UNIVERSITÀ CATTOLICA DEL SACRO CUORE

CAMPUS OF MILAN

Faculty of Banking, Financial and Insurance Sciences

Master Degree of Science in Statistical and Actuarial Sciences

Curriculum Actuarial Sciences for Insurance

PARAMETRIC INSURANCE COVERAGES AGAINST NATURAL CATASTROPHE RISKS: A NEW RISK TRANSFER SOLUTION IN A WORLD OF CLIMATE EXTREMES

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Academic Year 2022 / 2023

"l'amor che move il sole e l'altre stelle"

Dante Alighieri
(Paradiso, XXXIII, v. 145)

A chi c'è sempre stato
A chi ha sempre creduto in me
A chi mi ha resa la ragazza che sono oggi
A chi mi ha donato tutto
A chi che devo tutto

Ai miei genitori

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Introduction

In a world of increasing uncertainty, one thing is sure: bigger and more frequently occurring catastrophes are set to test the reliability of (re)insurance modelling in a world of climate extremes. Furthermore, risks are rising, as populations grow along exposed coastlines and mega-cities rapidly expand, merged with the global warming affecting the frequency and intensity of some extreme events. When these risks are merged with other socio-economic factors, as pandemic or wars, they become even harder to face. So, climate risk, and more specifically natural disasters, has become a challenging issue for the insurance industry, since it involves potential extremely large losses. The private (re)insurance industry cannot continue to provide coverage against natural catastrophes, as it has done in the past without opening itself up to the possibility of aligning their underwriting policies, their risk modelling and benchmarking capabilities to capture the loss experience exacerbated by climate change. In such an environment, the future of catastrophe modelling with an ever-shifting spectrum of risk is most timely and it inevitably requires to be involved today in the creation of new risk transfer mechanisms in the developing world: the parametric insurance coverages. The following analysis is structured as follows. The Chapter 1 begins by defying what is a catastrophe risk and by giving a short description of the current natural catastrophe risk environment focusing on the main natural disasters occurred in 2022-year all over the world. Subsequently, the most relevant loss drivers of natural catastrophes and the big issue of high protection gap level are reported with a brief presentation of the Italian insurance market situation. Passing to a more technical section, the Chapter 2 presents the catastrophe modelling fundamentals based on a module mechanism. After having shown the main three CAT models currently used, this part explains the main statistical distributions applied for model claim count and model claim size in cat modelling together with their pros and cons. Then, the Chapter 3 offers an overview about the main insurability criteria for catastrophe risk and how the primary insurance companies face the increasing demand for additional capital under the principal regulatory constraints. Since there is the increasing possibility that some natural disasters would become insurable, Alternative Risk Transfer Solutions are presented as a valid option to diversify large risks ranging from capital market securities to the traditional reinsurance alternatives available nowadays up to the growing collaboration between the public and private sectors through government programs. The focus of the analysis is represented by the Chapter 4, in which the parametric disaster insurance is deeply described in its technical definition, mechanism, advantages, issues, such as basis risk, and application fields. Moreover, it has been given a display about the general design of a parametric insurance index with the presentation of the most common index insurance structures used up to today and it has given evidence to two recent indexes developed in USA and in EU, the ACI and E^3CI, used as a prompt benchmark for the (re)insurance and public sectors. Finally, the Chapter 5 is the practical application of a particular insurance index-based product, the weather-based crop insurance, in India as an innovative solution against adverse weather conditions on agricultural crop production. After a general overview about agricultural risk management and Indian presentation in terms of agricultural production and historical weather-based crop insurance market, the analysis will give evidence on how Weather-Index Insurance product (WII) is implemented and works by applying an index based on a climate variable, the excess and/or deficit rainfall.

CHAPTER 1

THE NATURAL CATASTROPHE RISK ENVIRONMENT

Introduction

This chapter presents the main characteristics to properly identify a natural catastrophe risk and its increasing impact in worsening the number of losses and victims caused by extreme weather events. Then, this section gives an insight to the main natural disasters occurred in 2022-year all over the world, followed by showing the trend for the correspondent insured losses and by discussing how the re/insurance underwriting cycle is affected. Subsequently, the most relevant loss drivers of natural catastrophes, their relationship with climate change effects and with the problem of high protection gap level are reported to give evidence of their impact on the re/insurance industry. Finally, it is presented how the Italian insurance market faces the increasing number of disasters, the demand for coverage extension from earthquake and flood risks and the lack of a good insurance level penetration on the entire peninsula.

