International Catastrophe Pooling for Extreme Weather

An Integrated Actuarial, Economic and Underwriting Perspective

October 2019

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Acknowledgment: This research is commissioned by the Society of Actuaries. We thank members of the Project Oversight Group and reviewers including Sara Goldberg, Marlene Howard, Nan Jiang, Achille Sime and Remi Villeneuve. Our gratitude also goes to Dale Hall, Scott Lennox and Erika Schulty for their guidance and support. Kai-Uwe Shanz and Simon Young have provided valuable input and comments.

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Executive Summary of "International Catastrophe Pooling for Extreme Weather"

Background

The Society of Actuaries (SOA) and the Institute and Faculty of Actuaries commissioned this research study to analyze the main catastrophe pooling structures currently in place, including the strengths and weaknesses of their designs, and suggest possible improvements and expansions to better address small nations' insurance needs. The purpose of this report is to study catastrophe insurance pools covering losses caused by extreme weather events, including flood and drought. To achieve a good mix of mature and emerging market catastrophe pools, five established schemes have been chosen for an analysis and comparative studies: (1) Florida Hurricane Catastrophe Fund (Unites States); (2) Flood Re (United Kingdom); (3) Caribbean Catastrophe Risk Insurance Facility (Cayman Islands); (4) African Risk Capacity (Bermuda); and (5) Pacific Catastrophe Risk Assessment and Financing Initiative, including the Pacific Catastrophe Risk Insurance Company (Cook Islands). Furthermore, these five pooling schemes have been set up for entirely different purposes, ranging from a transitional vehicle for the promotion of availability and affordability of flood insurance for homeowners (Flood Re) to the protection of food security for vulnerable populations (African Risk Capacity).

The Approach

This research report starts with a discussion of the extent and root causes of natural catastrophe insurance protection gaps in advanced and developing countries, as well as potential remedies focused on risk pooling and the economics underpinning them. On that basis, the authors review five extreme-weather catastrophe pooling schemes, with varying degrees of public sector involvement. These pooling schemes are subjected to a comparative analysis, exploring key characteristics such as strategic rationale, funding and embedding in holistic risk management, and risk financing processes. Some of these findings were validated through interviews with lead actuaries and other stakeholders involved in the design of existing extreme weather risk pooling structures. The core of the report is an actuarial analysis of risk pooling, based on existing schemes and the pooling of random risks. The authors use loss exceedance probability curves for individual regions and countries before and after loss prevention and pooling measures to describe the potential loss impacts to participating member states and to the risk pool. They perform actuarial analysis of entity-specific, risk-bearing capacity and apply the market benchmark pricing tool (Wang Transform) to evaluate the economic costs and benefits to participating members of the risk pool. The authors conclude the study with some policy recommendations and suggest ideas for the improvement of existing and the implementation of new catastrophe pooling schemes.

Key findings

The ongoing climate change brings increased frequency and severity of extreme weather events around the world. Natural disaster losses (especially those caused by extreme weather) are on the rise. In the meantime, there is a huge and growing gap between economic and insured natural disaster losses, with a 10-year average economic loss of $120 billion and the average insured loss of $33 billion (Swiss Re (2017); Aon (2018)). In some developing and emerging countries, the share of uninsured in total losses can reach close to 100%, bringing into question the relevance of (commercial) insurance to mitigate the effect of calamity. Countries in Africa, the Caribbean and the Pacific have always been particularly exposed to extreme weather events such as hurricanes, droughts and floods, but in recent years, this exposure has grown further on the back of population growth, urbanization dynamics, overexploitation of natural resources, environmental degradation, and changing climate and weather patterns. More than ever before, the Damocles sword of natural catastrophes hangs over national development strategies and, more important, millions of lives and livelihoods.

Building on mature markets' experience with public and private-public pooling schemes, some of these vulnerable countries, supported by development agencies and donors, have joined forces by pooling their scant financial resources in regional risk-sharing vehicles. The best-known examples are the Caribbean Catastrophe Risk Insurance Facility (CCRIF), established in 2007; the African Risk Capacity (ARC), set up in in 2012; and the Pacific Catastrophe Risk Assessment and Financing Initiative Facility (PCRAFI Facility), launched in 2016. In exchange for an annual premium, these facilities offer participating countries limited parametric payouts designed to cope with the immediate aftermath of major disasters.

Despite much common ground, there are significant differences between the various schemes. Product design and other key operational factors vary greatly among CCRIF, ARC, PCRAFI as well as mature-market schemes such as Flood Re UK and the Florida Hurricane Catastrophe Fund (FHCF). Whereas the FHCF and Flood Re can both be characterized as reinsurance pools with an exclusive focus on residential property risks, the former is a government-run mandatory scheme with little reliance on private reinsurance markets, whereas the latter is a voluntary transitory arrangement that enables participating insurers to offer competitive premiums to high-flood-risk households on the back of subsidised open-market reinsurance.

ARC, CCRIF and PCRAFI, on the other hand, are sovereign schemes that are based on government membership and designed to relieve public budgets from strain after natural disasters. The payouts are designed to only cover public expenditures for disaster-related emergency and relief measures, rather than large-scale reconstruction measures (The maximum payout per country is capped at US$100 million for CCRIF and US$30 million for ARC).

The policy objectives underlying these sovereign schemes exhibit major differences. Whereas ARC is primarily an insurance risk pool committed to enhancing food security and efficiently protecting the livelihood of low-income people, capitalizing on the natural diversification of weather risk across Africa, PCRAFI also places significant emphasis on facilitating a dialogue between the participating countries on integrated financial solutions for the reduction of their financial vulnerability to natural disasters and to climate change. To a lesser extent, this wider remit is likewise characteristic of CCRIF, which aims to strengthen regional resilience through optimized disaster risk management and climate change adaptation practices, assisting governments and their communities in understanding and reducing the socio-economic and environmental impacts of natural catastrophes. Having said this, the most striking feature is the different approaches to the use of payouts: While CCRIF and PCRAFI were designed to help cover postdisaster contingent government liabilities and fiscal cash shortages, ARC is about mitigating drought-induced famines and ensuring food security among the poorest segments of the population.

Actuaries can contribute greatly to informing the many complex decisions and trade-offs associated with catastrophe pooling schemes. Beyond standard analyses, actuaries can perform dynamic financial analysis for the CAT pool. Actuaries may also opine on the relevance of historical data in light of climate change, a dynamic socio-economic environment, volatile insurance market conditions, or even conduct a quantitative examination of the CAT pool's financial and operational efficiency.

Policy recommendations for sovereign decision-makers

Based on the findings of the report, the authors have formulated four specific policy recommendations for sovereign decision-makers in setting up catastrophe pools.

Recommendation 1: Prior to setting up new pooling schemes, alternative funding structures should be carefully examined.

Recommendation 2: CAT pools should offer explicit risk premium discounts to reflect the effects of risk mitigation and prevention.

Recommendation 3: CAT pools with parametric triggers should proactively address basis risk by establishing mechanisms to smooth the financial impact of this risk.

Recommendation 4: CAT pools should be able to accumulate retained earnings to the benefit of its members and/or beneficiaries.

Section 1: Extreme Weather Disaster Losses and Insurance Protection Gap

1.1 INTRODUCTION

Calamities arising from climate changes and extreme weather do not only pose threats to human lives, livelihoods and health; they can also severely impair socio-economic growth and development through direct damage to assets, such as infrastructure and buildings, as well as indirect costs due to business interruption, loss of jobs and reduction in tax revenues. Certain regions are left with elevated risk of uninsured catastrophic property losses—the focus of this report—because insurance coverage remains insufficient. This growing mismatch is observable in both mature and developing economies. In the U.S., for example, highly susceptible regions not considered privately insurable may be covered for certain damages through a policy with the National Flood Insurance Program. Outside of the U.S., insurance availability and penetration vary widely. In many small and low-income nations, virtually all economic disaster losses remain uninsured (Swiss Re (2015); Aon (2018); Munich Re (2019)). These countries are dramatically ill-equipped to manage looming catastrophic risk, with potentially crippling effects on their economies and societies. This vulnerability is particularly acute for countries in Africa, the Caribbean and the Pacific that are highly exposed to extreme weather events, such as hurricanes, droughts and floods, especially as, in recent decades, these events have increased in frequency and severity, while their impact has been further exacerbated by urbanization trends and climate change, for example.

In light of these challenges, governments have stepped up their efforts to address the insurance protection gap, resulting in major progress at negotiations of the three United Nations-facilitated international framework agreements. In 2013, the United Nations Climate Change Conference - the 19th Conference of Parties (COP19), concluded the Warsaw Framework for Reducing Emissions from Deforestation and Forest Degradation (REDD+). In 2015, more than 190 member states adopted the Sendai Framework for Disaster Risk Reduction 2015–2030 and the 2030 Agenda for Sustainable Development. In 2016, representatives of 196 state parties at the 21st Conference of the Parties of the UNFCCC adopted the Paris Agreement on Climate Change. The last of these explicitly recognizes the importance of insurance and risk pooling.

In general, there is an increasing political momentum favoring insurance-based solutions that mitigate disaster and climate risks. Many of these initiatives are government-sponsored, in close partnership with the private sector. Examples include the establishment of multicountry regional risk-pooling platforms (as elaborated on further in this report), the expansion of innovative risk-transfer schemes based on parametric insurance, and the utilization of technology in micro insurance (Schanz/Sommerrock (2016)).

Although there are some encouraging success stories, the jury is still out as to the scalability of these efforts toward meaningfully strengthening economic and societal resilience. The insurance sector can help design and launch relevant and innovative risk-transfer solutions in response to disaster risks, particularly in regions where insurance is still in its infancy. Examples include reinsurers' support of innovative regional sovereign risk-pooling schemes, such as ARC.

Actuaries have a solid basis for analyzing risk-transfer mechanisms and a technical understanding of how risk-pooling works will help susceptible nations and their facilitators to structure financially feasible and sustainable pooling schemes. Having said that, most actuaries have very limited knowledge about existing catastrophe pooling schemes, just as most sovereign decision-makers do not fully understand insurance mechanisms. However, actuaries and sovereign decision-makers interested in managing the financial impact of catastrophic climate risk must strive to achieve catastrophe risk-transfer and pooling literacy to make the most informed business decisions. They should become versed in the major objectives and benefits of catastrophe pooling and should understand the range of the products and the operational characteristics of existing CAT pools.

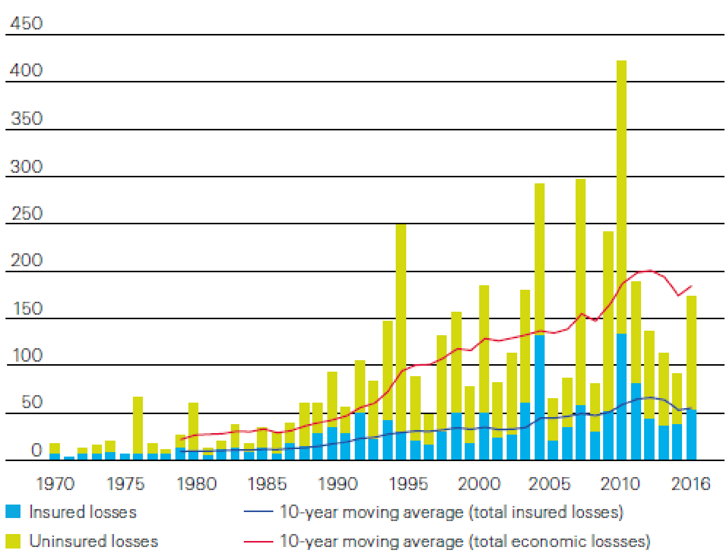
In natural catastrophe insurance, the protection gap is generally defined as the share of uninsured losses in total economic losses. This definition, however, assumes the maximum level of risk transfer, which, in reality, is neither desirable nor economically plausible. There are rational economic reasons for not fully insuring. Insureds usually retain some risks according to their risk appetite and risk-bearing capacity. Also, institutional factors such as extensive social security and public insurance schemes reduce the need for individuals to take out private insurance. Against this backdrop, the most appropriate definition of insurance protection gaps is the difference between the amount of insurance that is economically beneficial—taking into account some intentionally chosen self-insurance—and the amount of coverage actually purchased. The theoretical elegance of this approach, however, is offset by severe difficulties in quantification and operationalisation (Schanz/Sommerock (2016)).

1.2 THE SIZE OF THE PROTECTION GAP

Figure 1 shows the difference between insured and economic losses since the 1970s. In absolute numbers, the global catastrophe protection gap in 2016 amounted to approximately US$121 billion, which is broadly in line with the 10-year average. It is striking that the rate of growth of economic losses (5.6% in terms of 10-year rolling averages) has outpaced the growth of insured losses over the last 25 years (4.6%) (Swiss Re (2017); Aon (2018)).

Figure 1

INSURED VERSUS UNINSURED NATURAL CATASTROPHE LOSSES, 1970–2016, IN USD BILLION

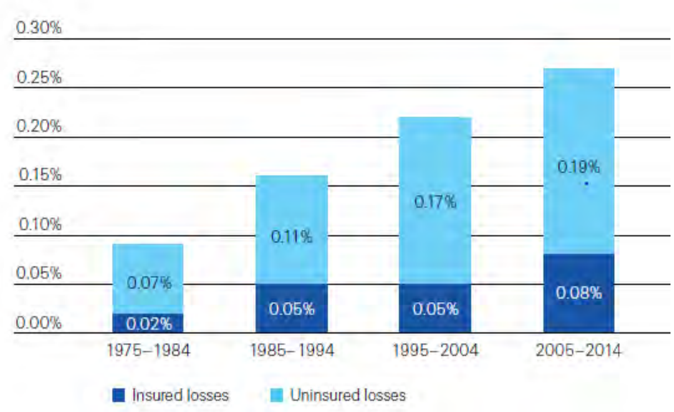


Source: Swiss Re (2017); Aon (2018)

Figure 2 presents the same argument measured as a percentage of global gross domestic product (GDP) over the last four decades. Total economic losses from natural catastrophes have increased from 0.09% to 0.27% of GDP or close to US$200 billion per annum. The uninsured portion of the losses has expanded from 0.07% to 0.19% of global GDP. The property protection gap has been aggravated as risk exposure, primarily driven by accelerating urbanization, outpaces insurance penetration, defined as premiums as a share of GDP (Swiss Re (2015); Aon (2018)).

Figure 2

GLOBAL INSURED AND UNINSURED NATURAL CATASTROPHE LOSSES IN PERCENT OF GDP

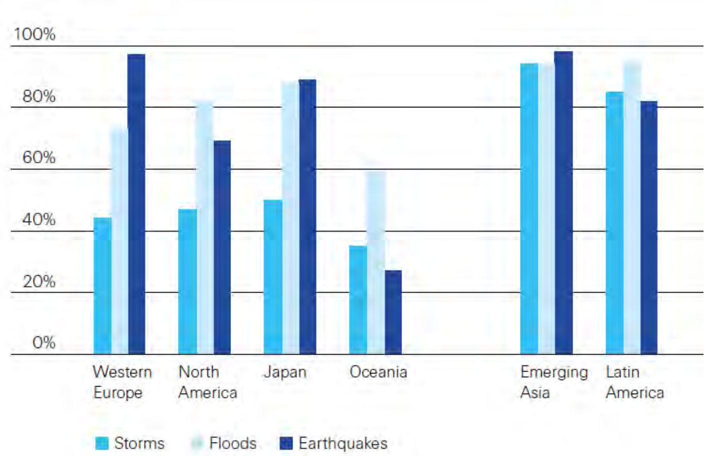


Source: Swiss Re (2015); Aon (2018)

As revealed by Figure 3, the share of uninsured property catastrophe losses varies by region and peril. As expected, the gap tends to be smaller for countries with higher levels of income. For lower-income regions, the catastrophe protection gap can reach close to 100%.

Figure 3

UNINSURED LOSSES AS A SHARE OF TOTAL NATURAL CATASTROPHE LOSSES, 1975–2014



Source: Swiss Re (2015); Aon (2018)

However, as Figure 3 suggests, the protection gap is a global, not just a developing world issue. Coverage gaps are equally pronounced in many advanced economies. The April 2016 Kyushu quake in Japan, for example, caused economic losses of up to US$30 billion, with less than US$5 billion insured. The insurance shortfall is even more dramatic in Italy, where the quakes that hit the central part of the country in August and October 2016 resulted in combined economic losses of US$6 billion, of which less than 5% were covered by insurance (Swiss Re (2017); Munich Re (2019)).

Flood risk is another example. Population growth and continued asset accumulation in flood-prone areas have elevated society's exposure to flood risk around the world. This is also true of the U.S., where the National Flood Insurance Program provides the majority of flood coverage. However, at around US$10 billion per annum, the flood risk protection gap in the U.S. remains severe. For example, the National Flood Insurance Program absorbed less than 20% of total storm surge losses from Hurricanes Katrina and Sandy (Swiss Re (2017); Aon (2018)).

1.3 ROOT CAUSES

In low-income countries in particular, underinsurance reflects the still-low levels of risk awareness and risk culture. This is not only true for property catastrophe insurance. For 2015, the Geneva Association estimates the annualized health protection gap for all emerging markets at around US$310 billion, or 1% of these countries' combined GDP (Schanz (2019)).

These protection gaps can also be viewed as a result of institutional legacies and cultural peculiarities such as decades of state monopolies and cultural or religious reservations toward the very concept of insurance. Affordability is another relevant reason for underinsurance, especially for lower-income households and small- and medium-sized enterprises. In general, insurance penetration levels rise as soon as economies have reached a certain stage of development and basic needs, such as food and housing are met (Enz (2000)). Immature regulatory and legal frameworks are another important impediment to insurance market development. Examples include unclear property rights or weak customer protection rules. Last, limits to insurability need to be taken into consideration. When assessing risks, any insurer or reinsurer must carefully weigh the fundamental principles of insurability, such as randomness, calculability and economic viability (Berliner (1982)). Disregarding these constraints would ultimately undermine the (re)insurer's solvency and compromise its ability to honor its obligations. Therefore, certain exposures (must) remain uninsurable.

1.4 POTENTIAL REMEDIES

Given the extent and complexity of protection gaps, the challenge of closing them requires a concerted approach from all relevant private and public-sector stakeholders. Specific actions to be considered include:

- Financial literacy programs jointly funded by insurers, advisers and governments;
- Microinsurance serving the needs of up to 4 billion uninsured people;
- Public-private partnerships: Governments and international or regional development banks stimulating insurance demand through conducive regulations, subsides, incentives and pool solutions;
- Effective compulsory schemes boosting penetration levels but carefully minimizing moral hazard and adverse selection;
- Industry bodies facilitating joint efforts to collect historical data, in addition to harnessing technology to tap into real-time data (Schanz/Wang (2014)).

The following sections will shed further light on sovereign risk pools (with varying degrees of private sector participation) as a means of narrowing protection gaps in the area of extreme weather risk.

Section 2: The Economics of Catastrophe Risk Pooling

Risk pooling is essential to the concept of insurance. It rests on the Law of Large Numbers according to which the larger the number of exposure units independently exposed to loss, the greater the probability that *actual* loss experience will be close to the *expected* loss experience. Against this backdrop, insurers seek to pool independent risks and aggregate the individual risk exposures.

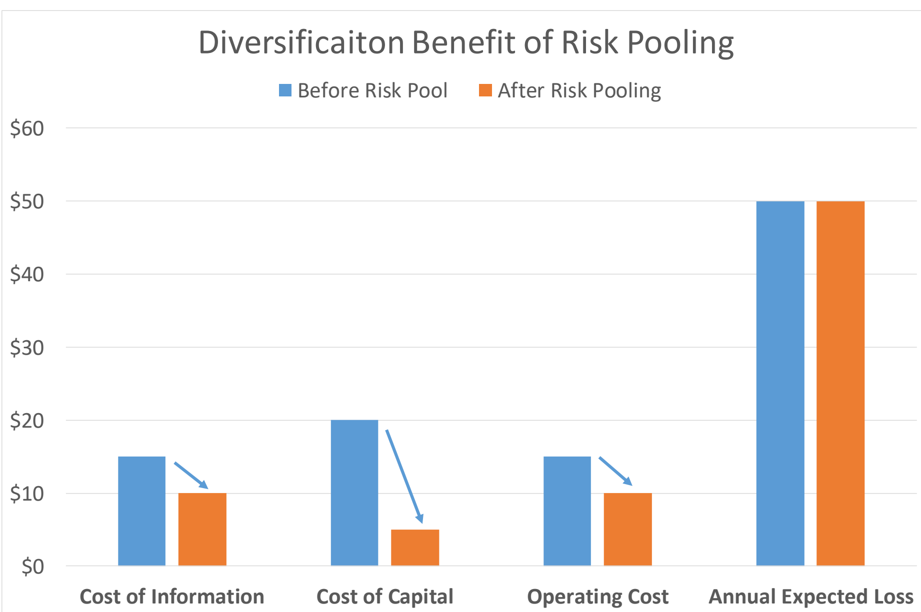
In the catastrophe space, however, the covariant nature of risk removes the intrinsic advantage of insurance based on the aggregation of independent risk. Economically beneficial catastrophe risk pooling, therefore, requires an adequate diversification of catastrophic risks within a particular insurance pool, both in terms of geographies and perils.

