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Financial instruments for disaster risk management and climate change adaptation

Joanne Linnerooth-Bayer · Stefan Hochrainer-Stigler

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Abstract The International Panel on Climate Change (IPCC) has called for a new balance between reducing the risks from climate extremes and transferring them (for example, through insurance) as means for effectively preparing for and managing disaster impacts in a changing climate. This paper elaborates on this balance with an overview of disaster risk financing mechanisms and how they contribute to disaster risk reduction and climate change adaptation in developing countries. We suggest a risk management approach that targets risk reduction and risk financing to different layers of risk, including a layer that represents a possible limit to adaptation. By reviewing traditional post-disaster financial arrangements, such as government compensation, and non-traditional pre-disaster instruments, such as index-based insurance, we show how risk financing can complement and stimulate risk reduction. We discuss the benefits of financial instruments, including the provision of post-disaster finances for recovery and pre-disaster security necessary for climate adaptation and poverty reduction. These benefits come at a cost, and we discuss the risks, challenges, and future prospects of risk financing in developing countries.

1 Introduction

The International Panel on Climate Change (IPCC) in its recent report, "Managing the risks of extreme events and disaster to advance climate change adaptation" (SREX) married the concepts of *disaster risk management* (DRM) and *climate change adaptation* (CCA) by emphasizing that both focus on lessening exposure and vulnerability and enhancing resilience to the potential adverse impacts of climate extremes. As one approach among many others for managing disaster risks, scientists as well as practitioners agree that insurance and other financial instruments can play an important role within CCA (IPCC 2012, Fig. 2). The recent UNFCCC "loss and damage" work program (United Nations Framework Convention on

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J. Linnerooth-Bayer · S. Hochrainer-Stigler (✉)
IIASA—International Institute for Applied Systems Analysis, Schlossplatz 1, 2361 Laxenburg, Austria
e-mail: hochrain@iiasa.ac.at

J. Linnerooth-Bayer
e-mail: bayer@iiasa.ac.at

Climate Change UNFCCC 2013) also emphasizes the role of risk sharing and transfer for addressing climate change impacts particularly in vulnerable developing countries (Warner and Zakieldeen 2012).

Despite general recognition that risk financing instruments have a role in CCA, there are concerns about striking the right balance between insurance and other financing instruments with needed efforts to reduce loss and damage. As reported in SREX (Cutter et al. 2012) risk sharing and transfer can be beneficial for adapting to climate change, but insurance and other financial instruments can dis-incentivize efforts to reduce risk, what is known as moral hazard. There is also a commonly held perception that risk sharing and transfer instruments serve to redistribute loss and damage, but not reduce it, thus limiting their role in CCA. Partly because of these concerns, the SREX report calls for a new balance between measures to reduce risk, transfer risk (e.g. through insurance) and effectively prepare for and manage disaster impacts in a changing climate (Mitchell and van Aalst 2011; Murray et al. 2012).

This paper extends the SREX discussion by elaborating on the balance between disaster risk financing and risk reduction, as well as the limits of risk financing as an adaptation measure. As we will demonstrate throughout our discussion, well designed financial instruments can reduce loss and damage as well as its societal burden by providing incentives for preventive behaviour (avoiding moral hazard) and safety nets to share the burden. These contributions to CCA, however, should be viewed in relation to the costs, risks and limits of financing instruments.

As a way of conceptualizing the contribution of DRM—risk reduction and risk financing—to CCA, we propose a framework that targets DRM to distinct probabilistic risk layers, including a layer "beyond adaptation" (Dow et al. 2013). A probabilistic framing for public risk acceptance was also suggested in the SREX report (Lal et al. 2012, Fig. 6-3). Our aim is to highlight the importance of the probabilistic risk-layer framing by differentiating between frequent, low-consequence events and rare, catastrophic events in designing an appropriate DRM response. This more nuanced view of disaster risk management can serve to illustrate the differentiated and complementary roles of disaster risk reduction and financing, and their contribution to CCA.