1.1 The main features of a catastrophe risk

1.1.1 Natural catastrophes and man-made disasters

Since the aim of this first chapter is to introduce the role and the environment related to the non-life catastrophe risk, it is relevant to start from the question: "What is a catastrophe risk?". Firstly, a catastrophe risk is related to a *disaster*, which is "a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts"[1]. The main features related to this aleatory event are described in the following points:

- it has low frequency
- it involves high number of people and things
- it produces, when it occurs, a damage with high level of severity.

[1] UNDRR, *Sendai Framework Terminology on Disaster Risk Reduction*, www.undrr.org

According to the classification made for the purpose of the *Sendai Framework for Disaster Risk Reduction 2015-2030 (para. 15)*, the kind of disaster related to the catastrophe risk is defined as *a sudden-onset disaster*: "*hazardous event that emerges quickly or unexpectedly (...) that could be associated with, e.g. earthquake, volcanic eruption, flash flood, chemical explosion, critical infrastructure failure, transport accident*"[2].

Secondly, it is important to make a distinction between natural catastrophes and man-made catastrophes, making reference to the insurance field.

Natural catastrophes, also known as *Acts of God,* are injurious events that have been originated by the forces of nature. The entity of these events depends on numerous factors, such as:

- the fury of natural elements
- the construction techniques of the damaged or destroyed buildings
- the prevention measures adopted
- causal factors, for example, the exact moment at which the event occurs because it affects the number of victims caused, such as for the earthquake event.

The main events originating natural catastrophes are associated to:

- floods
- storms
- earthquakes
- tsunamis
- volcanic eruptions
- droughts / forest fires / heat waves
- cold waves or frost
- avalanches
- hail

While, man-made catastrophes, or *technical catastrophes*, concern events directly linked to the activities of men that lead to huge injures. Under the insurance profile, these events are related to only one single insured of high entity, located in a limited place and involve a limited number of contracts. They are classified into:

- big fires and explosions
- shipping disasters
- aviation and space disasters
- road and rail disasters

[2] Ivi

- fire in mines and wells
- collapses of bridge and buildings
- miscellaneous (including terrorism)[3].

The following **Table 1** describes the main aspects that must be taken into account in order to identify the difference between natural catastrophe and man-made risk by considering both the relevance and the frequency of the risk:

Table 1: Classification of natural catastrophe risk and man-made risk

	Natural catastrophe risk	**Man-made risk**
Relevance of the risk	it hits a relevant number of individual risk but also the entire insured portfolio of an insurance company	it may hit one or more insured units but also, in the worst case, a set of units
Frequency of the risk	very low frequency both at single insured unit and at portfolio level of insurance company	low frequency for the single insured unit and medium-high frequency balanced at portfolio level of an insurance company

Source: La gestione dei rischi climatici e catastrofali, Stefano Miani

The relevance and the frequency of the natural catastrophe risk are key factors for a correct risk valuation and for assessing a fair premium because the insurance companies tend to under-estimate this kind of risk due to:

- Ex-ante analysis problems are a consequence of:
  - the lack of valid statistics, since large size natural events occur rarely
  - unreliable data
- Ex-post monetary analysis problems are consequence of:
  - the problematic quantification of the risk after its occurrence
  - distorted and long measurements of the risk
  - repeated values inside the data used for the calculation of the risk amount
  - long-term impacts caused by the disaster subjected to a separated analysis[4] .

[3] Luigi Selleri, *I rischi catastrofali e ambientali,* Milano, Edizioni Angelo Guerini e Associati Spa, 1996, p. 23, 24
[4] Stefano Miani, *La gestione dei rischi climatici e catastrofali*, G. Giappichelli Editore, Torino, 2004, p. 3

1.1.2 Primary and secondary perils

In addition to the previous classification, the *Swiss Re Institute* categories in a more accurate way the natural catastrophes as *primary and secondary perils*, for which the key differentiator is the accuracy of the insurance industry modelling for different perils with respect to the data collection, submission and underwriting process.