As illustrated by Figure 4, risk pooling can be an effective tool for reducing the technical risk premium, enhancing the efficiency of risk transfer. More specifically, these economic benefits can be captured:

- Reduced cost of capital—the pooling of reserves improves the pool members' ability to retain the first aggregate loss. In addition, based on a better structured and diversified portfolio, the cost of reinsurance and risk transfer in general decreases. Over time, catastrophe risk pools can also accumulate surplus (equity) capital, which improves the pool's risk retention capability and reduces its dependency on global reinsurance and capital markets for risk transfer.
- Lower operating costs—shared fixed costs enable economies of scale.
- Lower uncertainty loadings—a larger and more diversified risk portfolio translates into lower overall volatility and uncertainty.

Figure 4

HOW INSURANCE PREMIUMS BENEFIT FROM RISK POOLING AND IMPROVED RISK DATA



Source: Bollmann and Wang (2019)

2.1 REDUCED COST OF CAPITAL

A catastrophe risk aggregator is generally more efficient for participating risk carriers than holding capital on individual corporate or sovereign balance sheets. In this respect, the geographic diversification of catastrophe risks and the coverage of different exposures and perils within a specific pool are essential to capturing the benefit of reduced capital cost. Gains in capital efficiency are primarily a result of lower risk capital requirements to cover the aggregate risk in a diversified risk pool. In addition, the required return on capital should decrease with improved portfolio diversification and lower volatility.

2.1.1 THE BENEFITS OF GEOGRAPHICAL DIVERSIFICATION

Analyzing actual data from the Florida Hurricane Catastrophe Fund, Watson et al. (2012) found that significant economic diversification benefits can be achieved for events with return periods of 25 years and more (with benefits increasing with longer return periods), while there were no apparent benefits for the less severe, more frequent events. Furthermore, regardless of the number of exposures or the valuation of assets, a minimum critical distance of about 180 nautical miles between exposure points is required for recognizing any material diversification effects. The authors also found that a multistate overall risk portfolio required approximately only half of the reserves of an identical single-state portfolio. In sum, the study provides compelling evidence that catastrophe risk pooling of geographically diversified portfolios translates into lower risk capital requirements and costs.

From an international perspective, smaller developing countries have limited scope for spreading catastrophe risk geographically. For example, a hurricane hitting Jamaica is set to affect the country's entire economy. In such cases, regional risk pooling strategies have been adopted (Cummins/Mahul (2009); see also section 3 of this report).

2.1.2 THE BENEFITS OF A MULTIPLE-PERIL PORTFOLIO

An earthquake in a certain region is obviously not related to the occurrence of a tropical cyclone in the same or any other region of the world. Combining different and uncorrelated perils in one risk pool will, therefore, benefit insureds through substantially reduced risk-transfer costs. An analysis of typhoon, earthquake and crop risks in China has shown that the combined modeled loss for all three perils for the 100-year return period event can be significantly lower than the sum of the individual peril losses at the same return period. For the specific example of a geographically diversified nationwide portfolio, the combined modeled loss was about 20% lower than the sum of all individual peril losses (Wang/Chen (2013)), resulting in lower risk capital requirements for the risk-bearing entity.

2.2 LOWER OPERATING COSTS

Like any other insurance operation, catastrophe insurance carriers benefit from economies of scale. There is a significant fixed cost burden associated with IT infrastructure development and maintenance cost, for example, offering significant scope for lower administrative expense ratios as premium income increases. In addition, regulatory compliance and physical distribution networks are areas where insurers can benefit from significant economies of scale.

2.3 LOWER UNCERTAINTY LOADINGS

Uncertainty loadings in reinsurance pricing reflect a pessimistic evaluation of the distribution of insurance losses due to incomplete data. Uncertainty loadings are most commonly used for the pricing of low-frequency and high-severity events. For infrequent events, in particular in countries where data availability is poor, the uncertainty loading can be a significant component of the overall premium. Against this backdrop, one of the key benefits of risk aggregation in catastrophe pools is a reduced uncertainty of loss estimates, because there is a larger data set to draw from for statistical analyses. Expressed in terms of multiples of the average annual loss, an analysis of the FHCF found that the range of uncertainty for a multistate examination area (using the entire coast from Texas to Virginia as an example) was less than half of the range for individual states (Watson et.al. (2012)).

Section 3 exemplifies some of these benefits on the basis of select national and international extreme weather catastrophe pooling schemes.

Section 3: Case Studies: Five Catastrophe Pooling Schemes

Generally speaking, direct economic costs of catastrophic events can be reduced in two ways: either by mitigation measures such as building dykes or developing contingency plans or by reducing the financial impact on those directly affected. The latter approach is based on sharing disaster costs among a wider population through government and/or charitable aid or through insurance-based risk transfer. Most advanced economies rely on insurance to fund a significant portion of economic disaster losses and to diversify national disaster risk through international reinsurance markets.

The following section introduces five specific catastrophe pooling schemes. It explores their respective strategic rationale, operating history, operating principles as well as financial and nonfinancial performance and achievements. Three of these schemes cater to the needs of a total of 28 small and low-to middle-income countries covered through ARC, CCRIF and PCRAFI.

3.1 FLORIDA HURRICANE CATASTROPHE FUND

FHCF was established in 1993 as a tax-exempt state trust fund under the direction of the State Board of Administration to provide lower-cost reinsurance cover for hurricane losses.

3.1.1. RATIONALE AND STRATEGIC OBJECTIVES

The fund's establishment was the final consequence of a property insurance crisis in the 1960s, when insurance cover was a precondition for obtaining residential property mortgage finance and when many homeowners were threatened with mortgage default.

3.1.2. OPERATING HISTORY

As a first response, the Florida State Legislature required all insurers in 1970 to participate in the Florida Windstorm Underwriting Association (FWUA) program to provide affordable, not necessarily risk-reflective homeowner cover for catastrophic windstorm events in high-risk areas along the Florida coastline. Due to capacity constraints, the FWUA merged in 2001 with the Joint Underwriting Association, a temporary program established by the legislature to provide short-term cover for damage repairs after Hurricane Andrew in 1992. The merged entity, Citizens, is tax-exempt and funded by premiums, regular assessments on insurers, government and agency securities; corporate bonds; municipal bonds; and private sector securities.

With Hurricane Andrew in 1992 as a catalyst for its establishment, the initial motivation behind the FHCF's creation has been the provision of catastrophe reinsurance cover and not risk reduction per se. Faced with financial obligations potentially exceeding the industry's resources, insurers contemplated exiting the market. In an attempt to prevent such a market failure, the state government felt obliged to intervene in the market to secure the continued availability of reinsurance cover at affordable prices. Right from the beginning, the FHCF's objective was to keep premiums affordable across the board and to have policyholders in low-risk areas cross-subsidize those at higher risk.

3.1.3. OPERATING PRINCIPLES

Section 215.555 of the Florida Statutes requires all admitted residential property insurers to become FHCF members as a precondition of doing business in Florida. With only a very limited purchase of external risk transfer instruments such as reinsurance, this leads to a concentration of Florida's hurricane risk within the state, rather than its global diversification. For the foreseeable future, FHCF is expected to rely on accumulated cash and the issuance of bonds to maintain its claims-paying capacity.

In case of an emergency, FHCF is authorized to levy and collect emergency assessments on all property and casualty premiums to fund debt obligations. The emergency levy is limited to 6% of premium as to losses arising out of any one contract year and 10% of premium as to losses from multiple contract years.

Participating insurers can choose a coverage level of either 90%, 75% or 45%. While post-event revenue bonds are outstanding, the choice of a lower coverage level is limited. To assure the availability of the Fund's claims paying capacity for the next season, a statutory cap on the FHCF's single-season claims paying capacity is provided. According to Florida Statutes, US$10 million are appropriated annually from the FHCF to the Division of Emergency Management for the Hurricane Loss Mitigation Program.

3.1.4. FINANCIAL AND NONFINANCIAL PERFORMANCE AND ACHIEVEMENTS

Table 1

FHCF CUMULATIVE FINANCIAL PERFORMANCE (1999-2018)

	1999	2018	Nominal Growth	Relative Growth	CAGR
Total assets	US$2.6 billion	US$18.4 billion	US$15.8 billion	600%	17.6%
Total net position	US$2.6 billion	US$12.7 billion	US$10.1 billion	490%	14.2%
Net premium revenue	US$0.3 billon	US$1.1 billion		272%	11.6%
Cumulative net premium revenue, July 1, 1999–June 30, 2018				US$19.0 billion	
Cumulative hurricane losses, July 1, 1999–June 30, 2018				US$11.9 billion	

In 2004 and 2005, Florida was hit by four and three hurricanes, respectively. As of June 30, 2018, FHCF had paid more than US$11.8 billion in loss reimbursements to its participating insurers (see Table 1). The losses associated with the 2005 hurricanes produced payouts that exceeded FHCF's available cash. To address the cash shortfall, FHCF issued US$1.35 billion in tax-exempt post-event revenue bonds with a maturity date of 2012. This was the first time that FHCF had to issue bonds. In September 2017, Hurricane Irma made landfall in Florida, causing economic losses estimated at between US$58 billion and US$83 billion, according to Moody's Analytics. As of December 2018, FHCF's ultimate losses and loss reserves from Hurricane Irma stood at US$3.75 billion.

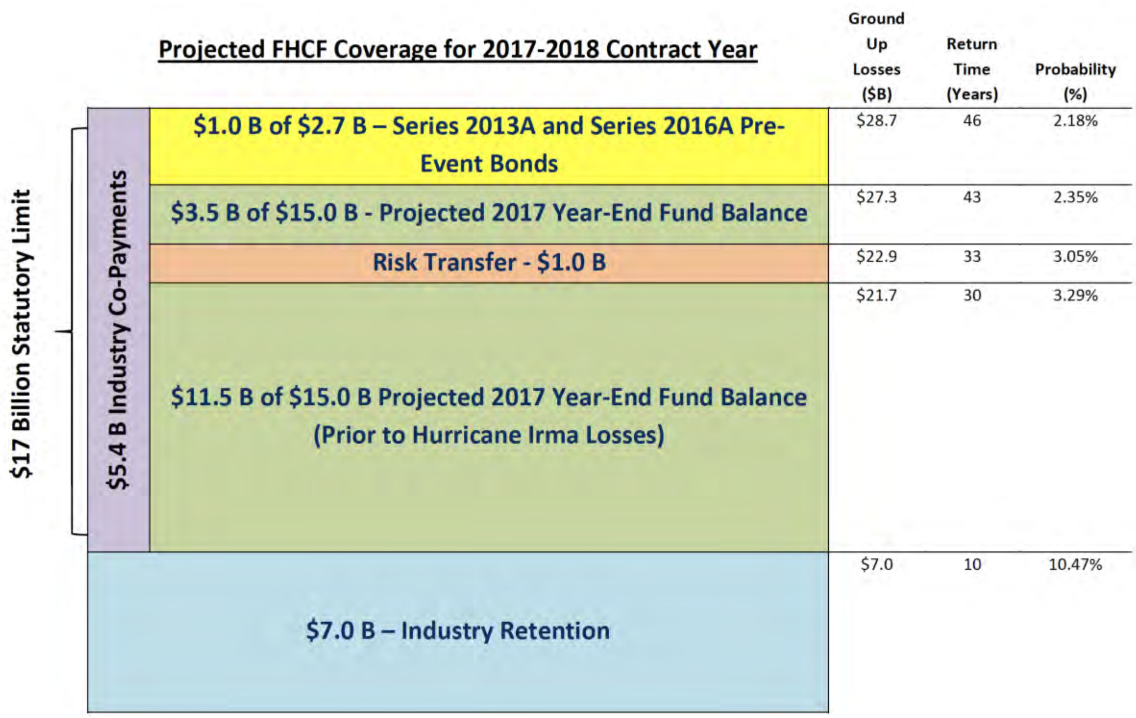
On October 10, 2018, Hurricane Michael made landfall near Mexico Beach, Florida. In terms of pressure, Hurricane Michael was the third most intense Atlantic hurricane to make landfall in the United States, causing estimated economic losses of at least US$25 billion (Bloomberg, Oct. 11, 2018). As of December 2018, FHCF estimated ultimate losses and loss reserves to be US$1.45 billion for Hurricane Michael.

In 2018, FHCF's maximum statutory single season capacity was US$17 billion. With an accumulated cash balance of US$13.9 billion, the maximum post-event issuance of bonds would be limited to US$3.1 billion for 2019. FHCF has low operating expenses and a relatively small staff of 13 full-time employees.

Figure 5 offers an overview of FHCF's funding structure.

Figure 5

FHCF CLAIMS PAYING RESOURCES FOR THE 2017–2018 POLICY YEAR



Source: FHCF (2017)

Over the last four years, reinsurance has become a component of FHCF's financial arrangements. Since 2015, FHCF purchased US$1 billion in reinsurance cover, at an attachment point of US$10.5 billion in 2018, compared to US$11.5 billion in 2016 and 2017 and US$12.5 billion in 2015. In June 2018, it renewed its US$1 billion reinsurance program for a premium of US$64 million, down 4% from the previous year (adjusted for the lower attachment point). The cover will trigger once losses have surpassed US$10.5 billion. In 2017, some 30 reinsurers participated on the 2018 program. The panel included traditional and insurance linked securities players from Asia, Bermuda, Europe, the United Kingdom and the United States. The 2018 renewal can be regarded as a successful result for Florida's State Board of Administration and FHCF administrators, because FHCF had to pay slightly more on a gross basis, but the net cost of this reinsurance to insurers included in FHCF's premium formula fell again. According to the State Board of Administration, the reinsurance premium cost of $63 million could actually drop once the final FHCF reimbursement premium is known.

Reinsurance can clearly help optimise FHCF's capital structure while simultaneously reducing the risk of a potential shortfall, enhancing FHFC's ability to pay claims after the occurrence of a major hurricane. Additionally, the risk transfer to international markets shifts the risk outside of Florida and reduces FHCF's dependency on debt capital markets.

3.2 FLOOD RE UK

Flood Re is a U.K. government-backed reinsurance scheme to promote the affordability and availability of flood insurance for homeowners across the country. It became operational as a nonprofit organization on April 4, 2016.

3.2.1. RATIONALE AND STRATEGIC OBJECTIVES

The decision to create this new entity was made after long discussions among the government, the Association of British Insurers and other market participants, such as international reinsurers. It was created as a transitional vehicle to be in place until 2039 to enable the continued availability of affordable insurance cover. Over time, the scheme aims to reach 350,000 households. The scheme enables participating insurers to offer competitive premiums with lower policy deductibles for high-flood-risk households. To do so, insurance companies can buy subsidized reinsurance from Flood Re through a commercial arrangement. The insurance industry owns Flood Re but has designated it as a public body, which makes reporting to parliament mandatory.

3.2.2. OPERATING PRINCIPLES

Flood Re is not available for homes constructed after Jan. 1, 2009, because it is assumed that such homes were either constructed outside of floodplains or in flood-resilient ways. Applying the same logic, and assuming that the above measure is strictly enforced, it is expected that the relative portion of high-risk households should decrease over time, while the number of new homes built to better standards will increase, thus improving the overall risk quality of the U.K. homeowners' flood portfolio.

To achieve affordable premium levels even for high-risk households, premiums that Flood Re charges to insurers are capped based on Council Tax bands. These premium thresholds have been set at levels that are below the risk adequate level for high-flood-risk households, hence providing a subsidy for those properties. But thresholds are still set sufficiently high to ensure that participating insurers only cede high-risk properties to Flood Re, because the scheme does not intend to interfere with the established open market for affordable and already commercially sustainable flood risks. Insurers still set the final pricing for high-flood-risks to consumers, but the risk premiums for the flood element of a property insurance policy are capped. A standard deductible of GBP250 per claim applies to each flood insurance policy. Other elements of the property policy, such as theft or fire, are not subject to any premium thresholds. At the start of each policy year, premium thresholds will increase in line with the Consumer Price Index.

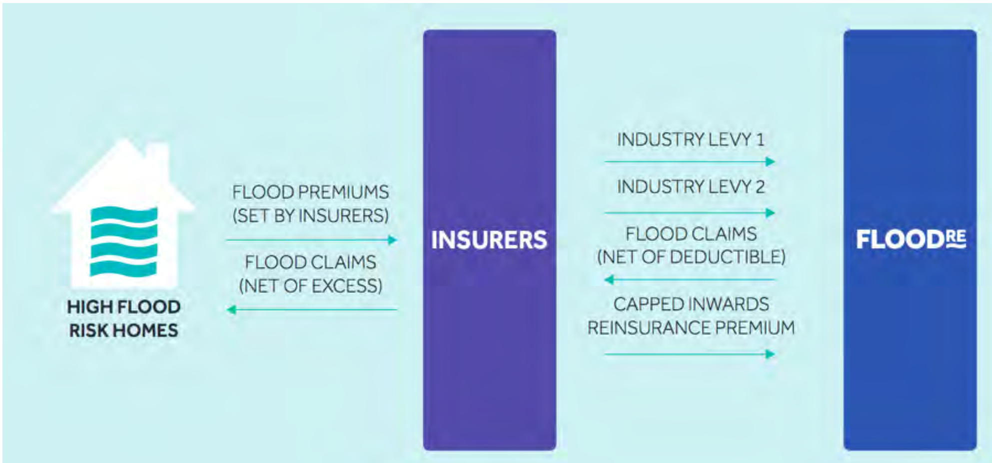
The difference between capped flood premiums and the corresponding risk-adjusted flood premiums is a subsidy that insured high-flood-risk households receive under the Flood Re scheme. To finance this subsidy, a statutory annual levy (known as levy 1) of GBP180 million per year is paid by all insurers authorized to write home insurance in the U.K. Based on each insurer's market share, the total amount is shared between insurers. It is expected that during the first five years of operation, levy 1 will be fixed at GBP180 million. In case this levy should be insufficient to meet the financial requirements in any given year, Flood Re can issue a compulsory call for additional funding from the industry (known as levy 2).

To achieve a smooth and successful transition to a flood insurance market with risk-adequate pricing between now and 2039, Flood Re plans to reduce the subsidy provided through the scheme and the associated industry levy, with a first reduction of the levy 1 planned for 2021.

Figures 6 and 7 illustrate the key mechanics of Flood Re as well as the proposed phasing out of the premium subsidy.

Figure 6

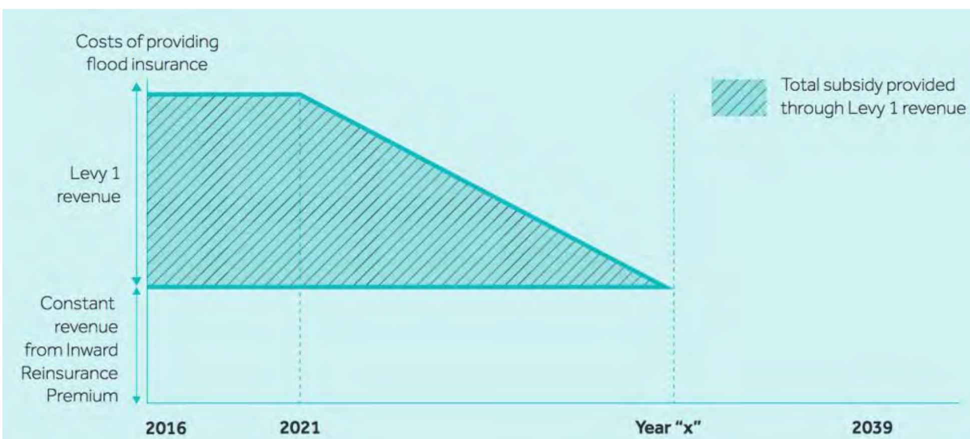
BASIC PRINCIPLES OF FLOOD RE



Source: Flood Re (2016)

Figure 7

ILLUSTRATIVE AND SIMPLIFIED EXAMPLE OF PHASING OUT THE SUBSIDY PROVIDED THROUGH FLOOD RE



Source: Flood Re (2016)

For the year ended March 31, 2018, Flood Re purchased outward reinsurance protection matching the full liability limit of GBP2.133 billion (2017: GBP2.100 billion). The U.K. government is liable for damage costs related to flood events with estimated return periods in excess of 200 years.