At the outset, it is important to note that risk financing (as part of DRM) is not fully synonymous with CCA (Asian Disaster Preparedness 2013). Insurance and other pre-disaster risk financing instruments are not appropriate for slow-onset climate impacts, such as desertification or sea level rise. Moreover, climate attribution complicates the DRM-CCA relationship. The observed long-term upward trend in weather-related disaster losses has been attributed almost entirely to changes in exposed assets and population. Yet, according to the SREX report, a role for climate change has not been excluded, and it is projected with high confidence that climate change will play an increasingly significant role with respect to disaster losses and damages. This means that current DRM activities, especially long-term investments and institutional arrangements (e.g., financial services) should take account of climate change, as well as limits to adaptation.

In the next section we introduce the risk-layer framework before turning in sections three and four to examining traditional post- and pre-disaster financing instruments. We discuss how these instruments target low-, medium- and high-risk layers. In section five, we present evidence on the benefits, costs and risks of these instruments, and section six discusses the limits of risk financing as an adaptation instrument. We conclude in section seven.

2 A risk-layer framework

2.1 Differentiating DRM by risk layers

As illustrated in Fig. 1, risk-financing and risk-reduction strategies can be targeted to different layers of risk in terms of their severity (Cummins and Mahul 2008; ERN-AL 2011; Hochrainer-Stigler and Pflug 2012; Benson et al. 2012). Particularly for structural investments, risk-reduction measures may be largely appropriate for low-loss events that occur frequently (low-layer risk), while risk sharing and transfer addresses risks, often at higher levels, that cannot be cost effectively reduced. In highly vulnerable countries, very low-probability, high-consequence (high-level) risks are typically absorbed by governments and donor organizations.

There is some limited evidence that structural risk reduction investments for low-level risks demonstrate higher benefit-cost ratios than for middle-and high-layer risks. Benefit-cost analyses (BCAs) carried out on structural risk reduction investments in the developing world show the potential for high returns for frequent events (Mechler 2005; Michel-Kerjan et al. 2013; Mechler 2012). However, with only some exceptions (Michel-Kerjan et al. 2013; ERN-AL 2011) these studies do not make use of probabilistic methods and thus do not differentiate between risk layers. Those analyses that base their calculations on probabilities typically estimate benefits based on the average annual loss, thus again not taking account of risk layer thresholds.

There is typically a point where the reduction of losses (by reducing the hazard, exposure and/or vulnerability) can become too costly or not feasible. This is the layer for which traditional or innovative financing instruments can help to lessen the burden on the victims

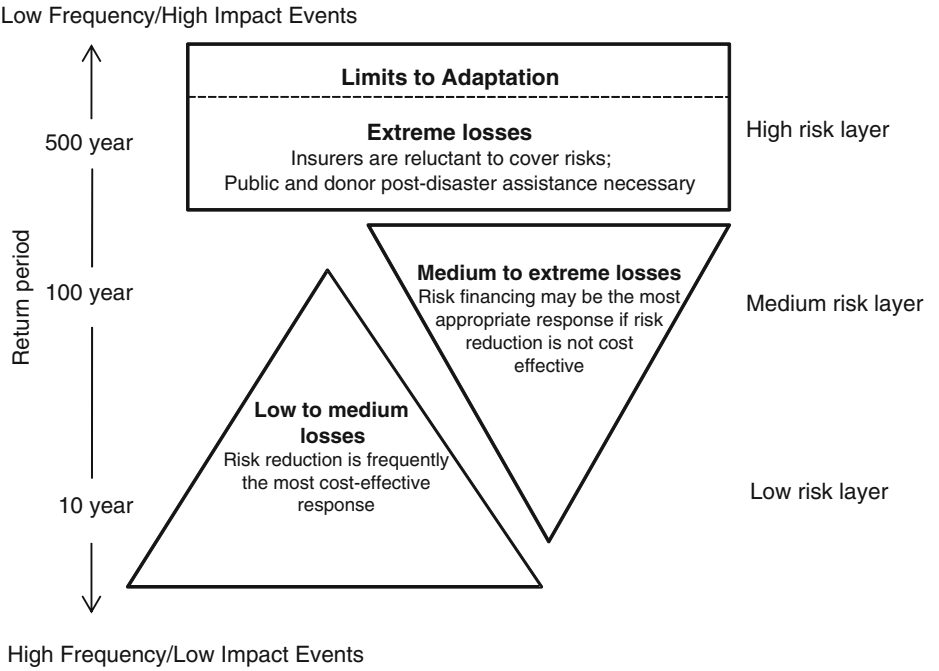

Fig. 1 Low-, medium- and high-risk layers. *Source*: Based on Mechler et al. (2009)

(World Bank 2007; Ghesquiere and Mahul 2010; Global Facility for Disaster Reduction and Recovery GFDRR 2013).