Primary perils are characterized by natural catastrophes that tend to happen less frequently with high loss potential including also secondary effects (e.g. European winter storms; tropical cyclones including inland flooding and storm surge; earthquake including tsunamis, liquefaction and fires as consequences), while secondary perils can happen relatively frequently and generate low-to medium-sized losses (e.g. Severe convective storms, floods, droughts, wildfires, landslides, snow, freeze)[5].

Moreover, the natural catastrophe estimation process is very difficult also for another peculiar aspect regarding the "*Law of Large Numbers*"[6], which states that:

> if $X_n(\omega)$ is a succession of random variables that are uncorrelated in pairs with $E(Xi) = \mu i < \infty$ and $Var(Xi) = \sigma_i^2 > 0$ ad if $\sum_{i=1}^{n} \sigma_i^2 \rightarrow \infty$ for $n \rightarrow \infty$, so $(X_n(\omega))_{n\geq 1}$ responds to the (weak) Law of Large Numbers with respect to
> $B_n = \sum_{i=1}^{n} \sigma_i^2$ and $A_n = \sum_{i=1}^{n} \mu i$: $\frac{S_n - \sum_{i=1}^{n} \mu i}{\sum_{i=1}^{n} \sigma_i^2} \rightarrow 0$ in probability.

It means that the equilibrium of the insured portfolio tends to improve as the number of insured units increases, but this principle does not hold for natural catastrophes. The reason is linked to the fact that, within a geographical area affected by the same catastrophic event, the size of the claim tends to increase progressively as the number of insured risks increases. According to this condition, it could seem that natural catastrophe risk is considered as uninsurable risk[7] because it does not respect specific features in order to be better managed by the insurer. An insurable risk is a pure risk that has to the following characteristics:

- **homogeneity**: a sufficiently large number of units are exposed to the same risk;
- **independence**: the occurrence of a specific event should not be the cause for another event to which a high number of units are exposed;

[5] Swiss Re Institute, *"Natural catastrophes and inflation in 2022: a perfect storm"*, Sigma N°1, www.swissre.com

[6] Diego Zappa – Silvia Facchinetti, *Appunti di stastitica II – Note a uso degli studenti*, EDUCatt, Milano, 2017, p.68

[7] Alberto Floreani, *Economia delle imprese di assicurazione,* Il Mulino, Bologna, 2019, p. 23, 24

- **measurability**: it is possible to estimate the probability of occurrence of an event (p) and the corresponding damage (D);
- **level of randomness**: this level should not be too high meaning a low probability of the event or too low with a high probability of the event almost certain;
- **random**: the event must not be caused by the will or actions taken by the subject exposed to the risk.

In the end, the catastrophe risk appears to be insurable because it has not correspondence with characteristics of independence, appropriate measurability, frequency that may cause a less efficient diversification among the portfolio of the single insurance company. Despite that, this point will be deeply object of discussion in the Chapter 3 because it is difficult to find a risk with a perfect insurability level and so the majority of risks, that do not satisfy one or more than the features just described, are anyway object of insurance contracts.

Nevertheless, even if these features of the natural catastrophe risks should discourage insurance companies to underwrite this kind of risks, these risks are managed through an elaborated allocation procedure that involves the whole insurance and reinsurance market with the contribution also of the capital market. For example, according to primary and second perils that have been described above, the developed insurance and reinsurance industry has specific techniques to use. In particular, primary perils are well-monitored with a less rigorous monitoring for secondary effects, which are not always explicitly modelled, while secondary perils have a less rigid monitoring and modelling with respect the primary ones due to weaker exposure data capture and claims tracking. But since this articulated point about insurability of natural catastrophic perils must be deeply analyzed and described, this is the reason why new modelling procedure and new financial and re/insurance products for managing natural catastrophes are object of discussion and technical insight in the following chapters (Chapter 2 and 3).

