of possible impacts of natural hazards and they can also model events over a broad time horizon (well in excess of the length of historical records).

Inputs

Sophisticated catastrophe models are typically composed of four components: a hazard module, an exposure module, a vulnerability module and a loss module. The hazard module itself is formed of two elements: a stochastic event set, and a local site model. The stochastic event set is a catalog of simulated natural hazard events which are characteristic of the observed or scientifically-modeled events in a region and contains information about their location, size (e.g., earthquake magnitude) and associated probabilities of occurrence. The local site model represents the small-scale impacts of the large-scale natural peril; for example, in the case of earthquake risk this element allows the prediction of the ground shaking intensity at a given location, due to the occurrence of an earthquake of given size and location some distance away.

The exposure module is a database of the physical characteristics of the assets (buildings, infrastructure etc.) at risk to the specific perils in the hazard module. As well as cataloging their economic replacement cost and geo-referenced location, sophisticated catastrophe models typically represent assets in terms of their usage (e.g., residential, commercial, industrial etc.), construction type (e.g., adobe, wood, concrete etc.), age and height (number of stories).

The vulnerability module characterizes the damageability of the assets in the exposure module to the natural perils in the hazard module. Essentially this component is a database of mean damage ratio relationships (and their associated uncertainty parameters) between local hazard intensity and the physical damage to structures in the exposure module. The vulnerability module of robust catastrophe models will demonstrate sensitivity to the various characteristics in the exposure database (as listed above) highlighting the need for accurate, high-resolution exposure data collection and collation. There is also a geographical element to the information in this module that requires capturing, as regional construction practices and building code enforcement will typically vary across a country.

Outputs

The final component, the loss module, is where the financial calculations are performed and rely on the process and outputs of the previous three modules. Conceptually, the first part of the hazard module describes the occurrence of an event with an annual rate of occurrence while the second part of the hazard module calculates the local intensity of the event for every asset under study (i.e., all the assets in the exposure module). The vulnerability module generates damage estimates based on the local intensity of the hazard and the characteristics of the assets at risk, which are translated into economic loss (e.g., 10% damage to a property with a US $100,000 replacement cost would equate to an economic loss of US $10,000). In order to calculate the total loss for a single event, then the aggregate loss from all of the assets at risk is taken. Once this process is undertaken for all of the events in the stochastic event catalog, the result is a table of event-by-event losses known as an Event Loss Table (ELT).

The ELT contains, for every event that causes damage, the annual rate of occurrence, total mean loss and related uncertainty parameters. By combining the frequency and severity of the losses in the entire stochastic event catalog, probabilistic catastrophe models are able to calculate the distribution of losses related to all of the possible events. Two common outputs of catastrophe models are Average Annual Loss (AAL) and Probable Maximum Losses (PML). The AAL is simply the sum product of all of the event annual frequencies and expected losses, and represents the expected annual economic loss from the modeled portfolio of assets exposed to the natural perils represented by the hazard module.

PMLs represent the annual chance that losses from the portfolio of assets being analyzed could exceed a given threshold. This metric can also be referred to in terms of return periods – for instance if there is an annual likelihood of 0.5% that a portfolio of risks could exceed US $100 million loss, this is the same as saying that, on average, a loss of US $100 million or greater is expected to occur once every 200 years. PMLs are derived from the production of Exceedence Probability (EP) curves by catastrophe models.

Probabilistic catastrophe model output can be of use to decision makers because it provides insight into the sizes of potential economic impacts across a range of timeframes. AALs and short return period PMLs (e.g., 5 year return period) can provide information on the likely impacts of relatively small, frequent natural events; while long return period PMLs (e.g., 200 years) can inform as to the likely economic consequences of low-frequency, high severity catastrophes. Such metrics have been used for the quantitative evaluation of potential disaster risk reduction (DRR) strategies (e.g., Michel-Kerjan et al., 2012), but their application in aiding the design and evaluation of SDRFI strategies has been somewhat limited.

While probabilistic catastrophe models are routinely used to represent the likely economic impacts of natural catastrophes, apart from the considerations related to the accuracy to which a computer model can represent physical work interactions, there are many potential limitations in their use. While it is commonplace to focus on what the models *can* do, their use in developing and evaluating SDRFI strategies should also include a robust understanding of what they *cannot* do. For instance, not all of the perils that could impact a country may be modeled, there may be secondary perils (e.g., tsunamis following earthquakes) that may not be captured in a particular model, or there may be specific elements (e.g., energy assets) not adequately represented.

Government use of probabilistic catastrophe models to inform sovereign disaster risk financing decision making

Probabilistic catastrophe models, as used by the international (re)insurance community, rely on outputs which represent *direct losses* resulting from the impact of natural perils. For governments, *indirect losses* must also be considered, given their impacts at a macro-level.