We see the potential for differentiating risk most acutely for low-frequency, catastrophic or extreme risks (high-risk layer), especially given the potential for climate change to shift risks toward more frequent catastrophic events. For the high-risk layer, public and donor support or publicly backed insurance are often the preferred options since insurers are often reluctant to cover catastrophic events. The potential limits on individual, government and donor financing mean that a risk layer "beyond adaptation" cannot be ruled out, especially for highly vulnerable countries facing more extreme losses. Even today, many highly exposed developing countries cannot finance their risks at the higher layers (United Nations Office for Disaster Risk Reduction UNISDR 2013). Furthermore, most if not all countries are far from reaching their cost-effective loss prevention potential, and risk financing for this layer can provide the appropriate incentives.

2.2 Differentiating risk financing by risk layers

The SREX report provides an overview of the portfolio of risk sharing and transfer instruments relevant for developing countries (Murray et al. 2012). The portfolio is summarized in Table 1, and includes traditional, innovative and publicly supported financial mechanisms as they are used by (1) households and small and medium enterprises (SMEs), (2) microfinance institutions and donor organizations, and (3) governments. Table 1 also indicates the risk layer that the different instruments primarily address.

As we see from this table, mechanisms to finance recovery range from government and humanitarian aid, savings and credit, informal risk sharing, to insurance and alternative risk-transfer instruments. In what follows, we review this portfolio of risk financing approaches as they target high-, medium- and low-risk layers (see also Ghesquiere and Mahul (2010) who distinguish instruments according to disaster phases). We also discuss how they contribute to reducing disaster loss and damage, and thus to CCA.

3 Traditional risk financing mechanisms

3.1 Solidarity

Especially for catastrophic events (high-risk layer), disaster victims in vulnerable countries typically depend on their governments and donor assistance to provide relief. Even in wealthy countries, private insurers are reluctant to cover very high-layer losses unless they can rely on public backup in the form of government guarantees. In small and highly exposed countries, governments themselves can face severe post-disaster fiscal constraints limiting their capacity to backup private insurers or even cover their post-disaster expenses on restoring public infrastructure. International assistance may come to their rescue, but voluntary donations from the international community of individuals, NGOs and governments have averaged only about 3 % of direct economic losses in developing countries, although significantly higher for widely publicized events (Becerra et al. 2012).

3.2 Savings and credit

Traditional risk-financing mechanisms include pre-disaster savings and post-disaster credit, which for the poor can take the form of stockpiles of food, grains, seeds and fungible assets.

Table 1 Examples of traditional and innovative financial mechanisms for managing risks at different scales

Instruments (typically most appropriate risk layer)	Households/SMEs/farms	Financial institutions/donor organizations	Governments
Traditional risk financing mechanisms			
Solidarity (High-risk layer)	Government assistance; humanitarian aid	Government guarantees/bail outs	Bi-lateral and multi-lateral assistance; EU solidarity fund
Savings and credit (Medium-risk layer)	Savings; micro-savings; micro-credit; fungible assets; food storage; money lenders	Emergency liquidity funds	Reserve funds; post-disaster credit;
Informal risk sharing (Low-risk layer)	Kinship and other mutual arrangements; remittances		Diversions from other budgeted programs
Traditional insurance instruments (Medium-risk layer)	Property insurance; crop insurance; national hazard insurance	Re-insurance	
New innovative risk financing mechanisms			
Novel insurance—related instruments (Medium to high-risk layers)	Index-based crop and livestock insurance; weather hedges	Catastrophe bonds	Sovereign risk financing; contingent credit; regional catastrophe insurance pools

Adapted from Linnerooth-Bayer et al. 2010

This may be adequate for not easily reducible losses that are in the medium-layer range, but can be insufficient for long-enduring catastrophic events. While micro-savings are costly to administer, there are wide benefits. A study in the Philippines showed that access to savings products increased women's economic empowerment, including decision-making power over purchases, family planning, and children's education (Ashraf et al. 2006). Despite strides in enabling formal savings, the poor spend their limited income primarily on consumption and livelihood investments, and many still lack access to safe, formal deposit services (Hochrainer-Stigler et al. 2012). Savings are increasingly channeled through micro-finance institutions (MFIs) and banks, which make them less appropriate for high-layer risks since MFIs, themselves, can be directly impacted by large catastrophes resulting in insufficient liquidity to handle a run on their accounts as occurred during the 1998 floods in Bangladesh (Kull 2006).