1.2 The rising impact of natural catastrophes

1.2.1 Natural catastrophe events at global level in 2022

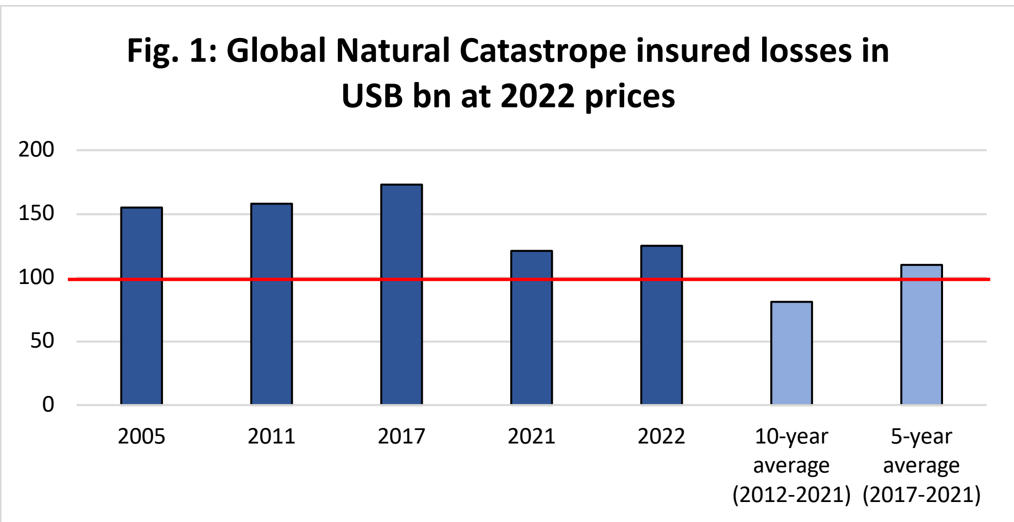
The year 2022 has been characterized by 285 catastrophe events, which have caused more than 35’000 victims all around the world and numerous damages.

Losses are divided into two main categories:

1. **Economic losses** are used as a general indicator and they are defined as "*financial losses directly attributable to a major event, such as damage to buildings, infrastructure, vehicles, etc. They also include losses due to business interruption as a direct consequence of the property damage.*" Global economic losses include all damages, both insured and uninsured but they do not include indirect financial losses and non-economic losses, such as loss reputation.
2. **Insured losses** are all insured losses except liability to allow a relatively smooth assessment of the insurance year but it could also underestimate the cost of man-made disasters. Life insurance losses are not considered.

In 2022-year, global economic losses count for USD 248 billion representing the 0.27% of global GDP, increased with respect the 10-year average of 0.23%, and these losses are divided between: USD 275 billion of natural catastrophes and USD 9 billion man-made. Insured losses are USD 132 billion that corresponds to 6% of global property direct premiums written, increased with respect the 10-year average of 4.6%. These losses are higher than the previous 2021 of USD 130 billion and also then 10-year average of USD 91 billion. The great part of Insured losses has been originated by **Natural Catastrophes losses** for USD 125 billion, of which 43% in terms of secondary perils (USD 54 billion) and 57% in terms of primary perils (USD 71 billion). Also here, the previous 2021 and the 10-year average of USD 81 billion have been both exceeded.

Part of the Global natural catastrophe insured loss values mentioned above are summarized by comparing them with values of specific years (such as 2005, 2011, 2017, 2021), with respect the 10-year average (2012-2021) and with respect the 5-year average (2017-2021) in the following **Figure 1**:



Source: Swiss Re Institute

At the end, 2022 natural catastrophe-related losses, driven mostly by extreme weather events, are the fourth highest value in any one year since 1970 on *Sigma Records*[8] and, for the first time, global insured losses exceeded USD 100 billion for two years running (in 2021 and in 2022).

Table 2 shows that the evolving of natural catastrophe landscape in 2022 has been both in terms of severity of single events but also the frequency of events hitting the whole globe quite equally, where each region of the world suffered a major event:

Table 2: Number of events, victims and insured losses by region, 2022

Regions	Events	Victims	in %	Insured Losses (USD bn)	in %	Economic Losses (USD bn)	in %	in % of GDP
North America	84	510	1.5%	10.8	77.6%	176	62.1%	0.64%
Latin America & Caribbean	20	906	2.6%	1.9	1.5%	17.4	6.1%	0.31%
Europe	37	23864	67.9%	12.2	9.2%	21	7.4%	0.09%
Africa	43	3044	8.7%	1.6	1.2%	8	2.8%	0.27%
Asia	92	6804	19.4%	8.4	6.3%	51.2	18.1%	0.13%
Oceania/Australia	7	29	0.1%	5.3	4.0%	9.7	3.4%	0.50%
Space	2			0.3	0.2%	0.3	0.1%	
World Total	**285**	**35157**	**100%**	**132.5**	**100%**	**283.7**	**100%**	**0.27%**