Direct losses are derived from the actual physical damage to building structures, their contents and the subsequent time-dependent interruptions (e.g., commercial business interruption). Indirect economic impacts typically include job losses, economic slowdown, decreases in tourism, and reduction in public revenues. While some work has been done on the macroeconomic impacts of natural catastrophes (e.g., Rose, 2007), there has been limited progress on applying this to governments. Recent initiatives have attempted to link estimates of government emergency loss requirements to direct physical damage estimates (e.g., see the Pacific Catastrophe Risk Assessment and Financing Initiative –PCRAFI–).

Since 1996 and the creation of its National Fund for Natural Disasters (Fondo Nacional de Desastres Naturales, FONDEN), the Mexican government has sought to implement an innovative sovereign disaster risk financing and insurance strategy, relying on a blend of risk-retention and risk-transfer instruments. A core part of this initiative is a probabilistic catastrophe risk assessment platform developed to estimate the government's contingent liability called R-FONDEN. The model takes as input a detailed exposure database (including details of buildings, roads, and other public assets) and produces as outputs risk metrics including AAL and PMLs. This model is currently used by the Ministry of Finance, in combination with actuarial analysis of historic loss data, to monitor the disaster risk exposure of FONDEN's portfolio and to design disaster risk transfer strategies. One example of the value of R-FONDEN in the SDRFI decision-making process was in helping to inform the design of the second catastrophe bond issued to protect FONDEN from earthquake and hurricane risk in Mexico (MultiCat 2009 and later MultiCat 2012 with an even larger coverage area).

In order for the SDRFI evaluation process to be undertaken in a consistent way across territories, it requires consistent inputs (probabilistic risk modeling output, as defined earlier) – therefore it is imperative that all four components of a model be developed and applied for this purpose. While there are insights that decision makers can gain from the information inherent in an exposure database or hazard catalog in isolation, these would not provide the appropriate inputs into the SDRFI decision-making process as outlined in this paper. This potentially poses challenges to its application in countries where there is limited information available to inform one or more of the risk model components; however this paper recommends that some effort must be applied to bridge these potential knowledge gaps. By way of example, in the case of a national exposure database containing individual geo-referenced assets and their associated physical and economic characteristics not being available, efforts should be made to develop a proxy-based alternative, perhaps at a coarser resolution – but nonetheless its existence would allow the production of preliminary risk modeling outputs.

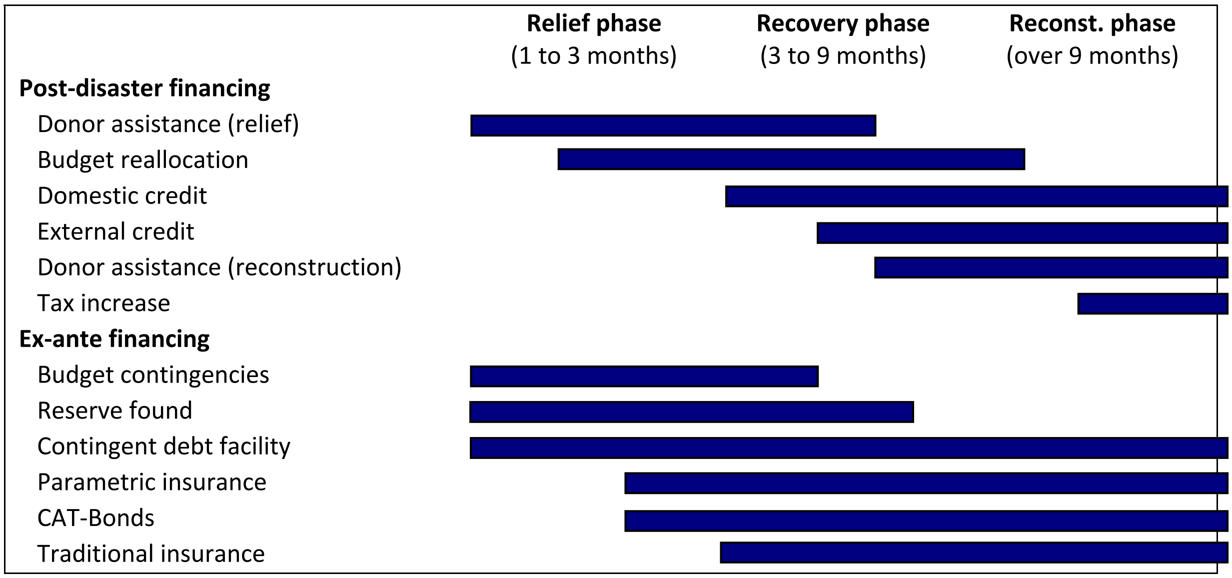
2. Sovereign Disaster Risk Financing and Insurance (SDRFI)

Instrumentation

Governments have a range of sources of financing available following the occurrence of a severe natural disaster. Typically these financing sources are categorized as either ex-post or ex-ante instruments. In the case of ex-post financing the instruments are not planned in advance and include budget reallocations, domestic credit, external credit, tax increases, and donor assistance. On the other hand, ex-ante funding instruments do require advance planning and include reserve funds, budget contingencies, contingent debt facilities, and risk-transfer mechanisms. The latter allow risk to be passed to external third parties such as national and international (re)insurance companies or the international capital markets community, through mechanisms such as traditional (re)insurance and alternative risk transfer (ART) products such as catastrophe (CAT) bonds (see Caballero, 2003; Freeman et al., 2003; Gurenko and Lester, 2004; and Hoffman and Brukoff, 2006).