Lacking savings, households and businesses typically borrow to meet their needs in the aftermath of a disaster, and the provision of small loans to the poor through micro-finance institutions has become mainstream. Although high compared to rates charged in wealthy countries, the 18–60 % interest charged on micro-credit is generally far below the 120–300 % often charged by local moneylenders (Grameen Foundation 2008). For highly catastrophic events (high-layer risk) post-disaster micro-credit can also fall short as post-disaster demand challenges the liquidity of micro-credit organizations. To provide needed and immediate post-disaster liquidity, development organizations and private investors in Latin America have created a novel intermediary institution, the Emergency Liquidity Facility.

3.3 Informal risk sharing

When savings, credit and government support are not forthcoming, at-risk individuals in developing countries traditionally rely on financial arrangements that involve reciprocal exchange, kinship ties and community self-help. Women access post-disaster capital by joining informal risk-hedging schemes, becoming clients of micro-finance institutions, or depending on reciprocal social relationships (Cox and Fafchamps 2006). Again, these arrangements can be inappropriate for high-layer, covariate risks, where whole families and regions may be affected, thus reducing the potential for informal risk sharing.

Alternatively, for low- and medium-layer risks, the widespread use of informal risk-sharing arrangements can be effective. According to multiple surveys about 40 % of households in low-and lower-middle income countries are involved in private transfers in a given year (Davies 2007). The most common form of assistance are remittances, which at well over USD 400 billion in 2012, surpass foreign direct investment and development assistance combined (World Bank 2012). Mohapatra et al. (2009) cite examples from Ethiopia, showing that households receiving international remittances are less likely to sell productive assets as a response to disasters. There is also a fledgling insurance market for migrants, covering disruptions in flows of remittances (e.g., to loss of jobs or death of the migrant) faced by migrants' families in their country of origins (Powers et al. 2011). Remittances are simple in concept, yet survey results show that the associated costs of an average transfer can vary between 2.5 and 40 % (Inter-American Development Bank 2007), which has been reduced by efforts to make financial services accessible to the poor, including mobile phone banking (International Fund for Agricultural Development 2010).

3.4 Insurance mechanisms

Insurance, in contrast to savings, pools risks across communities and regions and in so doing helps households survive shocks to their livelihoods and assets. Insurance can have added benefits, such as enabling productive investments and thus helping high-risk agents escape disaster-induced poverty traps (Barnett et al. 2008). Insurance also has advantages to donors since by providing support for these instruments they can ultimately reduce their post-disaster liabilities (Linnerooth-Bayer et al. 2005). Finally, and importantly, insurance instruments can be directly linked to reducing risks and losses if premiums reward investments in risk reduction. However, insurance is costly, often far above expected losses, and in the absence of donor support, it can be ill-affordable for the poor. This is particularly the case of high-level risks since insurers require large and expensive capital backup or reinsurance.

4 Innovative risk financing mechanisms

As discussed, traditional risk financing mechanisms while beneficial in many ways fall short on important dimensions, especially for high-layer risks. In the event of a major disaster, households may be forced to sell productive assets at very low prices; inflation may greatly reduce the value of savings; and governments, although more appropriate financiers of high-level risks, rarely cover more than a small percentage of losses in developing countries. The resulting liquidity deficit can greatly aggravate poverty by forcing families to give up assets essential for their livelihoods, withdraw children from school and even migrate to other (sometimes riskier) locations, although it seems unlikely that micro-insurance, particularly with low average claims, could stem disaster-related migration (Clarke and Grenham 2011). International donor assistance has failed to fill the gap, and the donor community is examining non-conventional risk-pooling and risk-transfer programs. Innovations include index-based (parametric) micro-insurance, sovereign catastrophe (cat) bonds and regional risk pools which help to increase financial resilience of the respective risk bearers.