To manage the transition to risk-adequate market insurance prices, Flood Re will also educate homeowners to become more aware of their individual flood risk and ideally take action to reduce that risk. It is also planned that Flood Re will play the role of an advocate, convener and source of data and research on the risks and costs of flooding.

Flood Re (2016) lists four scenarios as to how the proposed transition to risk-reflective rates may play out in terms of the availability and affordability of flood insurance cover:

1) Outcome A: Market will provide insurance to the majority of high flood risk households, but premiums are at a rate that most would find unaffordable.

2) Outcome B: Market with risk-reflective pricing exists and provides widely available and affordable flood insurance to high flood risk households

3) Outcome C: Transition not successful – market is small and very costly – the majority of high flood risk households cannot gain insurance at all

4) Outcome D: Market provides affordable flood insurance for small number of low risk properties with the remainder of the market finding not being covered.

3.2.3 FINANCIAL AND NONFINANCIAL PERFORMANCE AND ACHIEVEMENTS

Table 2

FINANCIAL PERFORMANCE OF FLOOD RE (2017-2018)

	2017	2018	Nominal growth	Relative growth
Total assets	GBP202 million	GBP309 million	GBP107 million	53%
Total equity	GBP98.0 million)	GBP208 million	GBP110 million	122%
Net earned premium	(GBP36.8 million)	(GBP43.0 million)		
Cumulative gross written premiums, April 1, 2017–March 31, 2018				GBP60.0 million
Cumulative premiums ceded to reinsurers, April 1, 2017–March 31, 2018				GBP149.8 million
Cumulative net written premiums, April 1, 2017–March 31, 2018				(GBP89.8 million)
Cumulative net insurance claims, April 1, 2017–March 31, 2018				GBP4.3 million

As shown in Table 2, Flood Re's gross written premiums totaled GBP32.4 million in 2018, corresponding to an estimated gross claims amount of GBP669 million for the 200-year return period flood (equal to an estimated maximum net claims amount of GBP175 million. (Flood Re (2018)).

Up from just 16 insurance providers in April 2016, the number of providers signed up to support the scheme increased to well over 60 insurers in 2018, representing 90% of the home insurance market. During the first two years of operation, more than 150,000 home insurance policies were backed by the scheme. By January 2018, approximately 80% of homeowners with prior flood claims benefited from an insurance price reduction of more than 50%. By October 2017, the share of homeowners with prior flood claims who managed to get quotes from at least two insurance companies increased to 100% from 9% before the introduction of Flood Re. Over the same time, the share of homeowners with prior flood claims who received quotes from at least five insurance companies increased to 93% from zero before. Seventy-four percent of households with prior flood claims could even obtain 10 or more quotes.

3.3 CARIBBEAN CATASTROPHE RISK INSURANCE FACILITY

In 2007, CCRIF was formed as the first multicountry risk pool in the world. In addition, it was the first insurance instrument to successfully develop parametric (or index-based) policies—a type of insurance that covers the probability of a predefined event happening instead of indemnifying the actual loss incurred—backed by both traditional reinsurers and capital markets.

3.3.1 RATIONALE AND STRATEGIC OBJECTIVES

Designed as a regional catastrophe fund, CCRIF mitigates the financial impact of devastating hurricanes and earthquakes on Caribbean governments. Nineteen Caribbean countries and one Central American country are currently members of the facility. The initial risk carrier capitalization was provided through a multi-donor trust fund financed by the government of Canada, the European Union, the World Bank, the governments of the U.K. and France, the Caribbean Development Bank, the governments of Ireland and Bermuda, and membership fees that participating governments have paid.

3.3.2 OPERATING HISTORY

CCRIF was established in response to Hurricane Ivan in 2004, which affected nine Caribbean countries and caused economic losses in excess of US$6 billion in the region. In 2014, CCRIF was restructured into a segregated portfolio company to facilitate offering new products and the expansion into additional geographic areas. The new structure, in which products are offered through a number of segregated portfolios, enables a total segregation of risk but still provides opportunities to share operational functions and costs and to maximize the benefits of diversification. Since 2015, with Nicaragua being the first country buying insurance, CCRIF is also offering coverage to Central American countries. The geographic expansion was financially supported by the European Commission and the U.S. and Canada governments.

3.3.3 OPERATING PRINCIPLES

CCRIF offers earthquake, tropical cyclone and excess rainfall protection and helps to mitigate the short-term cash flow strains governments typically suffer following major natural disasters, enabling the continuation of basic government functions following major disasters. For the 2017–2018 policy year, facility members purchased a total of 42 policies: 15 tropical cyclone policies, 13 earthquake policies and 14 excess rainfall policies. Members benefited from a discount of 10% of the gross premium for these policies.

At the beginning of the 2017–2018 policy year, CCRIF introduced the aggregate deductible cover (ADC) and the reinstatement of sum insured (RSIC) as new policy features for its members. The ADC represents a means by which CCRIF can help its members when modeled losses fall below the attachment point but where there are observed losses on the ground. In October 2018, Haiti was the first member country benefiting from an ADC payout. The RSIC is an addition to the main tropical cyclone and earthquake policy to establish a “reinstatement of cover provision” after the initial cover has been exhausted. This cover provides access to coverage even after the maximum coverage limit of a policy is reached. This prevents the situation of leaving a country exposed until the following policy year if their insurance cover is exhausted early in the current policy year.

CCRIF insurance policies cover “government loss” as a proportion of the full “national loss.” Policies are designed to provide funds within 14 days to assist governments with addressing immediate needs following a catastrophic event. The exact payout amount is based not only on the modeled losses after a tropical cyclone, earthquake or rainfall event but also on the terms of the policy that the country has selected—the amount of risk transferred to CCRIF and the maximum payout limit.

Regarding CCRIF policies and coverage selection, all countries are required to make three key decisions regarding their coverage selection:

- The selection of an attachment point (the minimum severity of the event loss that gives rise to a payment and, therefore, is the loss amount at which the policy is triggered)
- The selection of an exhaustion point (the severity of the event loss at or above which the maximum payment is triggered)
- The selection of the coverage limit (which is tied to the ceding percentage and determines the premium cost)

3.3.4 CCRIF FINANCIAL AND NONFINANCIAL PERFORMANCE AND ACHIEVEMENTS

Table 3

CCRIF CUMULATIVE FINANCIAL PERFORMANCE (2007-2018)

	2007	2018	Nominal growth	Relative growth	CAGR
Total assets	US$52.2 million	US$135.5 million	US$83.3 million	160%	10.0%
Total shareholder's equity	US$20.0 million	US$106.3 million	US$86.3 million	434%	18.2%
Realized premium income from parametric insurance contracts	US$19.5 million	US$30.5 million			
Cumulative realized premium income, June 1, 2007–May 31, 2018				US$220.1 million	
Cumulative reinsurance premium paid, June 1, 2007–May 31, 2018				US$121.6 million	
Cumulative gross claims payouts, June 1, 2007–May 31, 2018				US$130.4 million	
Cumulative claims recovered from reinsurance, June 1, 2007–May 31, 2018				US$30.5 million	

Since the inception of CCRIF in 2007 until the end of May 2018, the facility has made 28 payouts after hurricanes, earthquakes and excess rainfall to 13 member governments, totaling approximately US$130 million (see Table 3). On average, CCRIF member countries pay premiums of US$200,000 to US$4 million per year for a coverage of up to US$50 million.

Due to a favorable loss experience and a significant increase in shareholder's equity during the first year of operation, CCRIF decided in 2008–2009 to offer all member countries a premium reduction of 10% to extend their coverage. Many of the countries not only increased their coverage but also took advantage of selecting a lower attachment point for hurricane coverage, with six of the 16 participants choosing an attachment point at the minimum level available at that time (one in 15 years).

In 2013–2014, given the budgetary constraints of Caribbean countries, CCRIF decided to minimize premium costs, providing a 25% discount on risk-adequate premiums. The discount could be offered because of a favorable loss experience and a resulting significant surplus for the organization, which is run as a nonprofit entity. For the 2015–2016 policies, CCRIF again offered a 50% discount for hurricane and earthquake policies and a 15 % discount on excess rainfall policies, resulting in a total realized premium income of US$17.8 million (compared to a total risk-adequate premium of US$32.1 million).

For the 2016–2017 policy year, the government of the Bahamas, a member since the founding of CCRIF in 2007, decided to opt out of CCRIF after paying an accumulated premium of US$9 million over 10 years without ever having received a claims payment. The government decided to instead pay the annual premium of US$900,000 to a national Disaster Relief Fund. On Oct. 5 and 6, 2016 (CCRIF 2016–2017 policy year), Hurricane Matthew made landfall as a category 3/4 hurricane in the Bahamas, causing total economic losses of US$600 million as estimated by the government of the Bahamas.

With total payouts of US$61.4 million, 2017 will go down as the year with the highest loss burden in the history of CCRIF. Within 14 days after the passage of Hurricanes Irma and Maria, payouts were made to nine different countries under their respective tropical cyclone, excess rainfall and aggregate deductible covers.

3.4 AFRICAN RISK CAPACITY INSURANCE LTD.

In 2012, ARC was established as a specialized agency of the African Union to help member states improve their capacities to better prepare for and respond to extreme weather events and natural disasters, therefore protecting the food security of their vulnerable populations.

3.4.1 RATIONALE AND STRATEGIC OBJECTIVES

ARC is composed of two entities: the specialized agency and a financial affiliate, ARC Insurance Company Limited. The agency is a cooperative mechanism providing general oversight and supervising the development of ARC capacity and services as well as approving contingency plans and monitoring their implementation. As of March 2019, ARC Agency has 33 member states: Benin, Burkina Faso, Burundi, Central African Republic, Chad, Comoros, Côte d'Ivoire, Djibouti, Gabon, Gambia, Ghana, Guinea, Guinea Bissau, Kenya, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique, Niger, Nigeria, Republic of Congo, Rwanda, Sahwari Arab Democratic Republic, Sao Tome & Principe, Senegal, Sierra Leone, Sudan, Togo, Zambia and Zimbabwe.

ARC Ltd. is the financial affiliate that carries out commercial insurance functions of risk pooling and risk transfer in accordance with national regulations for parametric weather insurance in Bermuda where the entity is domiciled. There is a plan to relocate ARC Ltd. to an African country as soon as an equally favorable legal and regulatory regime exists in an African Union Member State. In 2017–2018, the mutual insurance facility ARC Ltd. comprised of the five African Union member countries Burkina Faso, Mali, Mauritania, Senegal and Gambia. The two capital contributors DFID (U.K. Department for International Development) and KfW (Kreditanstalt für Wiederaufbau/German Development Bank) are also members of ARC Ltd. Overall, the U.K. committed to a capital investment of up to GBP90 million, as well as a grant of up to GBP10 million for technical assistance and evaluation. Of this, an initial GBP30 million (matched by Germany) was paid in to capitalize ARC Ltd. and enable it to offer insurance.

3.4.2 OPERATING HISTORY

Since 2014, ARC Ltd. has enabled participating African governments to insure themselves against drought and respond rapidly when their citizens experience harvest failure. The inaugural risk pool, which covered the 2014–2015 rainfall seasons, consisted of four countries: Kenya, Mauritania, Niger and Senegal. For the

2015–2016 seasons, three additional countries—Gambia, Malawi and Mali—joined ARC, bringing the total number of risk pool countries to seven. For the third risk pool in 2016–2017, Burkina Faso joined, while Kenya and Malawi left, leaving a total of six countries in the pool. The fourth risk pool, covering the 2017–2018 agricultural season, had five countries: Burkina Faso, Mali, Mauritania, Senegal and Gambia. For the 2018–2019 season, the fifth risk pool reduced further to three countries: Burkina Faso, Senegal and Gambia.

3.4.3 OPERATING PRINCIPLES

ARC Ltd.'s risk capital comes from participating countries' premiums as well as one-time development partner contributions. ARC Ltd. works with member countries to calculate country premiums. The countries select the level at which they wish to participate by selecting the amount of risk they wish to retain and the funding they would expect from ARC for droughts of varying severity.

ARC uses satellite information to track rainfall during a country's growing season and compares it to the local crop's water requirements. At the point of harvest, the model predicts whether the harvest has been successful or failed and estimates the likely humanitarian response cost. When an insured event occurs, the insured government uses the ARC payout to launch early response activities as set out in its pre-agreed contingency plan, which includes specific information on how payouts will be used. An independent body (neither partnering reinsurance companies nor ARC's secretariat) evaluates these plans, and coverage will only be provided if a plan passes muster. ARC payouts have to arrive in the national treasury within two to four weeks of harvest so that the first assistance can reach needy households within 120 days, the time period at which asset depletion at the household level typically begins.

3.4.4 ARC FINANCIAL AND NONFINANCIAL PERFORMANCE AND ACHIEVEMENTS

Table 4

ARC CUMULATIVE FINANCIAL PERFORMANCE (2014-2018)

	2014	2018	Nominal growth	Relative growth	CAGR
Total assets	US$122 million	US$91.5 million	(USD 29.5 million)	(25%)	(6.9%)
Total members' equity	US$22.7 million	US$27.1 million	US$4.4 million	19%	4.5%
Net premiums	US$7.9 million	US$2.2 million			
Cumulative gross premiums written, Jan, 1, 2014–Dec. 31, 2018				US$66.7 million	
Cumulative reinsurance premiums paid, Jan. 1, 2014–Dec. 31, 2018				US$23.3 million	

Cumulative net premiums, Jan. 1, 2014–Dec. 31, 2018	US$43.3million
Cumulative gross claims, Jan. 1, 2014–Dec. 31, 2018	US$34.5 million
Cumulative reinsurers' share of claims, Jan. 1, 2014–Dec. 31, 2018	US$11.3 million

Since its establishment in 2014, ARC Ltd. has underwritten more than US$465 million of African drought risk and transferred a significant portion of this into the global reinsurance markets (see Table 4). For the first country risk pool 2014–2015, which comprised of four countries, ARC Ltd. issued drought insurance policies with a total sum insured of US$129 million for a total premium of US$17 million. Of this risk, US$55 million was placed in the international reinsurance markets. In early 2015, ARC paid out US$26 million when three countries in the Sahel (Senegal, Mauritania and Niger) were impacted by drought. These three countries had previously paid total premiums of US$8 million.

For the 2015–2016 season, the total sum insured increased to US$178 million for which seven countries paid US$24.7 million in premiums. ARC Ltd transferred US$72.7 million of that risk to the international risk markets. In 2017, ARC Ltd. paid out US$8.1 million to Malawi. Initially, Malawi's parametric drought insurance policy did not trigger a payout, because the AfricaRiskView (ARV) model indicated a low number of people affected by the drought. However, the government of Malawi estimated a much higher number of people impacted.

After thorough investigation, it was found that the model had performed as expected, given its initial parameterization by the Malawi government and the satellite-based rainfall data used. In addition, the satellite data were also in line with Malawi's ground-based rainfall data. To resolve the discrepancy between model outcomes and observations on the ground, ARC conducted extensive fieldwork and household surveys in partnership with Malawian technical experts, revealing that farmers had switched to a greater extent to growing a different type of crop than the one assumed in the ARV model. In recent years, farmers had shifted to planting maize with a 90-day growing period, compared to the maize variety with a growing period of 120–140 days as assumed in the customisation of Malawi's model. The rainfall pattern in 2015–2016 was particularly unfavorable to the shorter cycle maize, such that correcting this crop assumption in the model resulted in a very different modeled outcome. As a result, ARC recustomized the AfricaRiskView model to correct this crop assumption, resulting in a model outcome providing a reasonable representation of the situation on the ground. This, in turn, triggered the US$8.1 million payout under the revised policy to the Malawi government. In 2018, ARC Ltd. disbursed US$2.4 million to the government of Mauritania, which paid a premium of US$1.4 million for drought coverage.

In line with ARC's strategic framework for the years 2016–2020, AfricaRiskView was made available for underwriting private sector insurance in Africa, initially with a limited group of partners. This new initiative, called Licensing for Development (L4D), seeks to make additional development impacts in local communities and to strengthen domestic insurance markets. In addition, ARC will generate licensing fees through L4D, providing a new and innovative source of income to support the maintenance and continued development of AfricaRiskView.

3.5 THE PACIFIC CATASTROPHE RISK ASSESSMENT AND FINANCING INITIATIVE

Launched in 2007, PCRAFI provides the Pacific Island countries (PICs) with risk modeling and assessment tools to enhance disaster risk reduction.

3.5.1 RATIONALE AND STRATEGIC OBJECTIVES

As a joint initiative of the World Bank, the Asian Development Bank and the Pacific Islands Applied Geoscience Commission, with the financial support of the government of Japan and the Global Facility for Disaster Reduction and Recovery, PCRAFI is part of the broader agenda on disaster risk management and climate change adaptation in the Pacific region. Fifteen countries—the Cook Islands, the Federated States of Micronesia, Fiji, Kiribati, the Marshall Islands, Nauru, Niue, Palau, Papua New Guinea, Samoa, the Solomon Islands, Timor-Leste, Tonga, Tuvalu and Vanuatu—are involved in the initiative, which also aims to enhance the understanding of integrated financial solutions to reduce member countries' vulnerability to natural disasters and climate change. More than US$40 million in grants have been provided to the PCRAFI Multi-Donor Trust Fund, which the World Bank manages.

3.5.2 OPERATING HISTORY

From January 2013 until October 2016, a Pacific Catastrophe Risk Insurance pilot was an integral part of the Pacific Disaster Risk Financing Program. The insurance pilot was one of two program components, with the second component focusing on the provision of advice to member countries on the public financial management of natural disasters, including the development of a national disaster risk financing strategy, post-disaster budget execution and the insurance of key public assets. During the first season of the pilot, the World Bank placed a portfolio of catastrophe swap contracts that transferred tropical cyclone, earthquake and tsunami risk from the Marshall Islands, Samoa, the Solomon Islands, Tonga and Vanuatu on the international reinsurance markets. During the fourth season, the scheme provided an aggregate cover of US$43 million with total premiums of US$2.3 million. The combined 250 years probable maximum losses (PML) for the five PCRAFI countries was 58% below the sum of the individual country-specific PMLs.

In June 2016, the new Pacific Catastrophe Risk Insurance Company was officially established in the Cook Islands as a foundation that owns a group captive insurer. In its first year of operation, the facility received US$6 million in capital from the PCRAFI Multi-Donor Trust Fund. With the start of the fifth insurance season in November 2016, the facility had issued its first insurance policies to the Cook Islands, Marshall Islands, Tonga, Samoa and Vanuatu. These exposures were reinsured by five global reinsurers, providing a total coverage of US$38.2 million. In November 2017, PCRIC was able to secure an extended insurance coverage limit of US$45 million for five participating countries: Cook Islands, Republic of the Marshall Islands, Samoa, Tonga and Vanuatu. The reinsurance cover was provided by AXA, Hannover Re, Liberty and Mitsui Sumitomo Insurance.

3.5.3 OPERATING PRINCIPLES

The PCRAFI program is based on the following six key principles: (1) country ownership, giving PICs control and influence over the design of future disaster and climate risk tools; (2) financial sustainability in the long run, based on sound actuarial principles, adequate accounting for the underlying risks and operating expenses, ensuring that the initial capital injection is not depleted and can even grow over time; (3) contingency planning to ensure timely and effective use of funds; (4) accountability and transparency, also providing detailed information on how insurance payouts are being used (not yet a formal requirement of the program); (5) a comprehensive disaster risk financing strategy, with insurance being only one component; and (6) link with the Disaster Risk Management Agenda, aiming to mitigate and reduce disaster risks that PICs face. Launched in April 2016, the second phase of the PCRAFI program comprises two key pillars: (1) the PCRAFI facility and (2) the PCRAFI Technical Assistance Program.

With the establishment of the new insurance facility as an independent legal entity in the Cook Islands, PICs have demonstrated the willingness and commitment to establish their own management entity to ensure the sustainability and further development of the PCRAFI insurance program.

3.5.4 PCRAFI FINANCIAL AND NONFINANCIAL PERFORMANCE AND ACHIEVEMENTS

From January 2013 until October 2016, the pilot made two payouts of a total of US$3.2 million, both settled within 10 days of the disasters. In January 2014, Tonga received a payout of US$1.3 million following Tropical Cyclone Ian, while in March 2015, Vanuatu received a payout of US$1.9 million following Tropical Cyclone Pam. Although the two insurance payouts received by Tonga and Vanuatu were small in absolute terms, they were relevant in relation to the size of their government budgets (Vanuatu's budget amounted to US$130 million in 2014). But most important, the payouts provided immediate liquidity for emergency response and the maintenance of essential government services until additional resources became available. Like most other small nations, the PICs have very limited options for raising quick liquidity, because of their limited borrowing capacity and the limited access to international insurance markets. Other financing mechanisms, such as the cross-subsidization of affected regions by nonaffected areas is very difficult if not impossible due to the small size of the local economies and the limited geographic diversification of risk within one region.