Figure 1 shows the different types of financing instruments that can be used by governments to access funds to deal with disasters, and their utilization time horizon.

Figure 1: Sources of disaster financing.



Source: Ghesquiere and Mahul, 2010.

Strategy

Sovereign disaster risk financing and insurance strategies can help countries manage the budget volatility associated with natural disasters and should be guided by three main steps: (i) identification and assessment of the contingent liabilities associated with disasters; (ii) improving the post-disaster budget response capacity of the state; and (iii) reducing the long-term financial exposure of the state (for more details see World Bank and G20, 2013).

The two key factors that must be considered within an effective disaster risk strategy are the cost and timing of the available instruments. Immediately following a disaster a government will not require funding for the entire recovery and reconstruction program; although resources will be needed to support relief operations, most of the funds will not be required until the reconstruction programs commence – often several months after a disaster.

A number of governments have successfully implemented sovereign disaster risk financing strategies based on a combination of ex-ante and ex-post financing instruments. Typically, governments adopt a layered, bottom-up approach (Ghesquiere and Mahul 2010) which involves combining risk-retention and risk transfer instruments such that:

- Low-risk layers (frequent, low losses) are financed by a combination of risk-retention instruments such as reserve funds and contingency budgets;
- Intermediate-risk layers (less frequent, medium losses) are financed via budget reallocation and contingent credit (risk retention instruments);
- High-risk layers (infrequent, severe losses) are financed by a combination of risk-retention and risk-transfer instruments.

As a complement to these concepts, section 4 of this paper puts forward a decision making framework for SDRFI that aims at strengthening the decision process by using a formal model for analysis and communication, and at the same time getting the most value from probabilistic catastrophe risk models.

3. The Challenge of Appraising SDRFI Instruments

Deciding on sovereign disaster risk financial instruments requires consideration of the different types of disasters the country faces and the variety of their consequences on people, businesses, infrastructure, economic development and fiscal viability, among other possible impacts from natural disasters. Also, these decisions have to be made with uncertainty on the occurrence and magnitude of natural events, and uncertainty about the impact of those events on multiple constituencies and physical assets. Altogether, choosing the best SDRFI instruments to put in place is a challenging task. Probabilistic catastrophe risk models are valuable tools for appraising alternative SDRFI instruments: they provide a coherent framework for exploring the impacts on economy and society of the interplay of government's financial actions and uncertain natural phenomena.

a. The multiple dimensions of disaster risks

A state preparing for natural disasters faces a multidimensional problem that includes: the many aspects of severe natural phenomena, the range of their effects on society, economy and the environment, the multiple actions that government and society can carry out for prevention and remediation of natural disasters, the assortment of financial instruments that can be used to fund relief, recovery and reconstruction and, finally, the uncertainty about almost all elements mentioned above. Let us comment briefly on each of those dimensions of disaster risks.

A wide range of natural phenomena can have disastrous consequences for people, infrastructure, the environment and economic development; they include floods, earthquakes, hurricanes, droughts, snow storms and many others. These natural phenomena have very different origins, periodicity, duration and intensity, and also particular manifestations in countries or regions. The effects of some of them are felt immediately (e.g., earthquakes) and for others it may take years to felt the worst effects (e.g., droughts).

In terms of consequences, natural disasters may hurt people, damage infrastructure, destroy livelihoods, damp economic and social development, and harm the environment, in many different degrees. Planning how to respond to such a wide range of damaging consequences is an important and complex challenge.

Policy alternatives on the face of disaster risk can include both preventive and corrective measures. Preventive measures are usually more cost-effective than corrective ones (Mechler 2005), but more difficult to get approved. Setting the time horizon for decisions and choosing what to do and when to do it requires tough trade-offs.

Funding the programs for disaster risk management is a condition to be able to go from programs to action. There are a growing number of instruments for disaster risk financing (which by itself should be viewed as a positive development) but choosing between diverse financial instruments for retaining the risk, different instruments for transferring the risk or any combination of them, and for different time horizons, is a complex decision situation.

Uncertainty makes decisions about SDRFI particularly challenging. There is uncertainty on the occurrence, timing and intensity of the natural phenomena, its effect on infrastructure, the human toll of the disaster, the availability of required funds and the effectiveness of the disaster response efforts, to mention only a few of the most significant ones.

Appraising SDRFI instruments requires assessing costs, consequences and probabilities of uncertain events, and logically combining them to allow overall comparison between instruments; catastrophe risk models are fundamental tools for doing that.

b. The value of catastrophe risk models for deciding on SDRFI

Catastrophe risk models are designed to represent all of the elements mentioned above as well as their relationships. In particular, the use of probabilistic assessments for uncertain events makes these models a much better representation of reality than deterministic analyses.