4.1 Index-based micro-insurance programs

The intent of micro-insurance is to circumvent the high costs of traditional insurance in order to service low-income markets by offering limited cover and greatly reducing transaction costs (Hochrainer-Stigler et al. 2012). Micro-insurance can be indemnity based, where products are written against actual losses, or index-based, where products are written against physical or economic triggers, that is, against events that cause loss, not against the loss itself. A report by the International Fund for Agricultural Development and World Food Programme cites 36 weather index insurance programs, including 28 addressing individual farmer/herder, slum dweller, village or cooperative risk (Hazell et al. 2010). Index insurance reduces moral hazard since claims are independent of losses. As another innovation, albeit with only one pilot application, insurance payouts can be linked with forecasts so that clients have the liquidity to take preventive measures to reduce losses (Skees and Collier 2010).

The private sector is taking an interest in micro-insurance markets. For Swiss Re, the target market includes those who can afford commercially viable premiums, which they identify as the estimated 2.6 billion people living above the international poverty line of $ 1.25/day but below $ 4/day (Swiss Re 2012). Few insurers, however, are optimistic about the prospects of disaster micro-insurance for the very poor (below USD 1.25/day) unless it is supported by the government, NGOs or international donors.

4.2 Public sector risk transfer

If governments lack the necessary infusion of post-disaster capital to rebuild critical infrastructure, restore homes and provide humanitarian assistance, indirect costs can surpass the direct losses of a disaster (Global Facility for Disaster Reduction and Recovery GFDRR 2013). As one case in point, to survive the 1984-5 drought-induced famine, many Ethiopian households, lacking government assistance, sold productive assets. These households continued during the 1990s to experience considerably less annual per capita growth than those which had not experienced the drought (Wiseman and Hess 2007). The lack of government post-disaster support can also lead to serious secondary economic and social effects at the national scale, such as deterioration in trade, budget imbalances and an increase in poverty (Barnett et al. 2008). The tropical storms in Yemen in 2008 caused damages and losses of about 1.6 billion USD or about 6 % of GDP. It was estimated that in some of the regions poverty rates increased from 28 to 51 % and the national poverty by 1.1 % (Global Facility for Disaster Reduction and Recovery GFDRR 2009).

Especially small and highly exposed countries that cannot rely on a tax base for raising post-event funds should consider insurance and other risk transfer instruments in order to protect public property, contingent liabilities to the private sector and, perhaps also, to provide public support of private risk transfer products (Linnerooth-Bayer et al. 2005; Hochrainer and Pflug 2009).

4.3 National insurance programs

Even in wealthy countries, private insurers have been reluctant to offer region- or nation-wide policies covering high risk-level droughts, floods and other hazards partly because of the dependent or co-variant nature of the risks. Even well capitalized and diversified insurers can face a risk of insolvency if they face repeated high-loss events. To circumvent this problem, the first national public-private partnership in the developing world, the Turkish Catastrophe Insurance Pool (TCIP), was created to provide affordable cover for earthquake risk in urban areas. Its purpose is to reduce the government's fiscal exposure by gradually building up capital in an insurance pool funded by mandatory private contributions and guaranteed by the government and donors (Gurenko 2004).

4.4 Catastrophe bonds

An alternative to commercial reinsurance is a catastrophe bond, an instrument whereby the investor receives an above-market return when a pre-specified catastrophe (measured in terms of an index, for example, wind speed) does not occur but sacrifices interest following the event. The risks are not absorbed by international insurers but directly by financial markets via investors, who receive a contingent interest rate calculated on the basis of the estimated risk. The first developing country government to issue a catastrophe bond was Mexico in order to provide security to its catastrophe reserve fund in the event of a major earthquake (Cardenas et al. 2007; Michel-Kerjan et al. 2011). While the bond was more expensive than reinsurance, this does not appear to be generally the case (Cummins 2008).

4.5 Contingent credit

Because of increasing scarcity of post-disaster credit, governments can pay a fee for the option of a guaranteed loan at a pre-determined rate, contingent on a disaster or some other defined

event occurring. As an early example, Colombia secured contingent credit from the World Bank to provide immediate and less expensive capital to the government in the event of a natural disaster (Cummins and Mahul 2008). Although contingent credit can potentially provide a government with lower cost capital relative to either insurance or the accumulation of reserves, the major disadvantage is that it can also exacerbate a country's debt burden (Hochrainer 2006).