In February 2018, the newly established PCRIC made its first payout of US$3.5 million to the government of Tonga. The payout was based on Tonga's insurance cover against tropical cyclones after category 4 cyclone Gita made landfall on Tonga on Feb. 12, 2018.

Premium affordability and payments are a major challenge for PICs: In 2015, while the Cook Islands paid its premium without any donor support, Vanuatu, Tonga, the Marshall Islands, the Cook Islands and Samoa paid an average of 16% of the premium, with Japan assuming the balance. The expectation going forward is that members will pay premiums without donor support. Basis risk associated with parametric insurance coverage is another key challenge when it comes to securing an ongoing participation of PICs. In 2015, the Solomon Islands exited the insurance program after experiencing two events (the Santa Cruz earthquake and flooding in March 2014), neither of which triggered a payment from the scheme despite the fact that they had severe social and economic impacts on the country.

Table 5

2017–2018 KEY FINANCIALS

	FHCF	Flood Re UK	CCRIF	ARC Ltd.	PCRIC
Balance sheet					
Total assets	US$18.4 billion	GBP309 million	US$135.5 million	US$92 million	n.a.
Total liabilities	US$5.7 billion	GBP 102 million	US$29.2 million	US$64 million	n.a.
Total net position/shareholders' equity	US$12.7 billion	GBP208 million	US$106.3 million	US$27 million	n.a.
Credit Rating/Financial Strength Rating	Moody's Aa3 Standard & Poor's AA Fitch AA	Standard & Poor's A-	Not rated	Not rated	Not rated
Operating income statement					
Risk adjusted premiums	n.a.	n.a.	US$33.7 million	n.a.	n.a.
Gross written/earned/direct premiums	US$1.1 billion	GBP32.3 million.	US$30.5 million (discounted)	US$4.8 million (earned)	n.a.
Net premiums	US$1.1 billion	- *GBP43.0 million*	US$14.9 million	US$2.2 million	n.a.
Reinsurance premium paid*	US$61.0 million	GBP74.7 million	US$15.7 million	US$2.6 million	n.a.
Net income (loss)**	(US$1.3 billion)	GBP110 million	US$0.7 million	US$2.2 million	
Risk profile					n.a.
Aggregate exposure	US$2.177 trillion	GBP2.1 billion (annual aggregate loss limit)	US$651 million	n.a.	n.a.
Claims paying capacity	US$17.0 billion[1]	GBP2.1 billion	US$170 million[1]	US$47.0 million	n.a.
Retention	US$11.5 billion[2]	GBP100 million (max. annual accounting loss)	US$25 million[2]	US$6.0 million	n.a.
Reinsurance cover length	US$1.0 billion	GBP2.1 billion	US$145 million	US$41.0 million	US$38.2 million

*African Risk Capacity Insurance, Ltd.: Reinsurers' share of of gross earned premiums
**African Risk Capacity Insurance, Ltd.: Net underwriting income; Flood Re: Profit for the year

Notes:

1 Estimated return period for losses exceeding retention: FHCF ≈10 years; CCRIF, 5.2 years.

2 Estimated return period for losses exceeding total claims paying capacity: FHCF ≈46 years; CCRIF, 667 years; Flood Re, 200 years

Source: Compiled by Bollmann and Wang based on public disclosure

Table 6

COVERAGE CHARACTERISTICS

	FHCF	Flood Re UK	CCRIF	ARC Ltd.	PCRIC
Primary cover characteristics					
Covered perils	Hurricane (windstorm)	Flood	Earthquake; tropical cyclone; excess rain	Drought, Tropical cyclone (from 2017)	Tropical cyclone; earthquake
Covered interest/assets	Residential property	Residential property	Government economic losses	Livelihoods of low-income people	Government economic losses
Trigger primary insurance contract	Indemnity	Indemnity	Parametric index	Parametric index	Parametric index
Largest total claims payout/year	US$5.5 billion/2005	GBP2.5 million/2018	US$61.4 million/2017	US$26 million/2015	US$3.5 million/2018
Number of beneficiaries	n.a.	150,000 households	n.a.	n.a.	n.a.
Risk carrier characteristics					
Provision of insurance	no	no	yes	yes	yes
Provision of reinsurance	yes	yes	no	no	no
Government-owned risk-taking entity	yes	no	yes	yes	yes
Nonprofit risk-taking entity	yes	yes	yes	yes	yes
Government provision of risk capital	yes	no	yes	yes	
Donor provision of risk capital	no	no	yes	yes	yes
Government/donor payment of operational costs	no	no	yes	yes	yes
External provision of product development support	no	no	yes	yes	yes
External provision of technical expertise	no	no	yes	yes	Yes

Source: Compiled by Bollmann and Wang based on public disclosure

Section 4: A Comparative Analysis of Catastrophe Pooling Schemes

Comparisons of financial aspects and coverage structures for the five CAT pools (ARC, CCRIF, FHCF, Flood Re and PCRAFI) are summaried in Table 5 and Table 6.

4.1 VISION AND MISSION, STRATEGY AND OPERATIONAL TARGETS

Significant differences between the various schemes' overarching policy objectives explain why product design and other key operational factors vary greatly among ARC, CCRIF, FHCF, Flood Re and PCRAFI.

Whereas the FHCF and Flood Re can both be characterized as reinsurance pools, the former is a government-run mandatory scheme with little reliance on private reinsurance markets, whereas the latter is a voluntary arrangement that enables participating insurers to offer competitive premiums to high-flood-risk households on the back of subsidised open-market reinsurance. In addition, whereas FHCF is an open-ended cross-subsidization vehicle that intends to provide property insurers in Florida with a cost-effective source of reimbursement, Flood Re is temporary in nature, aiming at doing away with the underlying market inefficiencies that gave rise to its establishment in the first place. Also, Flood Re aims to incentivise public and private sector action by sharing data on high-flood-risk areas. A common feature, however, is FHCF's and Flood Re's exclusive focus on residential property risks in mature high-income markets.

ARC, CCRIF and PCRAFI, on the other hand, are sovereign schemes that are based on government membership and designed to relieve public budgets from strain after natural disasters. The payouts are designed to only cover public expenditures for disaster-related emergency and relief measures, rather than large-scale reconstruction measures (The maximum payout per country is capped at US$100 million for CCRIF and US$30 million for ARC (Scherer (2017)). Another differentiating feature of FHCF and Flood Re is their character as direct insurance pools.

The policy objectives underlying these sovereign schemes exhibit major differences. Whereas ARC is primarily an insurance risk pool committed to enhancing food security and efficiently protecting the livelihood of low-income people, capitalizing on the natural diversification of weather risk across Africa, PCRAFI also places significant emphasis on facilitating a dialogue between the participating countries on integrated financial solutions for the reduction of their financial vulnerability to natural disasters and to climate change. To a lesser extent, this wider remit is also characteristic of CCRIF, which aims to strengthen regional resilience through optimized disaster risk management and climate change adaptation practices, assisting governments and their communities in understanding and reducing the socio-economic and environmental impacts of natural catastrophes.

The different objectives are also reflected in the actual design of the schemes: CCRIF offers earthquake, tropical cyclone and excess rainfall protection and helps to mitigate the short-term cash flow strains governments typically suffer following major natural disasters, enabling the continuation of basic government functions following major disasters. Policies are designed to provide funds within 14 days to assist governments with addressing immediate needs following a catastrophic event. In 2014, CCRIF was restructured into a segregated portfolio company to facilitate the offering of new products and the expansion into additional geographic areas. The new structure, in which products are offered through a number of segregated portfolios, allows for a total segregation of risk but still provides opportunities to share operational functions and costs and to maximize the benefits of diversification.

ARC was established to help member states improve their capacities to better prepare for and respond to extreme weather events and natural disasters, therefore, protecting the food security of their vulnerable populations. For this purpose, ARC uses satellite information to track rainfall during a country's growing season and compares it to the local crop's water requirements. At the point of harvest, the model predicts whether the harvest has been successful or failed and estimates the likely humanitarian response cost. When an insured event occurs, the insured government uses the ARC payout to launch early response activities as set out in their pre-agreed contingency plan, which includes specific information on how payouts will be used.

PCRAFI is a comprehensive disaster risk financing strategy and part of a broader disaster risk-management agenda, aiming to mitigate and reduce disaster risks that member countries face, with insurance being only one risk management component. The other component is focusing on the provision of advice to member countries on the public financial management of natural disasters, including the development of a national disaster risk financing strategy, post-disaster budget execution and the insurance of key public assets.

4.2 OPERATING CHARACTERISTICS

The five schemes under review differ markedly as far as their funding features are concerned. On the back of significant capital accumulation due to low loss experience, CCRIF can, to a major extent, rely on retained earnings and is even in a position to grant premium discounts to its members. Having said this, CCRIF shares risk-adequate premiums with its members to preserve the important signaling effect that comes with insurance pricing.

For ARC, the situation is different: It has to repay loans, and its bias toward debt financing, in combination with relatively high levels of net risk retention, makes capital accumulation more difficult and premium subsidies (currently) unfeasible. PCRAFI even hands out premium subsidies in a genuine sense, funded by the Japanese government, which is committed to promoting political and economic stability in the region.

FHCF enjoys stable reinsurance capacity provided by Florida government, with little reliance on private market reinsurance. ARC, CCRIF and PCRAFI, on the other hand, rely on reinsurance at market conditions and, therefore, have to charge market prices at the direct insurance level. All schemes benefit from the fact that public sponsors have lower return requirements than private sector investors. From an economic point of view, this is tantamount to a cost of capital subsidy.

The schemes' operating characteristics also differ according to their specific target beneficiaries. Whereas, as mentioned above, ARC is about securing food security under conditions of severe drought (with transparency required from participating governments as to the payouts' low-income beneficiaries and the objective to charge risk-based premiums to all countries), CCRIF covers economic disaster losses suffered by middle-income country governments, with many degrees of freedom afforded as to the allocation of payouts. PCRAFI payout recipients also enjoy significant degrees of freedom in fund allocation. However, insurance is just one element of a broader and holistic risk management approach underpinning PCRAFI.

In the case of CCRIF and PCRAFI payouts are not even tied to specific expenditures. Countries may use payouts to finance disaster relief measures (e.g. the clearance of debris or the provision of shelter) or for any other purpose they consider appropriate. Scherer (2017) calls this a 'laissez-faire approach' which contrasts with the approach taken by ARC which only makes payouts if countries have submitted a contingency plan with detailed information about the intended use of the funds received. Specifically, the plan must outline a social program aimed at maintaining food security as well as the relevant political responsibilities and required procedures. These plans must be submitted even before a country can buy cover under ARC in order to prevent the abuse of funds as well as to incentivize disaster planning.

4.3 CONTRIBUTION TO MARKET DEVELOPMENT

To differing degrees, all schemes detailed in this report aim to contribute to insurance market development, going beyond a pure risk mitigation and transfer mission. As far as insurance market development is concerned, both supply and demand side measures are pursued. The former include the promotion of an enabling environment through data collection (e.g., ARC) and the enhancement of risk-management standards (e.g., the indirect promotion of building standards through Flood Re or PCRAFI's sovereign risk assessments), catastrophe model development (e.g., CCRIF's and ARC's proprietary efforts), and the incentivation of resilience. Demand side measures include, for example, premium subsidies as discussed above. The budgets allocated to these activities depend on the sponsors' specific motivation. Table 7 provides an overview of the five schemes' contribution to market development.

Table 7

ASSESSMENT MATRIX

	FHCF	Flood Re	CCRIF	ARC Ltd.	PCRAFI
Contribution to market development					
Improved data collection and availability	no	yes	yes	no	no
Improved insurance awareness	no	yes	yes	no	no
Promotion of risk management standards	yes	yes	yes	yes	yes
New catastrophe model development	no	no	yes	yes	yes
Incentivising resilience strengthening	yes	yes	yes, on a country level	yes, on a country level	yes, on a country level
Contribution to social safety nets	no	no	no	yes	no
Contribution to insurance demand					
Premium subsidies	yes, cross-subsidies	yes, cross-subsidies for high flood risks	no	no	yes, except for the Cook Islands
Premium discounts	no	no	yes	no	no
Insurance awareness campaigns	yes	yes	yes	Information not available	Information not available
Incentivised insurance take-up	yes	no	yes	no	no
Impact/benefits					
Affordable insurance premiums	yes	yes	yes	not yet	not yet
Affordable reinsurance premiums	yes	yes	no	no	no
Improved reinsurance availability	yes	yes	yes	yes	yes

Note: Yes means: Specific measures implemented or topic addressed in operational procedures

4.4 COMMON CHALLENGES

One challenge common to sovereign schemes in particular is member retention. Basis risk matters greatly under prevailing payout schemes, and countries may be left with no payouts even in the face of severe economic losses.

Another challenge is the sustainability of funding structures, in particular of those with a bias toward debt funding such as FHCF where the litmus test (e.g., another major hurricane such as Hurricane Andrew in 1992) is still outstanding.

Governance is a hot topic too. Among the three developing country schemes introduced in this report, ARC has the tightest controls to ensure good governance and high efficiency. It requires certificates of good standing from all member governments, which include transparency on the beneficiaries and the professional auditing of claims. These features make ARC unique among the sovereign schemes covered in this report.

Another challenge all schemes need to address is the potential erosion of the value of historical catastrophe data against the backdrop of climate change. Adapting risk analysis techniques used in insurance settings to incorporate the uncertain potential effects of climate change is a challenging task, whether an actuarial approach or a simulation modeling approach is used. Actuarial methods, which rely on analysis of historical data, are of limited applicability when confronted with climate change scenarios that are not reflected in past experience (Charpentier (2008)); see section 5 for a more in-depth discussion of this challenge. In practice, doubts as to the relevance of historical data translate into higher uncertainty loadings, e.g., for the severity of tropical cyclones. Generally speaking, there is no alternative to historical data.

Section 5: Actuarial Analysis of CAT Pools

For a CAT pool, there are participating member entities as well as the CAT pool itself as a formed financial entity. Actuaries are often called upon to advise countries in choosing terms of participation in the CAT pool tailored to the financing need of the country, or alternatively to perform independent actuarial analyses of the financial feasibility of the CAT pool itself.

Actuaries have a role to play by assisting countries in assessing their risk-bearing capacity and financial vulnerability in light of their exposure to potential disaster losses. Sound actuarial analyses are needed to help countries choose insurance terms with the CAT pool and to calculate the realized value of the insurance coverage to the participating country. The actuarial analysis starts with an assessment of the potential size of CAT losses to individual countries under various risk peril scenarios, summarized in a loss exceedance curve that reflects existing loss prevention measures. The actuary then examines the budgetary capacity of individual country perils and various risk pooling options (e.g., choices of deductibles and limits per individual country peril).

Actuaries can also perform an actuarial analysis of the financial feasibility of the CAT pool, including the diversification benefit created from the pooling effect, and the need for purchasing reinsurance to protect the CAT pool from extreme catastrophic outcomes. Actuarial analysis helps determine the CAT pool's aggregate loss distribution and evaluates its reinsurance purchasing decisions (e.g., working layers versus high excess layers). A comprehensive analysis of a CAT pool is essential to ensuring maximum transparency of associated costs and benefits for CAT pool participants, thereby assisting public sector decision-makers in making well-informed decisions.

More advanced actuarial analysis is needed to address the potential model risk (e.g., a financial model's inability to perform the tasks it was designed to) and basis risk (that is,., the potential mismatch between the triggered payouts and the actual losses suffered by policyholders) due to discrepancies between modeling assumptions and reality. The actuarial recommendations should also include a discussion of a CAT pool's viability and sustainability by analyzing the financial impact on different stakeholders under various scenarios of loss outcomes over time and provide opinions on complementary financial instruments available to participating countries—such as contingent loans and grants from donors and contingency assessments to enable a holistic financial risk-management approach. The optimal solution may well be a combination of complementary instruments. As stated in the World Bank report (2017), "The optimal solution may involve a combination of instruments to help address different risks (ranging from recurrent to more rare events) and different funding needs (ranging from short-term emergency relief to recovery and reconstruction)."

5.1 RISK ASSESSMENTS OF AN ENTITY'S LOSS EXCEEDANCE CURVE

Consider an entity (country, state) and the potential financial losses (response costs) due to a given peril in a given year, for instance, financial losses to Kenyan farmers of maize crop due to a severe drought.

The prospective size of loss (response cost) for the entity by a specified peril in a given year, *X,* has uncertain outcomes with respective probabilities. Under current exposure and adaptation measures, the possible loss outcomes and associated likelihood for the random variable *X* can be summarized by the probability distribution $F_X(x) = \Pr\{X \leq x\}$, for $x \geq 0$, or equivalently, the loss exceedance curve:

$$S_X(x) = 1 - F_X(x) = \Pr\{X > x\}, \text{ for } x \geq 0.$$

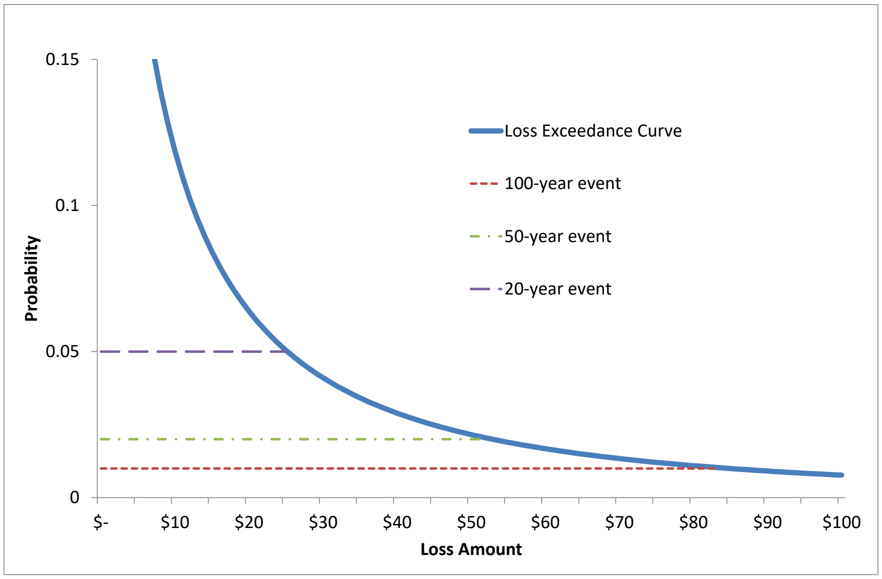
The expected annual ground-up loss is the total area underneath the loss exceedance curve:

$$E[X] = \int_0^\infty x\, dF_X(x) = \int_0^\infty S_X\,(x) dx$$

From a given loss exceedance curve, the actuary can infer maximum loss amounts for five-year, 10-year, 20-year, 50-year, 100-year and 200-year events. For illustration, Figure 8 shows a loss exceedance curve and the loss amounts at 20-year, 50-year and 100-year events.

Figure 8

AN ILLUSTRATIVE LOSS EXCEEDANCE CURVE



Source: Bollmann and Wang

A common metric for the risk-bearing capacity by country peril is the PML at a specified return period. Mathematically, the authors define the *n*-year event PML as:

$$PML_{\alpha} = S_X^{-1}(\alpha).$$

For instance, the 100-year PML refers to the maximum loss amount with an annualized 1% probability of reaching or exceeding the loss amount.

Generally speaking, a country has a natural risk-bearing capacity, *C,* as determined by its financial and budgetary constraints and risk appetite. Losses beyond the risk-bearing capacity can cause financial and budgetary distress, potentially leading to insolvency or a liquidity crunch. Therefore, the PML figures at various return periods (10-year, 20-year, 50-year, 100-year, 1,500-year, etc.) can help shed light on the gap in risk-bearing capacity of a country for the given peril.

For a specified return period n, if the *n*-year PML for a country peril exceeds its risk-bearing capacity C, the difference $PML - C$ represents a deficit (gap) in the risk-bearing capacity. A limited risk-bearing capacity is a fundamental reason for the formation of CAT pools, which enable participating countries to pool their risk-bearing capacities to collectively withstand big losses. Based on the law of large numbers, the impact of individual country-peril "spike" losses are softened through a risk-sharing mechanism. The risk-bearing capacities for all participants increases as a result of pooling as shown below.