Catastrophe risk models provide probabilistic valuation of costs and consequences, key inputs for any formal decision making process on SDRFI instruments, and make possible the probabilistic assessment of SDRFI instruments; this in turn enables the use of more sophisticated and useful analyses, e.g., formal quantification of risks, comparison of probability distribution of outcomes for different strategies, computation of the value of acquiring additional information about critical uncertain events.

For example, most developing countries do not have the conditions for applying a policy of risk neutrality (valuing each outcome proportionally to its impact, notwithstanding how extreme they are) for assessing investments on natural disasters and their outcomes: those countries cannot effectively diversify their risks or borrow enough to distribute losses between generations (Ghesquiere and Mahul 2010, p.2). This means that to properly assess the investment on SDRFI instruments and the undesirable outcomes they aim to mitigate, it is best to use a decision makers' risk tolerance (risk aversion) index that reflects the country's circumstances. A risk tolerance index can only be used in the context of probabilistic assessments like the ones catastrophe risk models provide.

Also, because in low-income countries "decision makers not only face fiscal constraints but also may lack adequate information on net economic and social benefits of DRR measures" (Michel-Kerjan et al. 2012, p.3), risk models, with their embedded knowledge of uncertain events and consequences, can help decision makers even when they have limited availability of technical expertise.

Identifying and quantifying uncertain events is a major challenge in appraising SDRFI instruments. Catastrophe risk models do not include all uncertain events and they do not have to include them; for risk models to be useful it is enough that they include the uncertain events with the highest impact; however, the level of impact depends on how much diverse outcomes are valued and therefore the impact level depends on the particular decision situation being analyzed. There should be a clear connection between the decision model and the catastrophe risk model.

Another challenge for building useful catastrophe risk models is to identify probabilistic dependence between uncertain events and, if granted, measure that dependence.

Some of the uncertainties modeled may be obvious, like the occurrence and severity of natural phenomena, while other may require a closer inspection to be identified, like the uncertainty on the time when specific resources will be available, and we may never be sure that all uncertainties have been identified and its importance assessed. However, there are so many catastrophe related uncertain events already identified, and in most cases they are so insufficiently taken care of that just properly using the catastrophe risk model and acting accordingly, would put most countries in a much safer and attractive situation. Nevertheless, when resources allow it, a thorough analysis may be granted to identify additional risks.

We expect that as the use of risk modeling techniques has helped significantly increase the resilience of the insurance industry (World Bank and G20 2013, p.30), the use of catastrophe risk models will continue to enhance the countries' ability to make better decisions and to better withstand extreme natural phenomena.

4. A Decision Making Framework for SDRFI

SDRFI instruments are a key component of disaster risk management: overcoming the effects of natural disasters often requires substantial financial resources and, in the case of developing countries, those requirements can even exceed their GDP (World Bank 2013, p.253). Available SDRFI instruments differ greatly in their cost, time to be available and maximum levels of financing: it is not easy to select the best set of financial instruments for responding to the natural risks a country faces, or even just put together a coherent strategy.

A decision model can be used to represent the overall decision situation and facilitate analysis and communication among stakeholders; an example of such model is presented in this section. Because the quality of a decision model derives from the process that led to its construction, a straightforward process is suggested for generating quality components for the decision model.

Finally, since catastrophe risk models play such an important role in appraisal of SDRFI instruments, it is worth tailoring them to facilitate the SDRFI decision process; some suggestions are presented at the end of this section.

a. SDRFI as a key element of disaster risk management

Responding to severe natural disasters requires financing, often at levels most developing countries find difficult to provide (Ghesquiere and Mahul 2010, p.3). Similarly, preparing for disaster, including preventive measures and organizational and logistic preparedness, requires significant financing.

Because the cost and availability of financing vary widely for different types of instruments (Ghesquiere and Mahul 2010, p.9), a good decision on what SDRFI instruments to use can make the difference between a feasible disaster risk management plan and one that cannot be afforded. Also, because the time to be able to make use of the funds and the maximum levels of financing vary considerable between financial instruments, the choice of SDRFI strategy strongly influences the opportunity and effectiveness of disaster response.

Notwithstanding its key importance, financial protection is only one component of a comprehensive disaster risk management strategy (Ghesquiere and Mahul 2010, p.2) and therefore the countries should also decide wisely on disaster prevention and response policies that complement (and are funded by) the financial instruments. A decision model can help in this undertaking.