4.6 Insuring donors that support governments

Like governments, donor organizations can also be strapped for cash especially after large-scale (high-risk layer) droughts and multiple disasters. This is particularly worrisome in the crucial time window between the observed natural hazard and its manifestations of avoidable losses—such as long-term health impacts to children due to malnutrition that can be addressed by timely food distribution. In such cases donors might consider insurance for rapid deployment of assistance, or alternatively they may help arrange insurance for vulnerable governments. This was the reasoning behind an innovative idea by the World Food Programme to set up an index-based insurance program that would provide timely cash to quickly scale up Ethiopia's Productive Safety Net Program (PSNP) in the case of an extreme drought (Wiseman and Hess 2007). A limitation of the Ethiopian system proved to be its integration with other programs targeting those chronically short of food, and especially nomadic herders. The insurance contract did not trigger in 2006 and was not renewed in 2007.

The potential for combining index-based approaches and safety net tools, according to Wiseman and Hess (2007), is substantial. In addition to ensuring that resources reach beneficiaries before negative coping strategies are employed, there are also spin-off benefits. Most importantly, the predictability of the system and related monitoring/evaluation systems can support more comprehensive contingency planning.

4.7 Insurance pools among small states

Developing country governments, particularly those of small states, pay international prices for insurance, which are subject to fluctuations often caused elsewhere. After Hurricane Andrew in 1992, Barbados experienced a ten-fold increase in insurance premiums despite Barbados not being impacted by the event nor lying in a major hurricane path (Cummins and Mahul 2008). Larger countries can generally absorb the impact of a severe adverse natural event (high-risk layer) since an affected region can be subsidized by revenues from unaffected regions. This type of geographic distribution of risk is not possible in small island states.

To circumvent the small-country problem, the Caribbean Catastrophe Risk Insurance Facility (CCRIF) was established to provide participating governments with immediate liquidity in the event of a major (medium to high risk layer) hurricane or earthquake at a significantly lower cost than if they were to purchase insurance separately in the financial markets (World Bank 2007). Governments of 16 Caribbean island countries contribute resources to the pool depending on their risk, and the fund is reinsured in the capital markets. In 2013, a similar insurance pool of Pacific island states was designed and arranged by the World Bank with the support of the Government of Japan. Five of the Pacific Island countries will receive protection against earthquake, tsunami and tropical cyclone risks from Swiss Re and other insurers at lower rates than had they insured separately (Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI) 2013).

A widely voiced concern about the long-term acceptance of the pool, however, is the risk that claims do not correlate with losses (basis risk). This was illustrated when Hurricane Dean

imposed damages on Jamaica in 2007 but as the weather index was not triggered, no claim payments were made.

5 Non-traditional financing instruments: benefits, costs and risks

Experience is too short to fully assess the current and prospective role of innovative financial instruments in contributing to DRM and CCA for the most vulnerable communities and their governments; yet, some insights on their benefits, costs and risks can be gleaned from recent experience.

5.1 Benefits

Partly because of the lack of coping mechanisms for extreme events, poverty can be reinforced by deliberate pre-disaster risk-averting livelihood choices. Benson and co-authors cite several studies that demonstrate significant livelihood losses from taking risk-averse production strategies (Benson et al. 2012). Marginal farmers in the Philippines, as one example, cultivate traditional, lower-yielding rice varieties because they are relatively more hazard tolerant, thereby reducing the risk of devastating crop failure at the expense of potential earnings (World Bank 2007). In drought-prone areas of India and Burkina Faso farmers may sacrifice 12 to 15 % of average income to reduce risk (Hazell and Hess 2010).

By providing low-income households, farmers and businesses with the right to receive post-disaster liquidity, micro-insurance and other financial instruments can lessen the burdens from disasters and expedite the recovery process—thus contributing to resilience. For many, an insurance contract can be a more dignified and secure means of coping with disasters than dependency on the ad hoc generosity of donors. Besides providing post-disaster liquidity, insured households and farms may be more creditworthy, meaning that insurance can enable productive investments and thus help high-risk agents escape disaster-induced poverty traps (Barnett et al. 2008). As we have emphasized throughout this review, insurance instruments can also provide incentives to reduce risk and losses, but only if they do not themselves encourage negligent behavior. Moral hazard is eliminated altogether with index-based or parametric contracts.