The authors define that an Excess-of-Loss layer X(a,a+h] with attachment point *a,* limit *h* and exhaustion point *a+h* has the following payoff:

$$\text{Payoff by Layer } X(a, a+h] = \begin{cases} 0, & X \le a \\ X - a, & a < X \le a+h \\ h, & a+h < X \end{cases}$$

The expected value of the payoff of the layer $X(a, a+h]$ is the area underneath of the loss exceedance curve over the interval (a, a+h]:

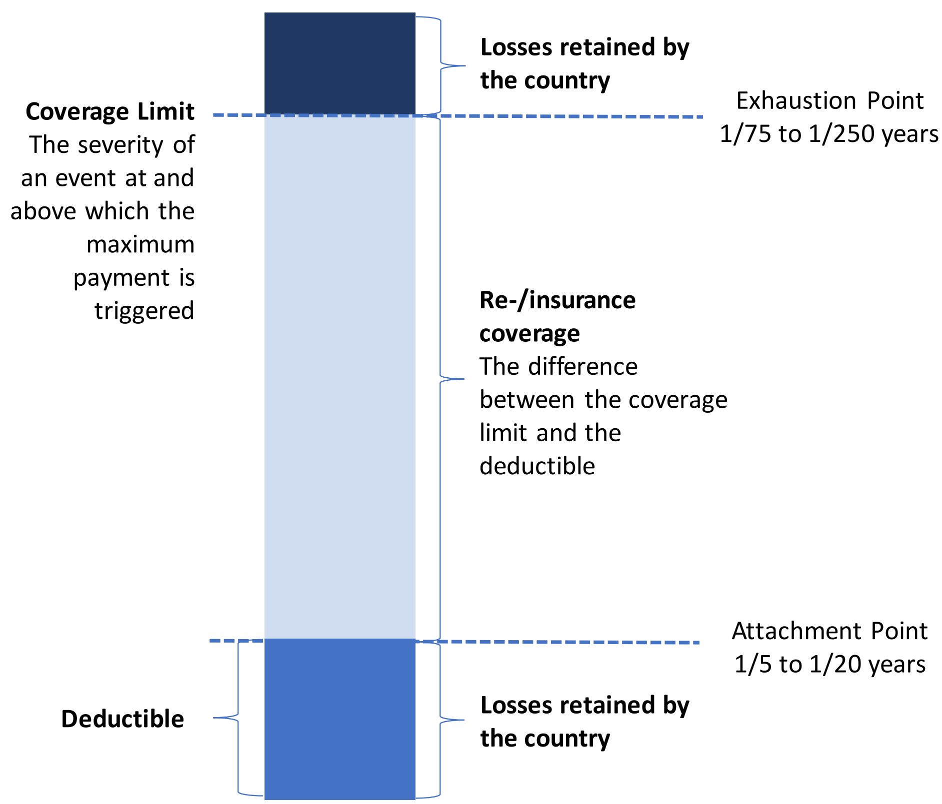
$$\int_a^{a+h} S_X(x)dx$$

Note that for a small limit "*h*," the expected payoff of the layer $X(a, a+h]$ can be approximated by $S_X(a) \cdot h$. Against this backdrop, the loss exceedance curve is also called "layer premium density" (see Venter (1991) and Wang (1996)).

For an individual peril, a country may choose to transfer only a portion (less than 100%) of the excess losses to a regional CAT pool. Figure 9 offers an illustration of typical attachment points and limits in terms of return periods.

Figure 9

TYPICAL DEDUCTIBLES AND LIMITS FOR RISK TRANSFER TO A CAT POOL



Source: Bollman and Wang (2019)

In practice, Loss Exceedance Curves are often provided by commercial CAT modeling firms, reinsurers or brokers, using event simulations to generate modeled losses based on a set of assumptions of underlying variables (e.g., amount of rainfall) and their financial impacts (e.g., financial loss due to loss of crop). For example, ARC's drought model, AfricaRiskView, uses satellite-based rainfall data by geographic areas to estimate the water level shortage for a reference crop in a specific country. Combining water level shortage data with model-embedded population vulnerability data for the affected geographic areas, the AfricaRiskView estimates the number of people affected by the shortfall and an estimated aggregate response cost.

CAT pool arrangements can be based on predefined payout triggers, for example, once the estimated response cost during the covered time period exceeds the deductible agreed in the insurance contract. Such a payout trigger can come in the shape of

- An indemnity trigger where the ultimate payment or contract settlement is determined by the amount of actual reported losses
- A parametric trigger where the ultimate payment or contract settlement is determined by a weather or geological observation or index, such as average temperature or cumulative rainfall over a given period or the intensity of an earthquake or windstorm
- A modeled loss trigger where the ultimate payment or contract settlement is determined by running event parameters against the exposure database in the CAT model.

For instance, the ARC CAT Pool is based on a modeled loss trigger: When the level of rainfall data is known (through satellite image), AfricaRiskView produces financial loss estimates using built-in assumptions of demographics of farms and the amount and type of crops that farmers planted.

Parametric and modeled loss triggers have the advantage of a timely assessment of financial losses, without having to wait for the verification of actual losses incurred, which may take months and may be subject to reporting errors. However, CAT pools based on parametric triggers have the drawback of basis risk (defined as the difference between actual loss amount and modeled loss amount in the context of CAT loss modeling). When analyzing the financial impact of CAT pool arrangements, actuaries should also comment on the associated basis risk.

In insurance, basis risk is unavoidable and neither unambiguously good nor bad, but it should not be ignored. A good risk adviser can help identify basis risk by both clarifying expectations and analyzing contract terms, including any index triggers. Most important, and potentially with the help of an actuary, an informed buyer can evaluate the inevitable trade-offs in price and basis risk to make better decisions potentially saving money. Under any index-based insurance contract, beneficiaries face two sources of uninsured basis risk. The first is idiosyncratic risk, or the risk that a loss unique to an individual policyholder may occur that the instrument does not observe. Savings and loans can help beneficiaries cope with unexpected idiosyncratic losses. On an institutional level, risk carriers could set aside a certain portion of the annual premium to cope with losses that are clearly associated to basis risk. Such a policy feature would be similar to a loss experience account established under certain finite risk insurance contracts.

The second source of risk is imperfections of the index as a predictor of actual losses. For example, a rainfall index predicts average losses for payout determinations. Thus, policyholders may experience losses greater than predicted, and losses may occur even if the index does not trigger payouts. The excess of rainfall coverage, which CCRIF first offered for 2014–2015 policy year, complements the hurricane coverage, which determines losses solely based on wind and storm surge. The excess rainfall product is aimed primarily at extreme high rainfall events of short duration, whether they happen during a hurricane or not. Both products are independent, and if both policies are triggered by an event, then both payouts are due. In that sense, the excess rainfall cover helps policyholders to reduce basis risk of the tropical cyclone insurance product. Another means by which CCRIF can help its members when modeled losses fall below the attachment point but where there are observed losses on the ground is the Adverse Development Cover. This new feature for tropical cyclones and earthquake policies was introduced in the 2017–2018 policy year. It also was designed to reduce the basis risk inherent in parametric insurance in which some events are missed or not identified.

Basis risk in parametric or modeled loss triggers came to prominence in 2015 when the AfricaRiskView assumed that open pollinated (or local) maize was planted for Malawi, while in reality farmers mainly planted short-cycle hybrid maize, which can have drastically different response cost implications for a given water level shortage. These examples illustrate that finding mechanisms to reduce basis risk is essential for successful, scalable insurance schemes.

5.1.2 QUANTIFYING THE EFFECTS OF LOSS PREVENTION

The process of participating in a CAT pool helps countries to make an assessment of their catastrophe risk exposures, including the impact of existing (or planned) adaptation and mitigation measures. In light of climate change and shifting precipitation patterns, flood and drought risks are becoming increasingly unpredictable and can cause greater damage. Therefore, adaptation and mitigation strategies may need to be developed to cope with such challenges, in addition to CAT pool arrangements. Actuarial analyses should take into account the effect of loss prevention measures, which can be described by loss exceedance curves for individual country perils before and after loss prevention measures.

The benefits of adaptation can be measured through (1) the reduction in expected losses, (2) the reduction in standard deviation and (3) a change in PML. PML may actually increase because of certain adaptation measures, such as flood protection dams, which may increase the asset values exposed to the risk of loss.

Haer et al (2017) discuss an economic cost-benefit analysis of adaptation or prevention measures using the differences in net present values of (1) reduction in annual damage and (2) initial investment plus annual maintenance costs:

$$NPV = PV(\text{Benefits}) - PV(\text{Costs})$$

$$NPV = \sum_{t=1}^{T} \frac{(1+\alpha)\cdot RAD}{(1+r)^t} - IC - \sum_{t=1}^{T} \frac{AMC_t}{(1+r)^t}$$

where

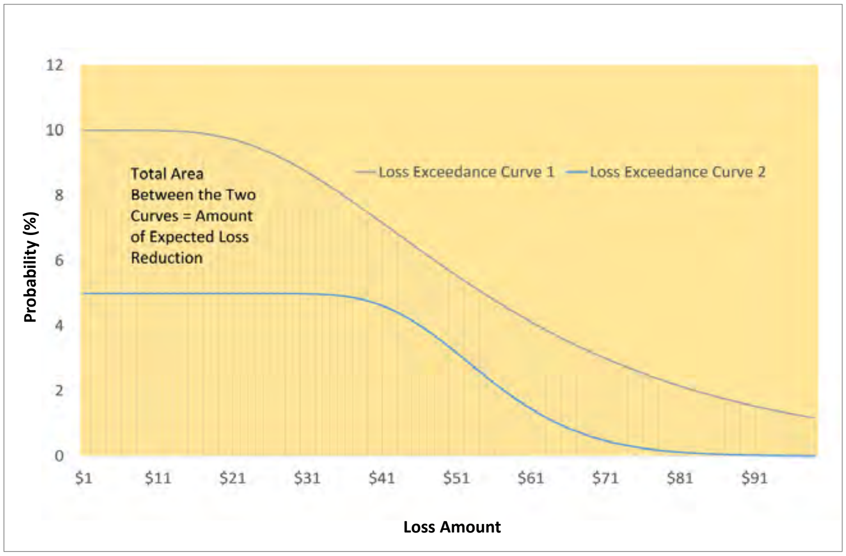
- *RAD* is the reduction in annual damage
- The value α is the ratio of indirect economic cost to direct economic cost
- *IC* is the initial cost
- *AMC* is the annual maintenance cost
- *NPV* is also the economic value created through adaptation.

Analytically, one can estimate the “reduction in annual damage” using the loss exceedance curves for individual country perils before and after loss prevention measures (see Figure 10). The expected loss reduction is the difference in the total area under loss exceedance curve 1 (before adaptation) and the total area under loss exceedance curve 2 (after adaptation).

According to UNDP (2012), “Every dollar invested into disaster preparedness saves seven dollars in disaster aftermath. Yet only 1% of international aid is spent to minimize the impact of these disasters.” Therefore, it is essential that the CAT pool arrangement offers explicit risk premium discounts to reflect the effects of risk mitigation and prevention, thus providing the right incentives for individual countries and organizations to adopt risk mitigation and prevention measures.

Figure 10

LOSS EXCEEDANCE CURVES BEFORE AND AFTER ADAPTATION AND PREVENTION MEASURES



Source: Bollman and Wang (2019)

Example taken from Rebound (2015): Hoboken, New Jersey, is prone to flooding due to its location on the Hudson River, low topography and waterproof concrete surfaces. In 2012, storm surge from Superstorm Sandy inundated low-lying areas of the city with between 4–6 feet of flood water. Subsequently, Hoboken received $230 million in federal funding for use to build coastal storm surge protection up to the 500-year surge level. Modeling results from Risk Management Solutions (RMS) indicate that this 500-year surge level is equivalent to a surge height of approximately 12.3 feet above NAVD88 at The Battery tidal gauge, New York. RMS modeling also showed that projects providing protection below 8 feet above datum are unlikely to have a significant impact on surge losses. Each foot of protection above 8 feet provides significant additional value.

Table 8

MODELED ECONOMIC LOSSES TO CITY TO HOBOKEN DUE TO HURRICANE DRIVEN STORM SURGE

Return Period	8-foot Surge Protection	9-foot Surge Protection	10-foot Surge Protection	11-foot Surge Protection
50 years	< $1	< $1	< $1	< $1
100 years	$361	< $1	< $1	< $1
200 years	$985	$985	$907	<$1
500 years	$1745	$1745	$1745	$1733
Average Annual Loss	$12.7	$11.9	$9.4	$6.4

Source: Risk Management Solutions (RMS), 2015

5.2 AN ENTITY'S RISK BEARING CAPACITY AND FINANCIAL VULNERABILITY

Consider an entity, which can be a nation, a state or a municipality. The entity faces potential direct loss *X* from a given peril natural disaster, with a probability distribution $F_X(x) = \Pr\{X \le x\}$ and loss exceedance curve $S_X(x) = 1 - F_X(x) = \Pr\{X > x\}$.

For a given entity, the authors introduce a concept of risk-bearing capacity *C* and financial vulnerability index α >1, such that the fiscal impact on the entity by a direct loss *X* is equal a stress-adjusted value: $w(X) \cdot X$, where the stress weight $w(X)$ equal one for losses below the risk-bearing capacity and increases for losses exceeding the risk-bearing capacity (see Figure 11):

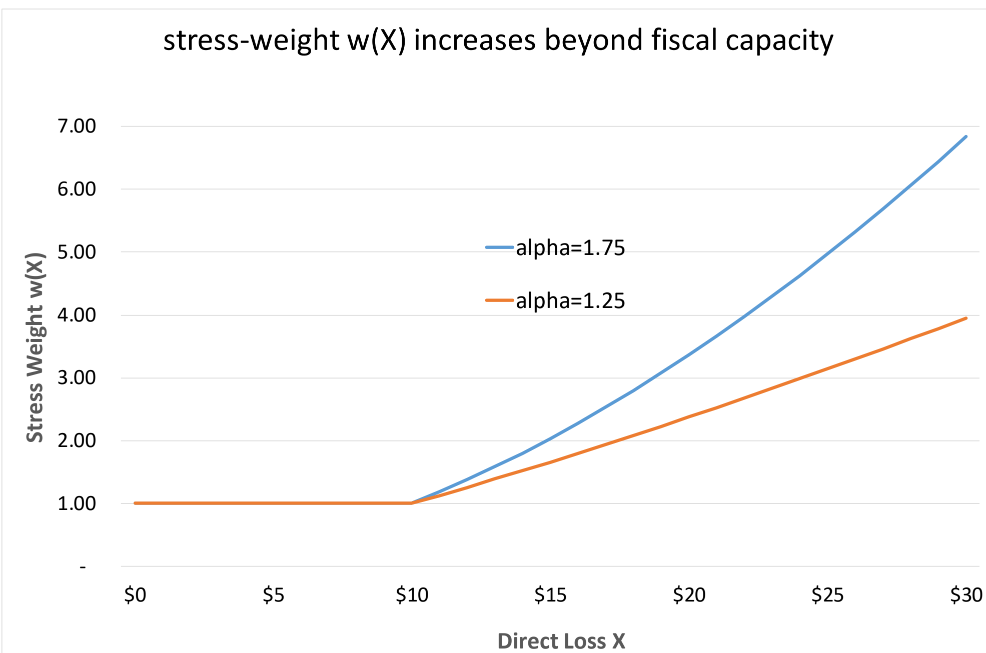
$$w(X) = \begin{cases} \left(\frac{X}{C}\right)^{\alpha}, & \text{when } X > C \\ 1, & \text{when } X \le C \end{cases}$$

The risk-bearing capacity *C* may be a function of the entity's GDP, the size of its annual budget or its contingency reserve. A rich nation would have a much higher risk-bearing capacity than a small nation: $C_{\text{rich nation}} > C_{\text{small nation}}$.

The financial vulnerability index α would depend upon the creditworthy of the entity (e.g., the borrowing power against future revenues). A rich nation or a rich state (e.g., Florida or California) would have a lower financial vulnerability index than a small nation: $1 \le \alpha_{\text{rich nation}} < \alpha_{\text{small nation}}$.

Figure 11:

AN ILLUSTRATION OF STRESS WEIGHT FUNCTION



Source: Bollman and Wang (2019)

For a given entity, the PML_{α} is the amount that will equal or exceed 100 α% of all possible loss amounts under various scenarios. For instance, $PML_{99.5\%}$ corresponds to the 200-year event worst-loss scenario. The maximum possible loss (MPL) is the maximum value of all possible values of X, or $PML_{100\%}$.

An entity may choose a threshold level α such that losses exceeding the threshold level PML_α are deemed beyond the practical concern to the entity. The chosen PML can be expressed as a multiple of risk-bearing capacity *C*.

In the literature, Ghesquiere and Mahul (2010) define a cost multiplier as the ratio between the opportunity cost of the financial product (e.g., premium of an insurance product, expected net present value of a contingent debt facility) and the expected payout of that financial product. Assume that the premium for insuring loss *X* is *P*(*X*), while the expected loss of *X* is *E*[*X*], the ratio $\frac{P(X)}{E[X]}$ is the cost multiplier for taking full insurance of disaster loss *X*.

The expected value of the direct loss *X* can be expressed as:

$$E[X] = \int_0^{MPL} x dF_X(x)$$

Using the authors' concept of risk-bearing capacity *C* and financial vulnerability index α, in the absences of insurance, the entity faces an expected stress-adjusted value of disaster losses:

$$E[w(X) \cdot X] = \int_0^C x dF_X(x) + \int_C^{MPL} x \left(\frac{x}{C}\right)^\alpha dF_X(x) \qquad \text{(Eq-1)}$$

Generally, the expected stress-adjusted value exceeds the expected loss: $E[w(X) \cdot X] > E[X]$.

The entity is indifferent to either (1) facing the risk exposure itself without purchasing insurance or (2) willing to pay a premium P(X) equal the expected stress-adjusted impact $E[w(X) \cdot X]$. The maximum premium the entity is willing to pay is the expected stress-adjusted value: *P*(*X*) = $E[w(X) \cdot X]$. As long as the insurance premium P(X) does not exceed the expected stress-adjusted value, $E[w(X) \cdot X]$, there is net economic benefit to the entity in purchasing full insurance. For the entity, the maximum tolerable cost multiplier is equal to $\frac{E[w(X) \cdot X]}{E[X]}$.

5.2.1 SMALL NATIONS VERSUS LARGE NATIONS

There are vast differences among countries with regard to the exposure to natural disasters and their capacities in responding to disasters.

Countries have different levels of exposure to natural disasters. Small island nations are particularly vulnerable to natural disasters and the effects of climate change. Densely populated coastal cities are subject to the increasing intensity of cyclones, storm surge and seal level rise.

Countries have different levels of financial resources in responding to disasters. While developed economies generally have more resources for responding to disasters, emerging economies and small nations often lack the resources and infrastructure in adequately responding to disasters.

Large and financially strong countries have managed to absorb the impacts of the most severe natural disasters that have caused a relatively small dent or ripple on their GDP. For instance, the total damages and losses stemming from Hurricane Katrina in 2005 were estimated to be $160 billion, or about 1% of real GDP (Federal Reserve Board of Governors (2005)). The immense damage caused by the 2011 Great East Japan Earthquake and Tsunami totaled US$228 billion, which is about 3.4% of Japan's GDP. In contrast, small nations can suffer a loss from natural disasters than amount to 15% to 60% (or even higher) of their annual GDP, which represent a sharp percentage fall in GDP, a much more severe damage to the national economy of small nations (See Table 9).

Table 9

TOP 10 CLIMATE-RELATED DISASTERS FOR LOSSES AS PERCENTAGE OF GDP 1998–2017

Name & Date	Country/Territory affected	Economic Loss (billion USD)	Economic loss as % GDP
Hurricane Irma–Sep.2017	Sint Maarten	2.5	797%
Hurricane Irma–Sep.2017	Saint Martin	4.1	584%
Hurricane Irma–Sep.2017	British Virgin Islands	3	309%
Hurricane Maria–Sep.2017	Dominica	1.46	259%
Hurricane Ivan–Sep.2004	Grenada	1.15	148%
Hurricane Ivan–Sep.2004	Cayman Islands	4.43	129%
Hurricane Georges–Sep.1998	Saint Kitts and Nevis	0.6	110%
Hurricane Erika–Aug. 2015	Dominica	0.5	90%
Hurricane Mitch–Oct. & Nov. 1998	Honduras	5.68	73%
Hurricane Maria–Sep.2017	Puerto Rico	68	69%

Source: CRED & UNISDR, 2018

5.2.2 COST MULTIPLIER FOR INSURANCE WITH VARYING DEDUCTIBLES

Now the authors considered a partial insurance that pays a proportional share θ ($\leq 100\%$) of "the loss in excess of chosen deductible *a*, and capped by a limit *h*." This insurance contract payoff can be expressed as

$$\text{Insurance Payoff Y(X)} = \begin{cases} 0, & \text{when } X \leq a \\ \theta \cdot (X - a), & \text{when } a < X \leq a + h \\ \theta \cdot h, & \text{when } a + h < X \end{cases}$$

The authors denote the premium for this partial insurance by P(Y).