b. Deciding on SDRFI instruments: A model and a process

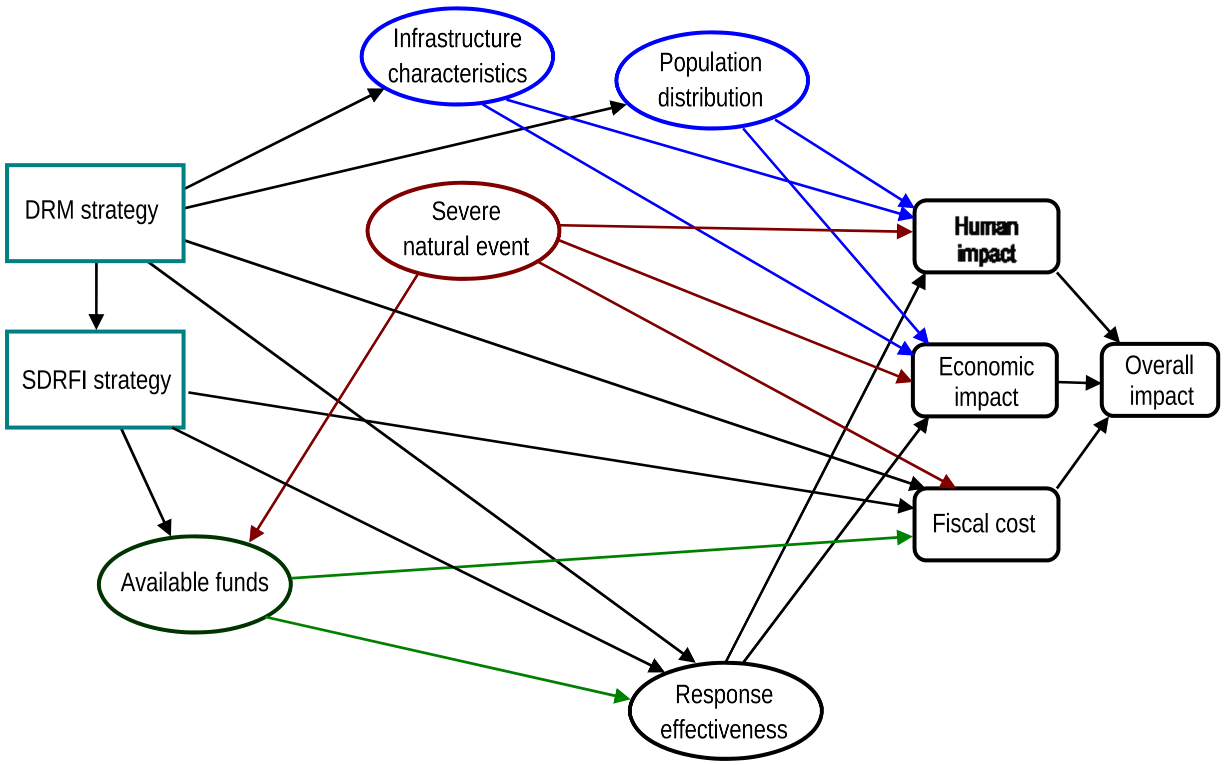
There are two linked sets of sovereign disaster response decisions: decisions on disaster risk management (DRM) and decisions on sovereign disaster risk financing and insurance (SDRFI) instruments; both can be represented using a decision model that also includes the objectives of the country and the uncertain events it faces.

The decision model can be an influence diagram (Howard and Matheson 2005). These diagrams give an overall view of the situation by showing the relationships between decisions, uncertain events and consequences. The influence diagram is a rigorous graphical representation of those relationships yet it is easy to understand without previous training.

As an illustration, let us consider the simplified influence diagram of Figure 2. The rectangles represent **decisions**, in this case on *DRM strategy* and on *SDRFI strategy*, and the arrows departing from them indicate the influence exerted through each decision on particular uncertain events and consequences.

The ovals in the diagram represent **uncertain events** with a probability distribution assigned to them; the arrows show that the *Infrastructure characteristics* and *Population distribution* at the time of a severe natural event are influenced by *DRM strategy*, and that in turn they influence (modify the probability distribution of) the *Human* impact and *Economic impact* of a *Severe natural event*. Similarly, it is shown that the uncertain *Available funds* for relief, recovery and reconstruction are influenced by the decisions on *SDRFI strategy* and, if the country has bought parametric insurance, the severity of the natural event will influence the amount of resources the country actually get hold of (this is represented by the red arrow pointing toward *Available funds*).

Figure 2. An example of decision model (an influence diagram) for sovereign disaster risk decisions.



Source: R. Ley-Borrás and D.J. Clarke.

In turn, the *Available funds* have an effect on *the Fiscal cost* for the country and the very important (but nevertheless uncertain) *Response effectiveness*: the ability of the government to help the population in distress and recover from direct government losses of infrastructure and revenue). The uncertain event *Response effectiveness* is also influenced by the *DRM strategy* because the strategy may include preventive actions than enhance the logistical and technical capabilities, among others, critical for effective response. This node is also influenced by *SDRFI strategy* because when a country contracts specific forms of insurance or re-insurance, it also commits to precise rules for loss adjustment methodology and funds spending, and that framework is believed to have a positive influence on post disaster response (Clarke 2013a, Dana and von Dahlen 2014, De Janvry et al. 2014). The diagram also shows that *Response effectiveness* has a direct influence on *Human impact* and *Economic impact*, expressed by arrows pointing to those nodes.

This influence diagram includes a *Severe natural event* uncertainty node that has no incoming arrows (because the occurrence of the event is not influenced by decisions) and its outgoing arrows show its impact on the three types of consequences being considered, as well as on the *Available funds* node (as mentioned). The magnitude of a disaster is a consequence of the severity of the natural event and of factors that the country can influence with its decisions: infrastructure characteristics, population distribution, available funds and response effectiveness.