Source: Swiss Re Institute

North America region is the area with the highest value of economic losses (USD 176 billion) counting for 0.64% of GDP, even if the 2022 North Atlantic hurricane season was in line with past evets: there were 14 storms compared to the average 14.4 annually in the period 1991-2020. Despite that, the 2022 season is considered the third most expensive hurricane season after 2005 (Katrina, Wilma and Rita) and 2017 (Harvey, Irma and Maria). The reason is linked to the presence of Hurricane Ian, the category 4 hurricane considered the year's biggest loss event, and rank as the second-costliest insurance natural catastrophe loss ever on Sigma Records after Hurricane Katrina in 2005. It made landfall in western Florida in September 2022, bringing torrential rain, storm surge and strong winds and resulting in estimated insured losses of USD 50 to 65 billion. This storm has highlighted the loss potential of an individual major hurricane hitting a densely populated coastline and the potential risks involved in regions more exposed to extreme weather events. These two last aspects should be considered as main loss drivers, to which will give evidence in the next paragraph. In addition, North America resulted in significant losses also from severe convective storms (SCS) that were above prior-period averages, driven by thunderstorms with hail and tornadoes in the US. Severe convective storms (SCS) are among the most damaging natural catastrophes in United States because they can

[8] Swiss Re Institute publishes annually sigma research for implication for the re/insurance industry

give birth to tornadoes or destructive straight-line winds, since they take origin from the combination of warm and moist air rising from the earth[9].

2022 was not a remarkable year only for the North America but also for the rest of the world that has not been spared by: starting from the highest-ever annual loss of USD 5 billion due to hailstorm in France. Another contributor was the severe just above average flooding in eastern Australia in February-March, that resulted to be the biggest natural catastrophe claim event ever in this region with USD 4.3 billion of insured losses. Another national costliest ever event was flooding in Durban in South Africa in April, originating an amount of insured loss of USD 1.5 billion.

In February 2022 a group of storms (Eunice, Dudley, Franklin) has touched the northwestern Europe leading to estimated insured losses of USD 4.1 billion. Even if winds in winter are less strong than in tropical cyclones, the European area has been hit by a single powerful storm that has originated damages in different locations seen as combined losses accumulated to multi-billion levels, also doubling the previous 10-year average.

On the opposite side, heatwaves and droughts due to weather variability and anomalous atmospheric circulation conditions led to crop yield losses in many regions, adding to a global food inflation pressures and high agriculture insurance losses. The countries with highest economic losses were, in decreasing order: Brazil, Europe, China and Morocco, with a corresponding very tiny insured loss amount of USD 1 billion, USD 0.6 billion, USD 0.8 billion and USD 0.04 billion. In Brazil and China, monsoon rains were below average, while the 2022 summer in Europe was the hottest on record and in Morocco there was a North Atlantic Oscillation phase of rainfall deficit.