The expected stress-adjusted value of insurance payoff Y is

$$E[w(X) \cdot Y(X)] = \int_0^C Y(x) dF_X(x) + \int_C^{MPL} Y(x) \left(\frac{x}{C}\right)^\alpha dF_X(x)$$

Under this partial insurance, the entity faces a net retained loss $Z(X) = X - Y(X)$:

$$Z(X) = \begin{cases} X, & \text{when } X \leq a \\ \theta a + (1 - \theta)X, & \text{when } a < X \leq a + h \\ X - \theta h, & \text{when } a + h < X \end{cases}$$

The expected stress-adjusted value of net retained loss is:

$$E[Z(X) \cdot w(X)] = \int_0^C z(x) dF_X(x) + \int_C^{PML} z(x) \left(\frac{x}{C}\right)^{\alpha} dF_X(x) \qquad \text{(Eq-2)}$$

The maximum tolerable cost multiplier $\frac{P(Y)}{E[Y]}$ is equal to

$$\frac{E[w(X) \cdot Y(X)]}{E[Y(X)]}$$

The value of the partial insurance to the entity is the difference

$$E[Y(X) \cdot w(X)] - P(Y)$$

For an entity, both the maximum tolerable cost multiplier and the "value of insurance" to an entity shall depend on a combination of factors:

1. The entity's risk-bearing capacity *C* and financial vulnerability α
2. Terms for the insurance coverage *Y*: deductible a and limit *h*, and the proportional share ϑ
3. The associated insurance premium *P*(*Y*)

Example: An entity faces a disaster loss *X*, which has a once-in-three-year occurrence, and given an occurrence, the size of loss distribution has a Pareto distribution:

$$F_X(x) = 1 - \left(\frac{40}{40 + x}\right)^3$$

The entity has a risk-bearing capacity of C=\$20 and financial vulnerability index of α=1.25.

Table 10

ILLUSTRATIVE RISK LOADING BY LAYER

Layer Option	Layer 1 Deductible = \$0 Limit = \$20	Layer 2 Deductible = \$20 Limit = \$20	Layer 3 Deductible = \$40 Limit = \$20
Expected Loss	E[Y] = \$3.82	E[Y] = \$1.13	E[Y] = \$0.61
Expected Stress-Adjusted Value	E[w(X) Y] = \$7.50	E[w(X) Y] = \$4.76	E[w(X) Y] = \$3.22
Maximum Tolerable Cost Multiplier	196%	359%	528%

This illustrative example (see Table 10) shows that the maximum tolerable cost multiplier depend on the deductible. As the deductible increases, the maximum tolerable cost multiplier also increases.

5.3 TIMELINESS OF PAYMENTS; BASIS RISK AND POLITICAL OWNERSHIP

The successful operation of a CAT Pool requires consideration of several factors including timeliness of payments, basis risk and political ownership, which shall be discussed in detail below.

5.3.1 TIMELINESS OF PAYMENTS

Suppose that there is a time delay Δt in insurance payment Y(X). The stress-adjusted value of the insurance payment will be discounted:

$$Y(X) \cdot w(X) \cdot e^{-\rho \Delta t}$$

The authors assume the discount rate ρ is higher than the risk-free interest rate and the financial vulnerability index α >1.

Delays or disputes in insurance payments can significantly reduce the value of insurance to the insured (entity).

For a CAT Pool participant (an entity), the value of CAT Pool insurance protection shall depend on the timeliness of insurance payments.

Consider an entity who paid premium P_i, incurred direct loss x_i and received insurance payments of y_i with time delay Δt_i, in year j (for j=1, …, m).

The realized value of insurance to the entity in year *j* is

$$y_j \cdot w(x_j) \cdot e^{-\rho \Delta t_j} - P_j$$

The cumulative realized value of insurance over a multiple year period *j*=1… *m* is

$$\sum_{j=1}^{m} \left(y_j \cdot w(x_j) \cdot e^{-\rho \Delta t_j} - P_j \right)$$

5.3.2 MAGNIFIED EFFECT OF BASIS RISK FOR SMALL NATIONS

Some insurance contracts whose payments are based on parametric or index metrics, which may differ from the actual amount of losses incurred.

Definition: Basis risk in a parametric index insurance is the difference between the parametric index V(X) and the entity’s (the insured's) actual loss X.

In a given scenario outcome, *j*, the entity suffers a big loss with $x_j > C$; if the parametric index significantly underestimates the loss, $V(x_j) < x_j$, it would create a big negative stress-adjusted value to the insured:

$$(v(x_j) - x_j) \cdot \left(\frac{x_j}{C}\right)^{\alpha}, \quad \alpha > 1$$

In other words, basis risk is magnified when the insured suffers a big loss at a time precisely when the insured needed the payment the most. The magnifying impact of basis risk is more pronounced for small nations with a low risk-bearing capacity.

Even if the parametric index is unbiased with *E*[*V*(*X*)]=*E*[*X*], the expected stress-adjusted value of the basis risk creates negative economic value to the entity:

$$E[(V(X)-X)\cdot w(X)] = \int_0^C (V(x)-x)dF(x) + \int_C^{PML} (V(x)-x)\left(\frac{x}{C}\right)^{\alpha} dF(x) < 0$$

For a small nation with low risk-bearing capacity *C*, the basis risk can generate a significant negative economic value, on an expected value basis.

5.3.3 CATASTROPHE RISK POOLING WITHIN A POLITICAL UNION

Now consider several small nations (states) $i = 1, 2, \cdots, n$. Each nation *i* faces a natural disaster loss X_i and has a risk-bearing capacity C_i. For simplicity, the authors assume that financial vulnerability index for each small nation is the same, $\alpha_i = \alpha$ >1.

Consider a special case that the small nations come together to form a political union through full risk sharing and resources pooling, such that the pool will pay all losses by individual nations:

$$S = X_1 + X_2 + \cdots + X_n$$

and that the pool will have access to the combined risk-bearing capacity

$$C_S = C_1 + C_2 + \cdots + C_n$$

The pool has a financial vulnerability index $\alpha_S \leq \alpha$. (The pool's collective borrowing power is stronger)**.**

Under this political union arrangement, the stress-adjusted value of aggregate losses to the pool is

$$E[S \cdot w_S(S)], \text{ where } \quad w_S(S) = \begin{cases} \left(\frac{S}{C_S}\right)^{\alpha}, & \text{when } S > C_S \\ 1, & \text{when } S \leq C_S \end{cases}$$

The stress-adjusted value of aggregate losses to the pool can be significantly lower than the sum of stress-adjusted value of losses to individual nations in the absence of the risk pool:

$$E[S \cdot w_S(S)] < \{ \textstyle\sum_{i=1}^{n} E[w_i(X_i) \cdot X_i] \}, \text{ where } \quad w_i(X_i) = \begin{cases} \left(\frac{X_i}{C_i}\right)^{\alpha}, & \text{when } X_i > C_i \\ 1, & \text{when } X_i \leq C_i \end{cases}$$

The difference $\{ \sum_{i=1}^{n} E[w_i(X_i) \cdot X_i] \} - E[S \cdot w_S(S)]$ represents the net benefit of risk pooling among the n small nations through political union in full risk sharing and resources pooling.

The pool is still vulnerable to extremely large correlated loss when most or all nations in the pool suffer losses at the same time. An economic case can be made for the pool to purchase reinsurance.

5.3.4 CATASTROPHE RISK POOL OF SEPARATE ENTITIES (NONPOLITICAL UNION)

In reality, participating members of the catastrophe risk pool are independent nations (states) with different political constituencies. When it comes to insurance pooling arrangement, each participating member may seek price discoveries and self-selection of the terms of insurance.

Even with perfect information of the underlying loss distributions for each participating member, actuarial risk pricing helps define an equitable risk sharing among member countries in the Sovereign CAT Pool; however, actual outcomes may favor some countries while penalizing other countries in terms of realized benefit of their respective insurance with the pool.

Thus, a key factor to the success of the catastrophe risk pooling arrangement is to ensure each participating member sees positive value in its insurance with the pool. This shall require adequate education of the participating members in understanding the random nature of outcomes in any given year.

This calls for careful considerations on how the pooling benefits are to be distributed to members, as part of pre-arranged operating formula of the pool.

International donors that contribute to the pool are in an ideal position to formulate and seek consent for mutually acceptable operating principles of the pool.

There are other intangible benefits for participating members, for instance, knowledge transfer and sharing of "wealth creation" in the operation of the CAT pool.

5.4 ACTUARIAL ANALYSIS OF DIVERSIFICATION BENEFITS OF CAT POOLS

An economic case for CAT pool is to smooth out the shocks of extreme catastrophic events through pooling and to provide liquidity in times of need. Here the authors present an analytical framework for quantifying the financial impact of CAT pools on its participants.

Consider a number of *J* country perils with the country-peril index $j \in \{1, 2, \cdots, J\}$. Consider a sample of simulated *K* scenarios, with the associated vector of losses to each country peril:

$$X(k) = \{x_1(k),\ x_2(k), \cdots, x_J(k)\},\ for\ k\ in\ \{1, 2, \cdots, K\}$$

where $x_j(k)$ represent the loss amount for country peril *j* in scenario *k*. Each (simulated) scenario $k \in \{1, 2, \cdots, K\}$ is assigned with a probability *p*(*k*) of occurrence and the sum $\sum_{k=1}^{K} p(k) = 1$. In the case of equal probability scenarios, *p*(*k*) =1/*K*.

Generally speaking, the losses from individual country perils can be correlated with the correlation structure embedded in the multivariate loss scenarios for all participating country perils.

For country peril *j*, let a_j and h_j be the *per-event* attachment point and limit, applicable to the ground-up losses X_j for country peril *j*. Let θ_j be the ceding percentage of losses to the layer $X_j\ (a_j, a_j + h_j]$. The ceded loss by country peril *j* to the CAT pool is $y_j(k) = \theta_j \cdot \min(h_j, \max(0, x_j(k) - a_j))$. The aggregate loss to the CAT pool consisting of all *j* country peril in the scenario *k* is the sum:

$$Z(k) = \sum_{j=1}^{J} y_j(k)$$

The diversification benefits of the CAT pool can be measured through (1) the reduction in PML and (2) reduction in standard deviation.

5.4.1 REDUCING PML

One can measure the reduction in PML (*n*-year return period) as follows:

1. Before pooling, the sum of individual country peril PML is $\sum_{j=1}^{J} S_{Y_j}^{-1}(1/n)$
2. After pooling, the CAT pool has a total PML: $S_Z^{-1}(1/n)$
3. The relative ratio in PML measures the percentage reduction in PML:

$$Percentage\ Reduction\ in\ PML = \mathbf{1} - \frac{S_Z^{-1}(1/n)}{\sum_{j=1}^{J}(S_{Y_j}^{-1}(1/n))}$$

Example 1: The authors use a set of simulated loss data output of AfricaRiskView for a hypothetical CAT pool arrangement. The dataset contains simulated losses of 18 country perils (including the two perils of drought and tropical cyclone). From Table 11, the percentage reduction in the 20-year return period PML is 65%, and the percentage reduction in the 200-year return period PML is 64%.

Table 11

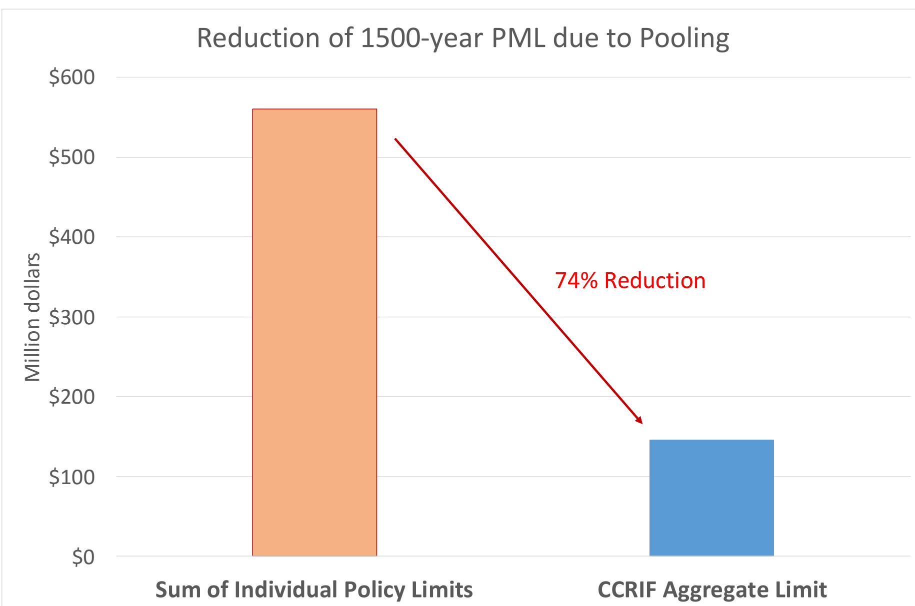
PERCENTAGE REDUCTION IN PML BY POOLING

n-year return period	Sum of individual PMLs	CAT pool PML	% reduction in PML by pooling
10	$ 107,252,411	$ 59,897,558	44%
20	$ 205,178,573	$ 72,035,172	65%
50	$ 261,096,597	$ 86,118,963	67%
100	$ 290,330,166	$ 95,815,007	67%
200	$ 292,609,819	$ 105,978,234	64%

Example 2: The authors also refer to CCRIF as an example to illustrate the diversification benefits of CAT pools. Technical analysis that supports CCRIF shows a 74% reduction in PML at the 1,500-year return period level (see Figure 12).

Figure 12

REDUCTION OF PML FOR THE CARIBBEAN CATASTROPHE RISK INSURANCE FACILITY (CCRIF)



Source: Bollmann and Wang (2019)

5.4.2 REDUCING STANDARD DEVIATION

A reduction in PML pooling generally also results in a reduction in standard deviation. The classic portfolio theory employs a correlation (covariance) matrix in evaluating diversification benefits. Ideally, scenario simulations of multiple country-peril losses can provide a richer correlation structure by explicitly incorporating the drivers of correlation. However, when the number of country perils increases, the task of simultaneously simulating losses to multiple countries can be very time consuming. Therefore, the correlation matrix approach complements scenario simulations in analyzing the portfolio risk of the CAT pool.

Here the authors provide a brief overview of the correlation matrix approach and the methods of moments for risk aggregation. Assume that the ceded loss Y_j by country peril *j* has the following mean and standard deviation, $E[Y_j]$ and $\sigma[Y_j]$, respectively. The correlation matrix of the ceded losses Y_j by country perils is

$$\begin{bmatrix} 1 & \rho_{1,2} & \cdots & \rho_{1,,J} \\ \rho_{2,1} & 1 & \cdots & \rho_{2,J} \\ \vdots & \vdots & \ddots & \vdots \\ \rho_{J,1} & \rho_{J,2} & \cdots & 1 \end{bmatrix}$$

The aggregate variance for the CAT pool is

$$Var(Z) = \sum\nolimits_{i=1,j=1}^{J} \rho_{ij} \cdot \sigma[Y_i] \cdot \sigma[Y_j]$$

The aggregate standard deviation for the CAT pool is

$$\sigma(Z) = \sqrt{\sum\nolimits_{i=1,j=1}^{J} \rho_{ij} \cdot \sigma[Y_i] \cdot \sigma[Y_j]}$$

One can measure the reduction in the standard deviation through pooling as follows:

1. Before pooling, the sum of individual country-peril standard deviation is $\sum_{\boldsymbol{j=1}}^{\boldsymbol{J}} \sigma(Y_j)$
2. After pooling, the CAT pool has a total portfolio standard deviation of $\sigma(Z)$
3. The relative ratio in standard deviation measures the percentage reduction in standard deviation.

$$\text{Reduction in Standard Deviation} = \mathbf{1} - \frac{\sigma(Z)}{\sum_{\boldsymbol{j=1}}^{\boldsymbol{J}} \sigma(Y_j)}$$

Example 3: The authors use the set of simulated loss data output of AfricaRiskView for a hypothetical CAT pool arrangement. They consider the sub-sample of loss data from 14 country perils (due to drought only).

Table 12

STANDARD DEVIATIONS OF SIMULATED LOSSES OF 14 COUNTRY-PERILS]

Country-Peril 1	Country-Peril 2	Country-Peril 3	Country-Peril 4	Country-Peril 5	Country-Peril 6	Country-Peril 7	Country-Peril 8	Country-Peril 9	Country-Peril 10	Country-Peril 11	Country-Peril 12	Country-Peril 13	Country-Peril 14
1,811,335	2,422,791	7,663,684	7,341,810	1,510,302	6,216,261	6,361,824	1,399,867	6,982,353	3,243,774	2,202,410	2,979,394	5,708,423	3,067,124

The diversification benefits can also be seen from the low correlation coefficients in the computed correlation matrix of excess-of-losses that contribute to the CAT pool losses.

Table 13

CORRELATION MATRIX OF 14 COUNTRY-PERILS

	Country-Peril 1	Country-Peril 2	Country-Peril 3	Country-Peril 4	Country-Peril 5	Country-Peril 6	Country-Peril 7	Country-Peril 8	Country-Peril 9	Country-Peril 10	Country-Peril 11	Country-Peril 12	Country-Peril 13	Country-Peril 14
Country-Peril 1	1.00	0.11	0.00	-0.07	0.10	-0.10	-0.01	-0.10	-0.09	0.47	0.25	0.26	0.12	0.01
Country-Peril 2	0.11	1.00	-0.01	-0.07	-0.07	-0.01	0.01	-0.09	-0.01	0.27	0.24	0.42	-0.01	0.00
Country-Peril 3	0.00	-0.01	1.00	0.09	0.09	0.46	0.01	-0.11	-0.01	-0.11	0.01	-0.01	0.10	-0.09
Country-Peril 4	-0.07	-0.07	0.09	1.00	0.01	0.08	-0.13	0.02	0.11	-0.09	-0.07	-0.08	-0.01	0.02
Country-Peril 5	0.10	-0.07	0.09	0.01	1.00	0.11	0.01	-0.08	0.01	-0.02	0.38	0.08	0.59	0.10
Country-Peril 6	-0.10	-0.01	0.46	0.08	0.11	1.00	0.11	-0.01	0.12	-0.10	0.00	-0.09	0.00	0.12
Country-Peril 7	-0.01	0.01	0.01	-0.13	0.01	0.11	1.00	0.12	0.11	-0.12	-0.10	-0.01	0.01	-0.09
Country-Peril 8	-0.10	-0.09	-0.11	0.02	-0.08	-0.01	0.12	1.00	0.27	-0.10	-0.10	-0.10	-0.09	0.27
Country-Peril 9	-0.09	-0.01	-0.01	0.11	0.01	0.12	0.11	0.27	1.00	-0.09	0.01	0.01	0.01	0.24
Country-Peril 10	0.47	0.27	-0.11	-0.09	-0.02	-0.10	-0.12	-0.10	-0.09	1.00	0.27	0.13	0.00	0.00
Country-Peril 11	0.25	0.24	0.01	-0.07	0.38	0.00	-0.10	-0.10	0.01	0.27	1.00	0.40	0.41	0.01
Country-Peril 12	0.26	0.42	-0.01	-0.08	0.08	-0.09	-0.01	-0.10	0.01	0.13	0.40	1.00	0.12	-0.01
Country-Peril 13	0.12	-0.01	0.10	-0.01	0.59	0.00	0.01	-0.09	0.01	0.00	0.41	0.12	1.00	0.10
Country-Peril 14	0.01	0.00	-0.09	0.02	0.10	0.12	-0.09	0.27	0.24	0.00	0.01	-0.01	0.10	1.00

From Table 12, the sum of individual country perils standard deviations is $\sum_{j=1}^{14}\sigma(Y_j)$=58,911,353. Using the correlation matrix in Table 13, the CAT pool has a total portfolio standard deviation of $\sigma(Z)$=21,445,582. Thus, the reduction in standard deviation is $1-\frac{\sigma(Z)}{\sum_{j=1}^{J}\sigma(Y_j)}$ = 64%.

Remark: Portfolio Theory explicitly estimates diversification benefits through a CAT pool, but its application has limitations. While CAT pools can be very effective in diversifying risks that do not hit all country perils at once, a CAT pool is ineffective in diversifying risks that hit all country perils at the same time. This reveals a limitation (or disadvantage) of regional CAT pools, highlighting the need for the CAT pool to purchase reinsurance or issue CAT bonds to capital markets to achieve further diversification and to address highly correlated scenarios (e.g., an extreme drought and a strong tropical cyclone causing high damages to all country perils in the same year).

5.5 BENCHMARK PRICING AND THE COST OF REINSURANCE

Now the authors analyze the portfolio risk of a CAT pool. Consider its aggregate loss as the sum of excess of losses from all *j* country perils

$$Z=\sum_{j=1}^{J}Y_j\ ,$$

where $Y_j=\theta_j\cdot\min(h_j,\max(0,X_j-a_j))$ is the loss contribution from country peril *j* after applying individual attachment point a_j, limit h_j and ceding percentage θ_j to the ground-up loss X_j.