In each specific situation the node *Severe natural event* will include the probability distribution for the full characterization (e.g., frequency, intensity, location) of earthquakes, hurricanes or other specific type of event, or the node will be replaced by a set of uncertainty nodes, each corresponding to a particular type of sever natural event (and we can even model the influences between those events).

The rounded rectangles (value nodes) represent **consequences** related to the objectives of the decision makers. The diagram shows that each consequence (*Human impact*, *Economic Impact* and *Fiscal cost*) is a function of the outcomes of all uncertain events that have arrows directed to the consequence, and also a function of the alternatives chosen in the decision nodes that have arrows directed to the consequence. The partial value nodes contribute to a global value node that represents the expected *Overall impact* for the country of each strategy.

Influence diagrams are very flexible and can include all the decisions, uncertain events and consequences that are deemed important for deciding on DRM and SDRFI. They can include as much detail as necessary; for example, subsets of the influence diagram can represent how residents will respond to insurance offers, how builders and home owner will react to fiscal stimulus for reinforcing buildings or how the speed of government reaction to a disaster affects the probability that epidemics or social unrest may start off.

Another advantage of influence diagrams is that analysts and decision makers can use them as a vehicle for gaining consensus on what should be "on the table" when deciding about disaster risks actions and financing instruments. Once the nodes and relationships of the influence diagram are defined, the probability values and consequences should be quantified (using probabilistic catastrophe risk models) and then the strategies can be evaluated using off-the-shelf computer programs for influence diagrams.

Using probabilistic risk models for assessment of SDRFI alternatives

For the SDRFI decisions represented in the influence diagram, catastrophe risk models provide the essential valuation of uncertain variables and consequences, and they can do that with great detail for each type of severe natural phenomena, specific geographic area and vulnerability of infrastructure and residents: a most valuable contribution.

In order to assess the value of SDRFI instruments for a particular country, it is important to identify explicitly the government policies that will be assumed to be in place: the worth provided by a SDRFI instrument or strategy will likely be different for different sets of government policies.

It is also important to be explicit about government policies because otherwise the underlying assumption may be that those policies are the ones that work best with the SDRFI alternatives being evaluated, but that may not be the case. We should be aware that unstated and unrecognized assumptions, likely play a role in affecting judgments in many important policy decisions (Keeney 2008, p.5).

In addition, probabilistic risk models allow us to explore the interactions (synergetic or otherwise) of the financial and policy decisions; we can do that by assessing the value of SDRFI instruments or strategies for different sets of government policies.

Building coherent SDRFI strategies

The decision node *SDRFI strategy* in the influence diagram means deciding among a set of sovereign disaster risk financing strategies, each set consisting of a number of financial instruments to be used by the country. Each strategy may include instruments for *risk retention for high frequency events* (reserves, calamity funds), *risk retention for medium frequency events* (emergency loans, contingency credits (CAT-DDO), budget reallocations), *risk retention for low frequency events* (tax increases, domestic or external credit) and *risk transfer for low frequency events* (catastrophe bonds, parametric insurance, traditional insurance) (Ghesquiere and Mahul 2010, p.20). Even if not all the instruments are available for a particular country, the number of possible combinations of instruments can be enormous. It may be impractical to enumerate all combinations of instruments, and much more to evaluate them.

To design a small number of coherent strategies that are both feasible and promising, we can use a *strategy generation table* (Howard 1988). This tool consists of a table with columns labeled with the name of a financial instrument that is feasible to use for a specific country. The body of the column includes possible levels of use of the instrument, say from making it a key part of the strategy to not using it at all, or by different ways of using the instrument. A strategy is formed by selecting a level or form of use from each column.

An illustration of a partial strategy generation table is shown in Figure 3; it includes only financial instruments for responding to low frequency events but, nevertheless, the six types of instruments considered, with only three or four alternatives each, can generate 3,072 combinations. Because not every combination is a reasonable strategy, it is valuable to use the table for designing coherent strategies that are significantly different from each other.

Figure 3. An illustration of a partial *strategy generation table*. Two strategies are shown.

	Risk Retention for low frequency events			***Risk Transfer for low frequency events***		
Strategy theme	Tax increase	Domestic credit	External credit	Traditional insurance	Parametric insurance	Catastrophe bonds
Risk Retention Emphasis	Consumer tax	Up to Z amount	Contingent credit	Flood insurance	Flood insurance	Wide earthquake bond
	Special purpose tax	Up to Y amount	Line of credit	Earthquake insurance	Earthquake insurance	Pilot earthquake bond
Risk Transfer Emphasis	Mix of several taxes	Up to X amount	Conventional credit	Flood and Earthquake insurance	Flood and Earthquake insurance	No catastrophe bond
	No tax increase	No domestic credit	No external credit	No traditional insurance	No parametric insurance	

Source: R. Ley-Borrás

Two strategies are identified in the table; one named *Risk Retention Emphasis* that concentrates on domestic revenues and traditional insurance, and the other named *Risk Transfer Emphasis* that relies mainly on external credit, parametric insurance and the emission of catastrophe bonds. Other strategies can be defined so that the country has a set of strategies that span the range of possibilities but includes a small enough number of strategies for discussion and appraisal. Once the strategies are defined, risk and decision models will be used to assess the value of each strategy.