At the national scale, sovereign risk financing instruments can have large payoffs to governments. Due to limited tax bases, high indebtedness and low uptake of insurance, many highly exposed developing countries cannot fully recover by simply relying on limited external donor aid. By providing ex post liquidity that enables governments to provide relief to the most vulnerable and to invest in reconstruction and recovery—and quickly get back on their feet—insurance reduces long-term losses and the resulting development set backs. Just like investments in prevention, insurance can therefore save lives and livelihoods. With internationally backed risk-transfer programs, developing country governments will rely less on debt financing and international donations, and assured funds for repairing critical infrastructure can help attract foreign investment—thus increasing disaster resiliency.

The benefits from risk financing innovations include their contribution to climate change adaptation or CCA. Innovative instruments, such as indexed insurance systems, require knowledge, infrastructure and institutions that will lay the foundations for disaster safety nets as climate change continues to contribute to loss and damage. For example, insurance systems require risk assessments based on extensive data on the hazard, exposure and vulnerability, which builds capacity in developing countries

(Kull et al. 2013). Indexed systems require long-standing infrastructure, such as weather stations or even satellite observation systems, as well as regulatory institutions essential for the sustainability of disaster safety nets. By providing incentives for reducing risks, for example, changing building codes, financing instruments also build essential knowhow and resilience for the future.

5.2 Costs and risks

The benefits of risk financing, including its potential for promoting DRM and CCA, do not mean, of course, that households, farmers and government should enter into costly risk-transfer contracts. In contrast to other types of non-covariant insurance (e.g., health or funeral expenses) catastrophe cover can be exceptionally expensive since micro-insurers offering cover for co-variant risks face large, stochastic losses and thus must hold expensive capital reserves, diversify, or purchase reinsurance, all of which "load" or add to the premium. Moreover, providing insurance at a small scale can involve high transaction costs for reaching clients, estimating risks and handling claims. Because of these costs, and the return anticipated by insurers for entering high-risk markets, the premium on micro-insurance products and sovereign insurance instruments can greatly exceed expected losses. Besides the costs, other limitations to non-traditional risk financing instruments are discussed below.

5.2.1 Moral hazard, adverse selection and basis risk

Moral hazard and adverse selection, while absent in the case of index-based programs, have contributed to the reluctance of private insurers to enter many catastrophe markets and motivated governments to form public-private insurance systems. Basis risk may be one of the most difficult challenges facing index-based programs, and particularly the weather pilots discussed in earlier sections. If weather stations are not located very densely, rainfall measurements may not be closely correlated with an individual farmer's experience. One potential innovation for reducing basis risk is the use of satellite data for measuring rainfall specific to insured fields.

5.2.2 Institutional stability, public confidence and trust

Without competent regulatory bodies that assure conditions for both insurers and clients, the market cannot provide sustainable insurance contracts. Among other reasons, there will be no protection for clients if insurers renege on claims, and well capitalized firms will be undercut by those with insufficient capital. Responses to a survey in Malawi showed widespread mistrust in the implementing institutions and insurance mechanisms, notably in the administrating NGO, the private insurer and the weather station data (Suarez et al. 2007). Even more worrying is the apparent lack of understanding of the insurance contract, for instance, in Malawi many farmers did not fully understand the index-based system.

Both trust and financial literacy can be improved through educational awareness, and simulation games have been developed to improve understanding of insurance products (Patt et al. 2010). A field experiment in India found that communicating the need for personal financial management and the utility of formal hedging of agricultural production risks increased demand for an insurance product by over 5 % (Gaurav et al. 2010).

5.2.3 Modeling and pricing uncertainties

Data quality and availability are crucial factors determining the viability of micro and sovereign insurance schemes (Grossi and Windeler 2005). Advances in modeling have increased the feasibility of risk-transfer programs in developing countries by making it possible to better estimate and price low-probability extreme event risks, even if there are limited historical data available. Still, the models need data for calibration, and in cases of "fat tailed" distributions, reliance on historical data is problematic.