The CAT pool needs to purchase its own reinsurance on the aggregate loss *Z* with attachment *A* and limit *H*

$$\text{Reinsurance Payout}(k) = \min(H, \max(Z(k) - A)).$$

The cost of reinsurance is normally one of the largest expense items of any regional CAT pool and thus can have major financial implications for its participants and sponsors. A key question is whether the CAT pool is better off purchasing reinsurance for working layers (for two- to five-year return periods), intermediate excess layers (for five- to 10-year return periods), or high excess-of-loss layers (beyond 10-year return period). One advantage of purchasing reinsurance for working layers is that reinsurance is expected to pay out every couple of years; while the total ceded premium is higher than for higher layers, the relative (percentage) loading is usually smaller than with higher layers. In this case, the value of reinsurance is more obvious to CAT pool participants. On the other hand, intermediate and high excess-of-loss layers provide more protection against extreme loss scenarios. For high excess of loss reinsurance layers, the risk load can exceed the expected loss (with an expected loss ratio of less than 50%); when participants review the cumulative loss ratio (total reinsurance payouts relative to the total reinsurance premium) over a period of several years, they may start to question whether they are getting value from reinsurance arrangements. This can become a sensitive issue when the CAT pool participants are small, low-income countries.

Theoreticians and academics argue that an adequate amount of risk load is required to compensate reinsurers who subject their capital to support the assumed reinsurance risk. If the level of risk load is very high, it will attract more capital to the reinsurance market and thus increase the supply of reinsurance, which will lead to a lowering of the risk load, with an ultimate equilibrium price (clearing price) of reinsurance. In a competitive market, at a given time period, the market clearing price of reinsurance (and the risk load contained in the market price) should not be too high or too low so that supply of and demand for capital are in balance. Conceptually, such an equilibrium price of reinsurance implies the existence of some benchmark pricing formula. The academic concept of equilibrium price is only valid for specific geographies and points in time. Whether the underlying is in a peak zone (with high value concentration) or not has a major impact on pricing. In addition, reinsurance pricing exhibits cyclical patterns and reacts to shock losses and large capital inflows and outflows, with alternating hard market years (where relative risk load to expected loss is high) and soft market years (where relative risk load to expected loss is low). As a result, the cost of reinsurance may vary significantly from one year to the next.

From a practitioner's point of view, the loss exceedance curve (and the expected reinsurance payout) is never precisely known. The various reinsurers and the cedent will all have their own view of the expected loss—which obviously directly influences pricing and induces variations of the implicit risk load.

Some practitioners point out that reinsurance cycle is on its way out—if one looks at the Guy Carpenter global CAT reinsurance Rate-on-Line plot for the last 30 years, the insurance cycle has dramatically reduced. Reasons include a better understanding of event probabilities and the much improved fungibility of capital (insurance-linked securities).

5.5.1 RISK LOAD AND BENCHMARK PRICE OF REINSURANCE

The optimal amount of reinsurance for the CAT pool to purchase depends on the trade-off of the cost of reinsurance and the benefit of risk reduction, as well as the collective risk appetite (risk tolerance) of participants of the CAT pool. To understand the cost-benefit of reinsurance purchases, one first needs to be able to compute benchmark prices for the reinsurance cover.

An appropriate methodology or actuarial price formula is needed to calculate the risk load, so that one can compare different reinsurance layer options (attachment and exhaustion points) and their relative prices. An actuarial pricing formula should contain relatively few pricing parameters that can be estimated or inferred from real-world reinsurance transactions.

Benchmark pricing parameters inferred from market transactions may change over time, reflecting the market conditions (hard market or soft market). Nevertheless, at any point in time, a set of pricing parameters can be used to compute reinsurance prices for different layers or to compare the reinsurance prices of two different portfolios.

We define *benchmark reinsurance prices* as the prices calculated from an actuarial price formula with given pricing parameters. In the actuarial literature, there is a vast body of papers dedicated to calculating benchmark reinsurance prices. There are three general approaches:

1. Applying more weight to large losses that is rooted in the utility theory (e.g., Hardy (2006))
2. Deriving a transformed loss exceedance curve (see Figure 13) such that the reinsurance price of a layer is the area underneath the transformed loss exceedance curve (e.g., Wang (1996, 2000, 2004))
3. Quantifying a risk margin from an insurance portfolio capital requirement point of view (e.g., Kreps (1996), Mango (2006))

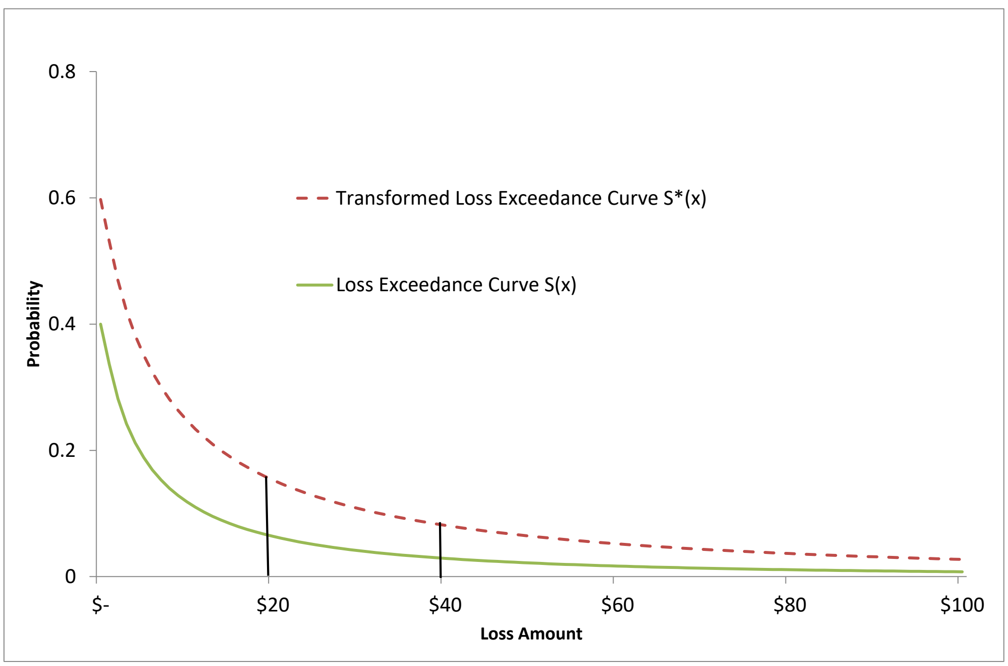
Among these different methods, the Wang Transform stands out as a popular formula for the purpose of deriving benchmark reinsurance prices. Mathematically, Wang Transform maps a loss exceedance curve $S_Z(z)$ to a risk-adjusted pricing curve $S_Z^*(z)$ with the following formula:

$$S_Z^*(z) = t_k\left[\Phi^{-1}\left(S_Z(z)\right) + \lambda\right],$$

where λ corresponds to the Sharpe Ratio, Φ is the cumulative standard normal distribution and t_k represents student-t distribution with k degree of freedom.

Figure 13

APPLYING WANG TRANSFORM: AN ILLUSTRATION



Source: Bollmann and Wang (2019)

Using empirical loss exceedance curves and yield spread data from 28 CAT bond transactions in the years 1999 and 2000s, Wang (2004) fitted the 28 empirical CAT bond prices by the following two-parameter Wang Transform

$$S_Z^*(z) = t_5\left[\Phi^{-1}\left(S_Z(z)\right) + 0.45\right],$$

where the parameter value of λ=0.45, Φ is the cumulative standard normal distribution, and t_5 is the student-t distribution with degree of freedom (def) 5. Over the years, CAT bond prices and the risk load changed significantly. Thus, the Wang Transform parameter λ (the Sharpe Ratio) has dropped significantly from the 2,000 level; and the student-t degree of freedom has increased from the 2,000 level. The authors give a set of parameters (λ=0.45 and student-t degree of freedom of 9) for soft markets.

One caveat is that formula-driven benchmark prices are based on the assumption that market participants agree on the precise loss exceedance curve; in reality, the loss exceedance curve is never precisely known, and reinsurers and cedents are likely to differ in their assumptions.

Example 4: The authors use a dataset of model simulated loss data output of AfricaRiskView for a CAT pool. The dataset contains simulated losses of 18 country perils in a CAT pool (including two perils of drought and tropical cyclone). The authors chose two sets of pricing parameters for the two-parameter Wang Transform (in Table 14).

Table 14

TYPICAL PRICING PARAMETER RANGE FOR HARD AND SOFT INSURANCE MARKETS

Market Pricing Competition	Level of Risk Load	Lambda (Sharpe Ratio)	Student-t degree of freedom
Hard Market	High	0.45	5
Soft Market	Low	0.1	9

In real life, the level of pricing may deviate from these two sets of pricing parameters. Nevertheless, the authors use them to illustrate a risk load calculation, layer by layer, as shown in the Table 15.

Table 15

ILLUSTRATIVE RISK LOADING BY LAYER USING 2-PARAMETER WANG TRANSFORM

		Hard Market; Wang Transform (lambda=0.45, def=5)		Soft Market; Wang Transform (lambda=0.1, def=9)	
Layer (a, a+h]	Annual Average Expected Loss	Benchmark Reinsurance Premium	Risk Load %	Benchmark Reinsurance Premium	Risk Load %
10M XS 60M	$ 761,108	$ 1,852,994	143%	$ 1,077,333	42%
10M XS 70M	$ 427,442	$ 1,297,440	204%	$ 697,638	63%
10M XS 80M	$ 222,575	$ 895,395	302%	$ 441,623	98%
10M XS 90M	$ 107,803	$ 616,570	472%	$ 276,469	156%
10M XS 100M	$ 53,950	$ 447,624	730%	$ 183,368	240%
10M XS 110M	$ 23,289	$ 313,642	1247%	$ 115,297	395%
10M XS 120M	$ 9,438	$ 224,046	2274%	$ 73,507	679%
10M XS 130M	$ 3,201	$ 155,061	4744%	$ 44,540	1291%
10M XS 140M	$ 1,500	$ 124,731	8215%	$ 32,819	2088%
10M XS 150M	$ 1,389	$ 121,718	8661%	$ 31,731	2184%
10M XS 160M	$ 473	$ 61,024	12810%	$ 14,920	3056%
Combined 110M XS 60M	$ 1,612,167	$ 6,110,246	279%	$ 2,989,243	85%

In general, one can observe that, regardless of being in a hard or soft market, at a point in time, the relative loading increases at higher layers, which has implications for choosing the CAT pool's attachment point and the limit of reinsurance protection.

From this illustrative example, one can see that, in a hard reinsurance market environment, for high excess of loss layers, the risk loading can exceed the expected loss to the reinsurance layer. This would imply an expected loss ratio to the excess reinsurance layer of less than 50% in a hard reinsurance market.

It is important to highlight that the benchmark prices in Example 4 are illustrative only, for a hypothetical CAT pool (not the actual CAT pool where reinsurance was placed). The actual pricing that ARC Ltd. achieves in the reinsurance market reflects a CAT pool portfolio that differs significantly from the one assumed in Example 4, and the actual price is even much lower than the soft market benchmark risk loads.

5.5.2 ALLOCATION OF THE CAT POOL RISK PREMIUM (INCLUDING REINSURANCE COST) TO PARTICIPATING COUNTRY-PERILS

The operation of the CAT pool incurs expenses in the following categories:

1. Operating expenses
2. Expected aggregate net retained losses plus a loading or margin to build up capital reserves
3. Cost of reinsurance for the aggregate excess-of-loss layer with retention "A" and limit "H."

Allocation of items 1) and 2) to individual country perils can be based on some simple rules of thumb, e.g., proportional to the expected contributing losses to the CAT pool by country peril. Item 3) is more complex and needs to reflect how each country peril contributes to the extreme right tail of the CAT pool aggregate loss distribution.

From the practitioner's point of view, the cost of reinsurance approach that has been adopted to date for CCRIF, ARC and PCRAFI uses the same assumptions as best fit the underlying reinsurance pricing. So, if a simple expected loss load fits for reinsurance pricing from markets, then that has been the (simple) way to pass on those costs.

Theoretically, as a way of reflecting varying contributions by participating countries to the cost of capital, the actuary can calculate conditional expected losses, conditional that the aggregate loss *Z* already cuts into the reinsurance layer (exceeding the attachment point *A*):

$$E\left[Y_j \mid Z > A\right]$$

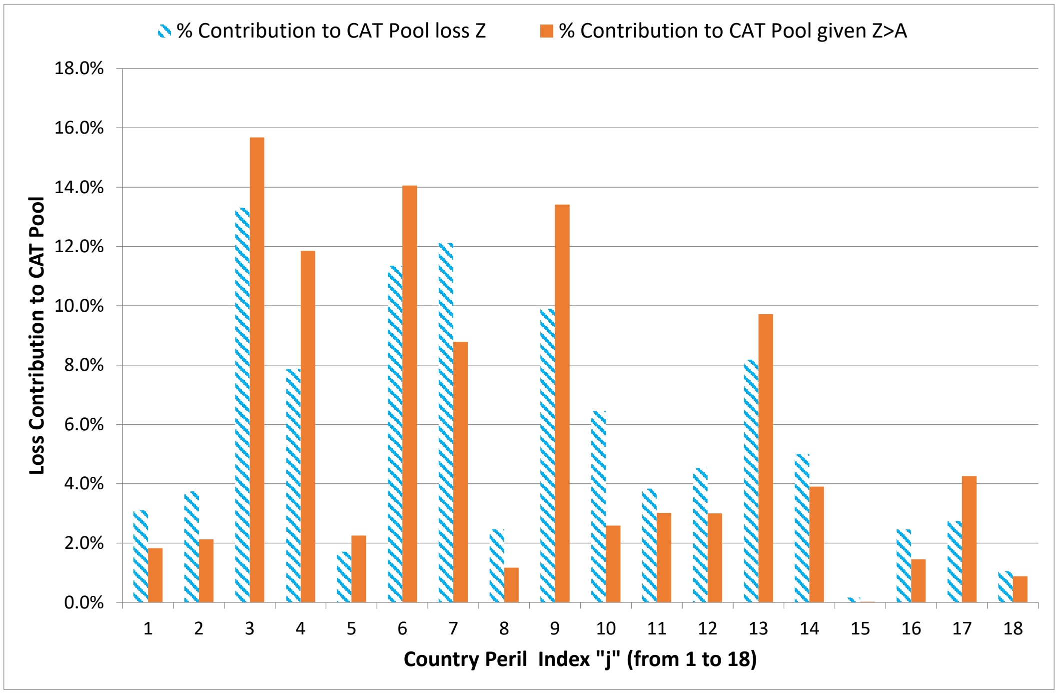
Admittedly, due to the rare event nature at the extreme right tail of the aggregate loss distribution, the conditional expected loss can be subject to large estimation errors. In practice, the allocation of the cost of reinsurance needs to balance between (1) the need for risk sharing among country perils, and (2) the need for risk-reflective risk premiums. Therefore, the allocation of reinsurance cost to country peril can be based on a combination of percentage contributions to the CAT pool:

$$\frac{E[Y_j]}{E[Z]}\text{, and } \frac{E[Y_j \mid Z>A]}{E[Z \mid Z>A]}$$

Example 5: This example uses the set of AfricaRiskView simulated losses of 18 country perils in a CAT pool of 12 African countries with two risk perils of drought and tropical cyclone. Consider an excess-of-loss reinsurance program on the CAT pool with attachment point of A=$60 million or approximately the 10-year return period PML. Figure 14 shows the percentage breakdown of loss by country peril, $E\left[Y_j\right]/E[Z]$, and $E\left[Y_j \mid Z > A\right]/E\left[Z \mid Z > A\right]$, respectively. Please note that one gets different percentage allocations of reinsurance cost to individual country perils based on these two ratios. Based on a conditional percentage contribution to losses that exceed the attachment point *A*, country perils 1 and 2 would have lower cost allocations than if based on ground-up losses. The converse is true for country perils 3 and 4.

Figure 14

PERCENTAGE BREAKDOWN OF LOSS BY COUNTRY-PERIL



Source: Bollmann and Wang (2019)

5.6 ADVANCED ACTUARIAL ANALYIS OF CAT POOLS

Advanced actuarial analysis may be required to opine on the financial performance of a CAT pool. When evaluating the dynamic financial aspects of a CAT pool arrangement, there are several variables to consider. First, for each country peril, attachment points, limits and ceding percentages can be determined, with each decision impacting the aggregate loss exceedance curve for the CAT pool. Second, the reinsurance cost is dependent on global reinsurance or CAT bond market conditions. The actuary needs to perform dynamic financial analysis that tests the sensitivity of the financial condition of the CAT pool with respect to various options of attachment points and limits for each country peril and terms of reinsurance on the CAT pool.

Actuaries should be able to make projections of the financial condition of the CAT pool over the next few years. The CAT pool needs to have a reasonably high probability of accumulating capital reserves over time to be able to retain more risks within the pool (thus reducing the future cost of reinsurance). A CAT pool in a healthy financial condition is also more likely to retain participating members and attract professional staff to administer the CAT pool. A well-managed CAT pool has the potential to expand its membership and/or risk management services (such as advising participating governments on the most cost-effective mitigation and prevention measures).

Another area where decision-makers look to actuaries for advice is the relevance of historical data in light of climate change. Economic losses from natural disasters including flood and drought have been increasing during the past few decades, due to socio-economic developments and population growth in disaster-prone areas. As pointed out by Haer et al (2017), “Natural disaster damages are the outcome of a complex interplay of these changes in exposure with changes in vulnerability, caused by socio-economic development and decisions, and changes in hazard, which can be influenced by climate change or human interventions in the hydrological system. These interactions make it complicated to draw clear-cut conclusions on trends in the causes of natural disaster losses.

Future risks are projected to increase due to a combination of continued population and economic growth and climate change, which can cause increases in the frequency and/or intensity of extreme weather events, such as more severe droughts, storms, and floods (IPCC, 2014)."

One can make two observations when using historical data to project the future:

1. For the same country peril, in the absence of additional mitigation and adaptation measures, climate change may push the ground-up loss exceedance curves further to the right tail by assigning higher probabilities to larger losses;
2. The risk loading embedded in the expected rate of return of CAT bonds or in catastrophe reinsurance prices exhibit a downward trend due to a continuing softening of the catastrophe insurance market over the past few years.

5.7 A BROADER ASSESSMENT OF CAT POOLS

The World Bank report (2017) to the G20 identifies three key factors determining the efficiency of catastrophe risk pools: political ownership, financial efficiency and operational efficiency. Here the authors elaborate on how broader actuarial assessments can shed light on these three factors.

5.7.1 POLITICAL OWNERSHIP

The success of a CAT pool requires political uniformity as a pre-condition. For instance, FHCF can be attributed to the uniform jurisdiction of pooling within a single state, under the same state tax regime, the same state budgetary system and the same state governor. With the ability to impose contingent assessments, FHCF does not need to put up the full amount of cushion capital that would be required from a commercial insurance company. Furthermore, the potential for asking the federal government for disaster relief in extreme scenarios dampens the need for FHCF to purchase high-layer reinsurance protection, which by itself saves money. Political uniformity is essential to ensuring the success of a CAT pool. While pure actuarial theoretical analysis may point to additional diversification benefits of multiple state CAT pools (e.g., Florida, Alabama and Louisiana), in reality, the political risk of such schemes must be considered, such as residents of one state perceiving an unfair allocation of premiums or payouts and putting pressure on their elected state governor.

5.7.2 FINANCIAL EFFICIENCY

Actuarial analysis of a CAT pool can also examine whether the CAT pool is capital efficient by looking at the premium-to-surplus ratios. A very low premium-to-surplus ratio is an indication of an inefficient use of capital. Another indicator of financial efficiency is what percentage of premiums is used to pay claims, i.e., the loss ratio, benefiting participants of the CAT pool, and what percentage is used to pay for reinsurance in exchange for a reduction of volatility. Actuaries can also look into whether the CAT pool takes on other financial risks (e.g., foreign exchange risk). For any CAT pool's management, it is tough to explain to its members why the pool is also subject to noninsurance risks. Most of the CAT pools examined in this report regularly address and explain their exposure to financial risks, such as currency risk, interest rate risk, credit risk, liquidity risk, prepayment risk and price risk in a dedicated section of their financial statements. All five CAT pools remain liable under their insurance contracts for the portion reinsured to the extent that reinsurers do not meet their obligations to the pool assumed under the reinsurance arrangements. This credit risk is managed by transacting only with counterparties considered highly reputable, creditworthy and within strict established investment and derivative guidelines. To reduce its risk to foreign exchange fluctuations, CCRIF uses futures foreign exchange contracts.