A strategy generation table can be a tool for *catastrophe risk layering* (Ghesquiere and Mahul 2010 p.17); it simplifies the selection of instruments for risk retention and risk transfer for disasters of different frequency and severity, as well as for financing preventive measures.

A process for designing, understanding and owning SDRFI decisions

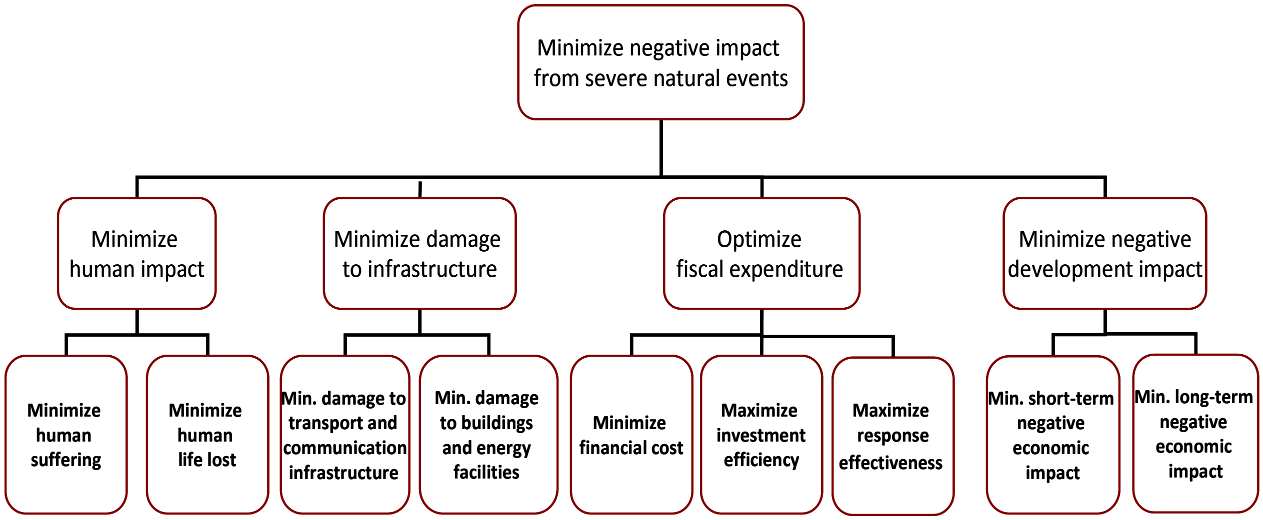
A decision model is only as good (valid) as the process that led to its construction. If some objectives are missing, alternatives lack creativity or uncertain events are ill-defined, no model or computation will lead to a high quality decision. Also, good decisions are not only a matter of content: the right participation is a key component. If decision makers actively participate in a well structure decision process, it is more likely that they will "own" the decision choice and that it will be successfully implemented. A similar effect has been observed on the crisis simulation exercise promoted by the World Bank where the ownership of the exercise by the participating public representatives was crucial for the success of the exercise (World Bank 2013, p.209).

To achieve quality of content and quality of participation, it is suggested to use a process based on the *Integral Decision Analysis* method (Ley-Borrás 2009) that includes the following interlocked steps:

1. **Define the decision scope**. Ideally an SDRFI decision would include financial protection for all types of disaster risks in the entire country, but if currently there is not enough time or resources for designing and implementing a comprehensive SDRFI strategy, a wise choice of a subset of geographical locations and/or risks may be the right decision scope to work within. Criteria for choosing the best decision scope considering the priorities and circumstances of the country are given in Ley-Borrás (2014).

2. **Structure fundamental objectives**. It is very important to identify all the country's objectives related to sovereign disaster risk financing (in the selected decision scope), but there is value in going beyond that and building a formal *structure (or hierarchy) of objectives*. Keeney (1992) shows how objectives relate to each other; high level decision makers should participate in that undertaking. An example of a structure of objectives is presented in Figure 4.

Figure 4. An example of a structure of objectives for risk reduction and recovery.



Source: R. Ley-Borrás

The structure shows at the top a global fundamental objective: *Minimize negative impact from severe natural events*. This objective is explained by dividing it into four fundamental objectives: *Minimize human impact*, *Minimize damage to infrastructure*, *Optimize fiscal expenditure* and *Minimize negative development impact*. Each of these objectives is further explained to be more precise, for example, *Optimize fiscal expenditure* is shown being integrated by the objectives: *Minimize financial cost*, *Maximize investment efficiency* and *Maximize response effectiveness*. There is no predefined level of detail the structure of objectives must have: we should only increase detail to add clarity.

3. **Generate a rich set of alternatives and strategies**. The World Bank has developed and helped develop a number of innovative financial instruments (Ghesquiere and Mahul 2010) that can be used directly or used as a starting point for designing new ones. These financial instruments can be part of strategies that aim at achieving the country's fundamental objectives.