5.2.4 Climate change

The insurance industry is seen as particularly important for the management of the anticipated increase in future climate-related losses (Mills 2009). However, for insurance to work, risk must be measurable in quantitative terms within reasonable confidence bounds. Insurers increasingly depend on models for pricing risk, which are typically backward-looking using historical trend data and assuming that the statistical properties of the risk remain constant over time, an assumption which is not fulfilled under future climate change and which leads to an underestimation of future risks. Hence, many in the insurance industry regard climate change as a serious threat to the sustainability of their business (Ernst and Young 2008). To address these concerns, climate change impacts are increasingly incorporated into catastrophe models to examine the implications on the insured risk as well as new possibilities to hedge risks, but these exercises are characterized by large uncertainties (Hochrainer et al. 2009), .

Partly because of concerns about climate change, some insurers see their role as contributing to DRM and CCA by developing, and in some cases financing pro-active preventive strategies to manage risk. Surminski (2010) documents a range of activities, mainly in developed countries, where insurers have promoted and financed actions to protect countries, businesses and communities from disruption and damage resulting from the effects of climate change. These activities, however, have been ad hoc and generally limited in scope, mainly contributing to risk communication. New approaches for identifying climate-related losses include loss modeling under future climates on public-domain platforms as a way of yielding better financial and economic assessments and policy pathways (Mills 2012) and setting up global insurance models.

6 The limits to risk financing

As this discussion has shown, there are limits on individual, government and donor financing in highly exposed and vulnerable countries, which suggests the possibility of a risk layer "beyond adaptation". As a start, traditional risk financing instruments, including savings, credit and reciprocal arrangements, can be ineffective for co-variant, catastrophic risks that impact savings and credit institutions, as well as family and neighbors. Because of the costs and risks of non-traditional risk financing instruments, micro-risk transfer programs today reach only a very small population of low-income farmers, herders, households and intermediaries. In addition, governments of vulnerable countries face limits in their ability to finance recovery and provide support to the public and insurers; similarly, donor institutions, which provide only a small percentage of post-disaster capital, can reach limits in their capacity to respond. Instruments that transfer sovereign risk to the capital markets can expand government and donor financing constraints; yet, they can be prohibitively costly for low-income countries and have proven difficult to implement for donor organizations.

Already today there is reluctance on the part of insurers to cover catastrophic events in the "tails" of the probabilistic distributions (Nguyen 2013). Lacking insurance, public authorities will increasingly be called upon to provide relief and post-disaster assistance, and many governments of highly exposed countries, themselves, face constraints on their ability to respond to disasters (Mechler et al. 2009). Moreover, there are limits on the financial ability of governments and the private sector to reduce risks, particularly for the very low probability events with extreme catastrophic consequences. As climate change impacts the poor and raises the stakes on disaster losses, risk-financing and risk-reduction limits will likely become more acute.

7 Concluding remarks

The SREX findings on extreme events, combined with projections of current and future changes in loss and damage (due, in part, to climate change), give impetus to the urgency and importance of disaster risk management as an integral part of climate change adaptation. In this discussion, we have demonstrated how the two legs of DRM—disaster risk reduction and risk financing—can be coupled in a probability-based, risk-layer framework that differentially targets both activities to distinct layers of risk. Sensitivity to the different layers of risk can help policy makers plan and invest in the most effective DRM and CCA options.

Financing instruments, such as micro insurance, not only complement disaster risk reduction activities, but they can greatly influence risk reduction and climate change adaptation, especially for low and medium layer risks. There are no magic bullets, however, for making micro-insurance and other financial instruments accessible and affordable to those most in need, and in many instances, more traditional means of financing or non-financial coping will be preferable. This is especially the case for high-layer risks, where donor and government support to the poor will continue to be essential. Many governments and donor institutions, however, face gaps in meeting their post-disaster financial liabilities, which signals the prospects of a risk layer "beyond adaptation", especially as climate change contributes to increasing risks.

Disaster risk reduction and risk financing contribute importantly to climate change adaptation by lessening exposure and vulnerability and enhancing resilience to the potential adverse impacts of climate extremes. Recognizing the complementarities between risk reduction and risk financing as they contribute to disaster events of different severities can improve the contribution of DRM to CCA. The risk layer approach can be helpful to policy makers and practitioners in striking the right balance between investments to reduce risk, transfer risk and effectively prepare for and manage disaster impacts, and to negotiators in appreciating the link between risk financing, risk reduction and climate change adaptation.

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