Actuarial analysis can help determine an optimal attachment point for insurance and provide a comparison with alternative risk financing instruments such as loans. Consider illustrative Example 4 in Section 5.4.1: For the US$110 million X US$60 million reinsurance cover, the indicated nominal risk load (benchmark reinsurance premium

US$2,989,243 minus annual average expected loss of US$1,612,167) is US$1,377,076 in a soft reinsurance market environment. This nominal risk load equals the cost of reinsurance above the average annual expected losses for the reinsurance program. The limit of the reinsurance program is equivalent to the principal amount of a loan (capital needs), the provider of which would require extra interest to compensate for the loan default risk.

By comparison, if a country would have to pay an annual interest amount of US$1,377,076 for a US$110 million loan, this would be equal to an interest rate of 1.25%. This rate, which in the authors' example is equal to the cost of making reinsurance capital available, is within the range of lending rates for sovereign guaranteed loans provided by the Inter-American Development Bank (World Bank (2017)) or the African Development Bank (2017) but certainly significantly lower than the lending rates that would be charged by international financial markets for developing country sovereign loans. Also by comparison, in a hard market environment, the nominal risk load for the same reinsurance program would be US$4,498,079, which is equal to a lending rate of 4.09% for a US$110 million loan.

5.7.3 OPERATIONAL EFFICIENCY

Actuaries can examine the expense ratio of a CAT pool and compare it to some benchmarks or planned expense numbers. Abnormally high expense ratios are an indicator of a lack of operational efficiency.

5.7.4 THE ROLE OF ALTERNATIVES

In performing broader actuarial assessments of a CAT pool arrangement, actuaries also should analyze potential alternatives to reinsurance. For instance, with other financing options such as contingent loans or compulsory calls for additional funding from the industry, the need for reinsurance may be reduced, allowing the CAT pool to retain risk loads over the years to increase its own loss absorbing capacity. Some may argue that FHCF and CCRIF represent two successful examples, while others may counter-argue that there was an element of luck. At the end of day, it is up to the individual countries to choose their preferred CAT pool arrangement or alternatives.

Another potential alternative is to view a CAT pool arrangement as a bank that accepts deposits based on individual country perils. International donors can make contributions to each country peril as seed funding or as a matching fund. With this approach, there is transparency regarding the funds available to each country peril. When an emergency fund is needed to draw down, inter-account borrowing can be arranged, with interest-free or interest-bearing loans. The CAT pool can facilitate such intercountry-peril loans.

Section 6: Long-Term Financing of Climate Risk

6.1 ASSESSMENT OF ASSET EXPOSURE TO LONG-TERM CLIMATE RISK

The financial implications of climate change represent a major challenge for asset managers. According to the EY 2018 report *Climate Change the Investment Perspective,* the financial industry is raising its attention to the risks posed by stranded assets— assets that unexpectedly lose value as a result of climate change. Insurers, pension funds and other asset owners are increasingly keen to address the financial aspects of climate change. Financial institutions are more inclined to report to their regulators, investors and the general public how they are managing climate-related risks and opportunities.

As reported by Delphine Strauss on Dec. 5, 2018, *Sustainable Finance: Central Banks Test Water on Climate Risks*, it is now generally accepted that climate change threatens financial stability. More frequent extremes of weather will damage property and disrupt trade, while policies to curb emissions and speed the adoption of green technology have the potential to trigger sharp falls in asset prices. Mortgage lenders' loan books will look riskier and so require more capital held against them, if governments decide it is uneconomic to protect certain areas from flooding

In October 2018, 18 central banks and supervisors, members of a new Network for Greening the Financial System (NGFS), signed a declaration stating that climate-related risks fell squarely within their mandate. We anticipate an increasing demand for assessment of various asset classes' exposure to climate risks and advising firms in managing their climate risk exposures. Being trained in long-term projections and valuations, actuaries have a unique role in helping financial institutions to assess their asset portfolio's exposure to climate risks.

Case Example 1: Hurricane Harvey struck the Houston area in August 2017, flooding close to 100,000 homes. In Harvey's federally declared disaster areas, 80% of the homes had no flood insurance, because they were not normally prone to flooding. Serious mortgage delinquencies on damaged homes jumped by more than 200%, according to CoreLogic. Houston could have seen a massive foreclosure crisis were it not for strong investor demand in the market. Houston's economy was strong before the storm, and its housing stock was lean. After the storm, investors swarmed the market, offering troubled homeowners an easy way out, largely in cash.

The mortgage industry needs to factor in the long-term potential losses resulting from extreme weather due to climate change. Houston residents still feel the impact of Hurricane Harvey. As a consequence of Hurricane Harvey, flood insurance for some of the Houston-area residents is now far more expensive because of Harvey.

REGULATORY REQUIREMENTS

Speaking in 2015, Bank of England Governor Mark Carney stated that insurers should stress-test the effect of environmental disasters on their finances and minimize the contribution of their portfolios to man-made climate change.

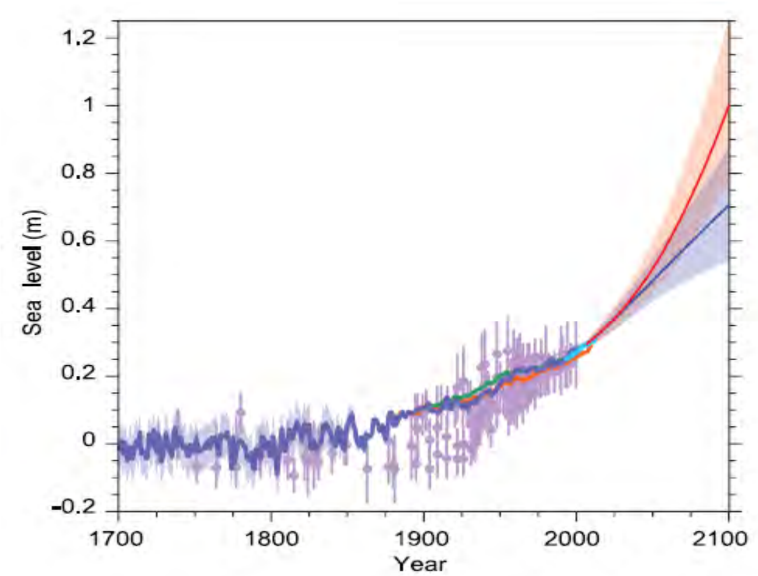
In 2018, the European Commission's high-level expert group (HLEG) published a report (Dimitriou, Davies (2018)) and recommended that regulators ensure insurers are taking climate risk into account not just in their annual pricing of risk but in their longer-term investment and strategy decisions. HLEG called for an E.U. taxonomy for sustainable finance with clear definitions, standards and methodologies. "The report noted that Solvency II incorrectly assumes that insurers trade all their assets and liabilities all the time, explaining that this was not consistent with either insurers' long-term business models or policymakers' desire for them to grow their long-term and sustainable investments." Instead, it is important to recognize the important difference between short- and long-term investment risks.

6.2 FINANCING LONG-TERM CLIMATE RISK

The impact of climate change is far reaching, not only can it cause dislocations and migrations but also major health issues for the mass population. Figure 15 shows projected sea-level rise.

Figure 15

PROJECTED SEA-LEVEL RISE 2020-2100



Source: IPCC 2014; a compilation of paleo sea level data, tide gauge data, altimeter data, and central estimates and likely ranges for projections of global mean sea-level rise for RCP 2.6 (blue) and RCP 8.5 (red) scenarios, all relative to pre-industrial values.

Case Example 2: The Singapore government will be investing in infrastructure in a big way and developing long-term plans to protect itself against the impacts of global warming, said Finance Minister Heng Swee Keat during his annual budget speech on Feb. 18, 2019. "As a low-lying island nation, there is nowhere to hide when sea levels rise," the Finance Minister said. Heng pointed out that it is very difficult to project spending needs so far ahead, although the different ministries have done some preliminary estimates. "We will continue to do our best to look forward, develop fiscal plans well in advance, and put in place the right approach to finance such long-lived major infrastructure."

The Government's Climate Action Plan, launched in 2016, has seen low-lying roads near coastal areas raised. New Changi Airport Terminal no. 5 is also being built 5.5 meters above the mean sea level. There are also pilot projects involving dikes and new reclamation methods to shed light on how to deal with rising sea levels.

The Observatory of Singapore gave the following projections specifically for Singapore for the year 2100:

1. High-emission pathway with continued growth of carbon dioxide emissions will lead to approximately 1.5 meter sea-level rise.
2. Moderate-emission pathway with stabilized emissions will lead to approximately 0.9 meter sea-level rise.
3. Low-emission pathway consistent with the Paris Agreement goal of net-zero carbon dioxide emissions will lead to approximately 0.6 meter sea-level rise.

The real question is decision under uncertainty: How much does the Singapore government need to invest now? What if the future trajectory of sea-level rise around Singapore deviates from the projections in unexpected ways? Is it over- or underinvesting now?

For a country known for its long-range planning, a financing mechanism needs to be designed. Due to government budget limitations, there is a need for hedging those long-term risks.

Some of the institutional investors (e.g., life insurance companies and pension funds) are known for their ability to hedge long-terms risks. Perhaps there is a role for the institutional investors to play a role in helping governments, organizations and individuals to manage long-term climate risks.

6.3 ROLE OF ACTUARIES

Actuaries explicitly recognize challenges posed by the long-term impact of climate risk (see Guerard (2018)): “Climate change is not limited to global warming, but combines uncertainty with risks of a variety of extreme weather events and rise in sea levels. The special expertise of actuaries in managing risks and uncertainty, combined with their understanding of future scenarios, entails a social responsibility.”

An industry survey (Rosa-Aquino (2019)) published by the Joint Risk Management Section and two other organizations that represent professional actuaries found that out of 267 actuaries surveyed, 2% identified climate change as their top emerging risk. It was also the top-ranked choice for combination risk and tied with cyber and interconnectedness of infrastructure for top current risk.

Equipped with a body of new knowledge of catastrophe insurance pools and actuarial projections of the broader economic and financial impact of climate risks on various products and organizations, actuaries can play a positive role in helping society actively manage the long-term climate risks.

Section 7: Conclusions and Recommendations

7.1 COMPARATIVE REVIEW OF EXISTING CAT POOLS

This report reviews five specific catastrophe pooling schemes and explores their respective strategic rationale, operating history, operating principles as well as financial and nonfinancial performance and achievements. Three of these five schemes cater to the needs of a total of 28 small and low- to middle-income countries covered through ARC, CCRIF and PCRAFI. The authors' comparative analysis shows that despite much common ground, there are significant differences between the five CAT pooling schemes. The authors have shown that product design and other key operational factors vary greatly between developing and mature market schemes. In addition, the report also demonstrates significant differences in the policy objectives of the five CAT pooling schems. For small nations in particular, the spectrum of objectives ranges from enhancing food security with a view to efficiently protecting the livelihood of low-income people to facilitating a dialogue between the participating countries on integrated financial solutions for the reduction of their financial vulnerability to natural disasters and to climate change.

7.2 ROLE OF ACTUARIAL ANALYIS IN THE DESIGN AND EVALUATION OF CAT POOLS

Against this intriguing backdrop of varying design features and policy objectives, this report discusses the scope and various levels of actuarial analysis in the design and evaluation of CAT pools. Standard actuarial analysis starts from assessing loss exceedance curves for individual country perils (before and after prevention and adaptation measures), then deriving the CAT pool's aggregate loss exceedance curve, reflecting specific choices concerning attachment points, exhaustion points and ceding percentages, as well as correlations between country perils. Because reinsurance spend is a major expense item for many regional CAT pools, actuaries can add significant value by calculating benchmark reinsurance prices, assisting decision-makers in evaluating different reinsurance options for the CAT pool.

Beyond standard analyses, actuaries can perform dynamic financial analysis for the CAT pool. On that basis, they may comment on the relevance of historical data in light of climate change, a dynamic socio-economic environment and volatile reinsurance market conditions. Decision-makers could draw on actuaries for projections of the CAT pool's future financial condition under various scenarios as well as for a better understanding of model risk, basis risk and alternative reinsurance options.

The broadest level of actuarial involvement would include an evaluation of the CAT pool's political ownership, financial efficiency and operational efficiency, with the ultimate objective of helping the CAT pool to effectively serve the interests of its main stakeholders (local populations and international donors in particular).

7.3 SPECIFIC POLICY RECOMMENDATIONS

Supported by a comprehensive review of five CAT pools and actuarial analyses using real-life data, the authors have formulated some specific policy recommendations in setting up catastrophe pools.

Recommendation 1: Prior to setting up new pooling schemes, alternative funding structures should be carefully examined.

Generally speaking, the establishment and capitalization of dedicated regional risk pooling schemes has proven effective, in particular for low-income countries that are highly exposed to extreme weather events. Prior to the hurricane season 2017, ARC, CCRIF and PCRAFI had made 28 payouts to 16 countries in the total amount of US$106 million (Scherer (2017)). In the aftermath of Hurricanes Irma and Maria in September 2017, CCRIF alone paid out more than US$55 million to seven of its member countries. All payouts were made within 14 days after the loss event. The combination of a strong capital base and a parametric insurance product allowed CCRIF to provide quick liquidity to governments in the Caribbean. Set up as nonprofit entities owned by donor organizations and pool members, with limited or no obligations to pay dividends, retained earnings can be used to the exclusive benefit of pool members, such as for strengthening the risk-retention capacity of the CAT pool, investing in new products and providing premium discounts to pool participants. This surplus generation ability is important, because relying on debt financing can be a risky proposition for CAT pools, in particular for small, developing country risk pools. The scope for raising new debt at acceptable terms in a financial stress situation after a catastrophic event may be very limited. Furthermore, reflecting macro-economic developments, fixed-income markets can turn quickly, creating significant funding risks.

The decision to use debt or equity for the capitalization of a risk carrier depends on a variety of factors. Most important, local regulators have a significant influence on capital resources needed to engage in insurance. This is true for both the amount of capital and its composition. The primary objective of insurance regulation and supervision is the adequate protection of policyholders and beneficiaries. Solvency regulations serve the purpose of ensuring that insurers will be able to pay claims and meet their legal and contractual obligations.

In each country, the local regulator specifies the minimum amount and type of capital that each of the regulated entities must hold. The recognition of certain capital components as regulatory capital depends on several qualitative aspects. These include the possibility to absorb losses on a going-concern basis or in the case of involuntary liquidation and the permanence of capital. Core capital is capital of the highest quality, because there is no contractual obligation to repay it (permanence) nor are there impediments to charging any losses to this category of capital. The main components of core capital are common equity capital and technical reserves (including reinsurance). They are recognized without restriction as core capital.

The setting of the risk retention level and the total claims paying capacity mainly depend on regulatory requirements, management's risk appetite, the cost of capital and access to finance. A higher risk-retention level would translate into lower reinsurance costs for the pool and, as a result, lower premiums for participating countries, addressing one of the biggest concerns for low-income countries: the affordability of premium payments. Smaller developing countries, in particular, often encounter difficulties to fund premiums. Consequently, prior to establishing new pooling schemes decision-makers should carefully examine alternative funding structures, such as contingent loan arrangements, both under normal operating and under stress scenarios.

The recognition of certain capital components as regulatory capital depends on several qualitative aspects. These include the possibility to absorb losses on a going-concern basis or in the case of involuntary liquidation and the permanence of capital. Core capital is capital of the highest quality, because there is no contractual obligation to repay it (permanence) nor are there impediments to charging any losses to this category of capital. The main components of core capital are common equity capital and technical reserves (including reinsurance). They are recognized without restriction as core capital.

All regional sovereign risk pools examined in this study, ARC, CCRIF and PCRAFI, already saw member countries leaving on grounds of insufficient affordability. In 2016 Kenya and Malawi withdrew from ARC. The government of Kenya explicitly cited political pressure to justify premium expenditure as a reason for its decision. This leads to the authors' second policy recommendation: Prior to establishing new pooling schemes, decision-makers should carefully examine alternative funding structures such as contingent loan arrangements, both under normal operating and under stress scenarios.

Recommendation 2: CAT pools should offer explicit risk premium discounts to reflect the effects of risk mitigation and prevention.

It is important that CAT pools are providing the right incentives for individual countries and organizations to adopt risk mitigation and prevention measures. The benefits of adaptation can be measured through (1) the reduction in expected losses, (2) the reduction in standard deviation, and (3) a change in probable maximum loss (PML). It is noted that the PML may actually increase because of certain adaptation measures, such as flood protection dams which may increase the asset values exposed to the risk of loss.

Building on this approach, climate risk insurance and disaster risk finance are most effective when embedded in a country's comprehensive risk management strategy, aiming to avoid negative impacts as far as possible in the first place. This risk management strategy also needs to be factored into the budget line of a state with the help of risk financing tools, enabling governments to react quickly and effectively according to predetermined criteria in the event of disaster. The United Nations Development Programme (UNDP) estimates that every dollar invested into disaster preparedness saves $7 in disaster aftermath. Nevertheless, only 1% of international aid is currently spent to minimize the impact of these disasters. Therefore, it is essential that the CAT pool arrangement offers explicit risk premium discounts to reflect the effects of risk mitigation and prevention, thus providing the right incentives for individual countries and organizations to adopt risk mitigation and prevention measures.

Recommendation 3: CAT pools with parametric triggers should proactively address basis risk by establishing mechanisms to smooth the financial impact of this risk.

In insurance, basis risk is unavoidable and should not be ignored. A good risk adviser, such as an experienced actuary, can help identify basis risk by both clarifying expectations and analyzing contract terms, including any index triggers. An informed buyer can then evaluate the trade-offs in premium savings and the residual basis risk to make better decisions, potentially saving money.

Idiosyncratic risk under any index-based insurance contract is one source of basis risk. Here, a loss unique to an individual policyholder may occur that the instrument does not observe. Savings and loans can help individual beneficiaries cope with this source of basis risk. On an institutional level, risk carriers could set aside a certain portion of the annual premium to cope with losses that are clearly associated to basis risk. Such a policy feature would be similar to a loss experience account established under certain finite risk insurance contracts.

Imperfections of the index as a predictor of actual losses is the second source of basis risk. Policyholders may experience losses greater than predicted, and losses may occur even if the index does not trigger payouts. Additional risk analysis and further trigger refinement can be used to anticipate and avoid problems related to this source of basis risk. As detailed in Section 3.3, the Bahamas cancelled its membership in the CCRIF scheme in October 2016, claiming that it had received no payment for Hurricane Matthew, a storm that caused an economic loss of approximately US$600 million. In 2013, PCRAFI made a similar experience when the Solomon Islands received no payment from the program after the February 2013 earthquake and tsunami in Santa Cruz Island, because the modeled loss was below the trigger threshold. One year later, no payment was forthcoming after the March 2014 flooding that killed 22 and left 10,000 homeless, with estimated losses of more than US$100 million. That time the policy didn't pay because a pure flood event was not part of the coverage. In consequence of these two experiences, the Solomon Islands government quit the scheme.

Finding mechanisms to reduce basis risk is essential for successful, scalable insurance schemes. For both, existing and future parametric insurance pools, basis risk can motivate countries leaving their CAT pools, undermining the parametric insurance structure to the point that the whole pool schemes could collapse.

Recommendation 4: CAT pools should be able to accumulate retained earnings to the benefit of its members and/or beneficiaries.

Retained earnings, asset growth and an increasing net worth are essential elements of the CAT pool's sustainability and long-term value creation. Actuaries are able to make projections of the financial condition of the CAT pool over a number of years. Over time, the CAT pool needs to have a reasonably high probability of accumulating capital reserves to be able to retain more risks within the pool, thus reducing the future cost of reinsurance.

When assessing the value for money of participation in a CAT Pool, sovereign decision-makers should not only take the cost of risk transfer into consideration but also asset and net worth growth. In that respect, CCRIF has demonstrated impressive success. Since 2007, CCRIF's total assets have grown by 160%, while total shareholder's equity has increased by more than 430%. All five catastrophe pooling schemes examined in this report have been established as nonprofit risk-taking entities with no obligations to return profits in the form of dividends to its shareholders and owners. This calls for careful considerations on how the profits and pooling benefits are to be distributed to members, as part of pre-arranged operating formula of the pool. Agreements can probably be reached more easily if the entity that pays the insurance premium is also an integral part of the entity that bears the risk.

Ensuring that each participating member sees positive value in the member's insurance with the pool is another critical success factor. Operational and financial efficiency aim to reduce the cost of insurance while simultaneously ensuring the financial viability of the pooling scheme. Understanding the random nature of financial outcomes in any given year requires adequate education of the participating member countries.

A CAT pool in a healthy financial condition is also more likely to retain participating members and attract professional staff to administer the CAT pool. A well-managed CAT pool scheme has the potential to expand its membership as well as risk-management services, such as advising participating governments on the most cost-effective mitigation and prevention measures.

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