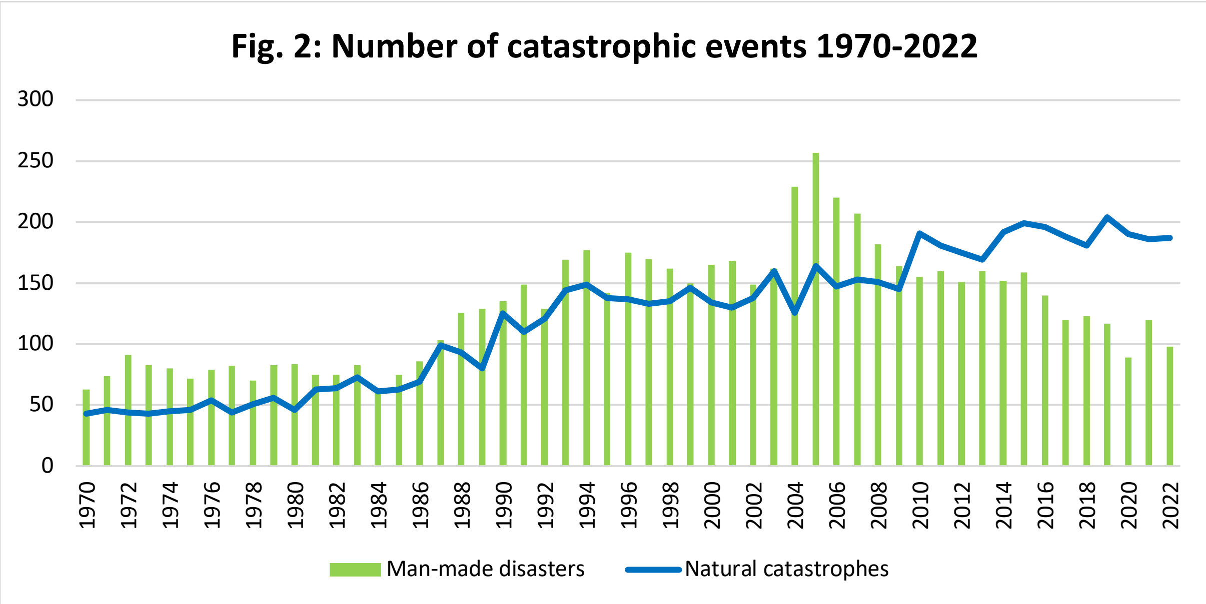
The last year 2022 has shown how the passage from the decade of long zero-to-negative interest rate environment, the Covid-19 pandemic, the Ukraine war has included very high level of inflation. This has caused the rising cost in the construction sector; it has increased the value of insured property assets and it has also associated higher cost for damage produced by weather events. High inflation rates have provoked instability also on financial markets forcing the central banks to hike policy rates rapidly.

To summarize, the 2022 major natural catastrophe events, each producing unique outcomes, were not outliers from the perspective of unprecedented losses but they were the result of known risk drivers, captured by previous record of data. As previously seen, each catastrophic events

[9] Insurance Information Institute, *Evolving risks call for innovation to reduce costs, drive resilience*, May 7, 2020, www.iii.org

have underlined specific aspects: a single storm as Hurricane Ian can have devastating effect among all, bigger winter storms will arrive in Europe, lack of data transparency can compromise risk assessment in South Africa, rising property losses after SCS and floods combined with exposure growth and inflation make losses higher. The losses were not generated by particular and exceptional feature of the specific event, but the result from the combination of different factor arising, which the re/insurance industry should consider to keep up with a fast-evolving world risk map[10].

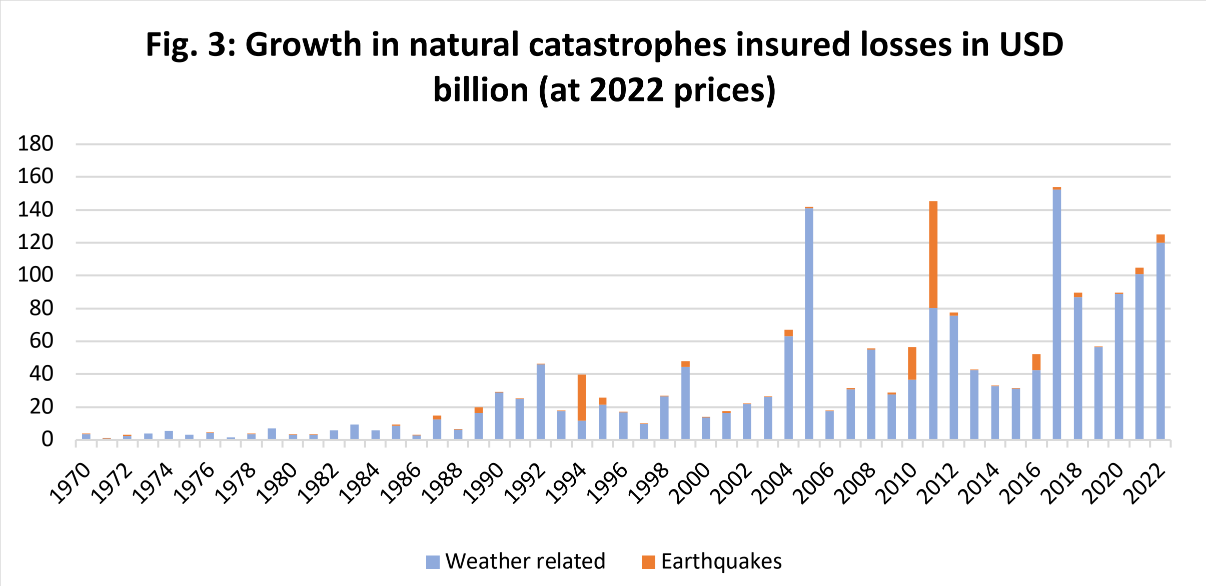
1.2.2 Trend in natural catastrophes insured losses