4. **Identify and measure key uncertain events**. In the context of protecting the country against natural disasters, identifying and measuring the risks from natural events is essential, but there are also "human made" events that can be as central to the consequences of a disaster as the natural event, and the risks from these other events should also be identified and measured.

These steps will provide quality elements to be modeled with an influence diagram and, together with the appraisal of strategies using probabilistic catastrophe risk models, will lead to good decisions on SDRFI instruments. The four steps are only sketched here; there is a rich set of techniques for performing the steps professionally and, while doing so, getting clarity and value for the decision makers.

c. Building catastrophe risk models that facilitate SDRFI decision making

Ideally, catastrophe risk models would include all (and only) the factors that can make a material difference in the choice of SDRFI instruments and other disaster risk management decisions. That is not an easy task and even if it is encouraging that catastrophe risk models keep growing in sophistication (World Bank and G20, p.261), more could be done.

To better serve the purpose of making good decisions on SDRFI instruments, it is suggested to build catastrophe risk models that:

1. **Include metrics for all fundamental objectives**. Financial and infrastructure cost are obvious candidates to be included in the models, but also human costs (e.g., hunger, illness, death, livelihood loss) and development cost (i.e., stagnant or negative economic development), and any other consequence associated with the specified fundamental objectives, should be part of the model: those are the issues the decision makers care about.

2. **Allow for the simultaneous appraisal of the instruments that form a strategy**. Each of the selected instruments may address different types of risks, different geographical locations and different time horizons, but they are interrelated and it is best to appraise them together and get a probability distribution of the consequences of the strategy, not only of its components.

3. **Include uncertainty about amount and availability time of post-disaster funds**. An advantage of ex-ante financial instruments is faster and less uncertain availability of funds; that should be reflected in the risk models.

4. **Include change over time of population at risk**. This risk should be computed for different sets of policy actions that can modify natural population trends. Population pressure by itself will likely add density in areas of high risk (e.g., near rivers, beaches and in the outskirts of cities) and so add risk exposure over time. Effective policies that move population out of high risk areas would have the opposite effect.

5. **Allow sensitivity analysis for assessing the robustness of the choice**. Link the risk models to the decision model being used to determine the range of values of an uncertain variable where the selected SDRFI strategy is still the optimal choice.

6. **Include administrative and legal preparedness**. Ghesquiere and Mahul (2010 p.12) argue that "administrative and legal dimension of risk financing should be at the core of any risk financing strategy" and it certainly is a factor when computing the probability of the funds being efficiently and effectively spent after a disaster.

7. **Include implicit and explicit contingent liabilities**. Take into consideration disaster costs the government will be expected to pay for as a legal obligation as well as for political and social considerations (Ghesquiere and Mahul 2010, p.13).

8. **Take into account indirect consequences**. Job losses, reduction in public revenue and other consequences are harder to quantify but can have important negative impacts on development achievements and poverty reduction efforts (World Bank and G20, p.13).

Some of the items in this list may be redundant if a good job is done in defining a complete structure of objectives and designing catastrophe risk models that take into consideration all the consequences related to the defined fundamental objectives.

Including the suggested elements and increasing the capabilities of catastrophe risk models will contribute to better informed decision making and likely to a stronger endorsement of the use of ex-ante financial instruments and other preventive policies.

Conclusions

Making good decisions on disaster risk management (DRM) strategy and sovereign disaster risk financing and insurance (SDRFI) strategy increases the probability that the countries maximize the value of their investments on disaster risk mitigation, minimize the negative impact from severe natural phenomena and, in general, achieve the objectives they set for disaster risk response. The significance of sovereign response to disaster risks and the variety and growing sophistication of SDRFI instruments makes the task of building better decision and risk models even more important.

Probabilistic catastrophe risk models are a fundamental element of the process of deciding on sovereign DRFI instruments. However, for a catastrophe risk model to be useful it is required that each of its components (hazard module, exposure module, vulnerability module and loss module) be developed. Even if that is done at a rough resolution, it would allow the production of risk modeling outputs; and those rough probability distributions will be valuable inputs for the decision model.

Deciding on sovereign DRFI instruments is a challenging undertaking, particularly for developing countries that do not have the same level of resources available as advanced economies (World Bank and G20 2013 p.9); it is also a responsibility with great impact on the economy and society. Using a clear and logical SDRFI decision process can help governments to better fulfill that responsibility.

Decision makers can use a decision model (e.g., an influence diagram) to have an overall image of what they can do, what uncertain events the country faces, what are the possible consequences of their actions and what are the relationships between these three elements. In addition, influence diagrams can facilitate productive participation and consensus building.

As part of that process, decision makers can design coherent SDRFI strategies and use probabilistic catastrophe risk model to better understand the consequences of each strategy and make a choice with the potential to create the most value for their country.

Better catastrophe risk models and a better decision process for SDRFI can get us closer to the higher objective of making disaster risk financing and insurance a cost-effective way of reducing poverty and improving valued development outcomes (Clarke 2013a).

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