Source: Swiss Re Institute

The previous **Figure 2** shows the evolution in terms of number of catastrophic events split between man-made disasters represented by green bars and natural catastrophes represented with a blue line along the period 1970-2022: it is evident the increasing trend for natural catastrophic outbreaks, from when in 2008 the blue line remains constantly above the green bars until 2022.

[10] Swiss Re Institute, Sigma Report 1/2023: *Natural catastrophes and inflation in 2022: a perfect storm,* March 22, 2023



Source: Swiss Re Institute

As seen from the **Figure 3**, since 1992 insured losses have grown by 5-7% on average each year, also including the period 2012-2016 when losses were at a lower annual mean. Starting from 2017, average annual insured losses from natural catastrophes have exceeded USD 110 billion, doubling the average of USD 52 billion over the previous 5-year period. Annual insured losses are expected to go above the USD 100 billion from hereon and this expectation is supported by predictions made by catastrophe loss modelling. The future aim of modelling will be to not underestimate loss potential of a year or period of below trend growth because in any one-year losses can vary depending on whether natural catastrophe events do or not strike urban and more populated areas.

Interpedently by the year volatility, insured losses will likely continue to grow at trend, even in case of a reduction of high inflations levels. This trend is expected to go on, driven by growing loss severity on account of rising property and values-at-risk exposures, urban sprawl, economic growth and a backdrop of hazard intensification due to climate change effects. The relevance of climate change as one of possible driving factor will be studied in deep in a specific subsection in the following paragraph.

The long-term loss trend of global insured losses is characterized for the stable contribution from the tropical cyclones and SCS, that they count on average 30% for each event over the last 40 years (1983-2022). The main difference between these two biggest peril categories is that tropical cyclones and hurricanes are considered primary perils because they happen less frequently, but one peak event can wreak very large losses. It is the main threat to residents and businesses. On the opposite, SCS are classified as secondary perils because they occur more frequently all over the world, but they generate low-to medium-sized losses. Even if the frequency is low, their aggregated annual loss amounts are less volatile. Another longer-term trend development is due to wildfires: doubling wildfire contribution to insured losses over the last 30 years from average of 3% to 6%. Even if fire-related losses were low in 2022 itself, large wildfires are rising frequently wreaked huge damage and unprecedented losses, particularly in North America (Canada 2016 and California 2017, 2018 and 2020). The increased wildfire events may be due to signal hazard intensification as the planet warms: extreme heat conditions and prolonged periods of heatwaves in the next decades will increase their frequency and loss severity of large wildfires and drought. The winter storms represent an ever-present primary peril loss threat in Europe and its share of insured losses is in line with the 7% from the 40-year average, even if the annual catastrophe-related losses have declined since the largest storms in 1990 and 1999. But a single winter storm can lead to significant property damage. Another primary peril is earthquake that, despite the low level of earthquake-related losses in 2022 with respect the 8% 40-year average, should not be underestimated: they are rare event but when a major quake strikes, especially on a heavily populated area, the resulting losses can be enormous.

In order to summarize, the annual growth losses have been driven mainly by rising severity of losses over the time period from 1983 to 2022 from medium-to high-loss secondary perils and high-severity primary peril events: tropical cyclones and SCS have been the main drivers to global insured losses. High severity of secondary perils events, such as floods and wildfires, have become to be considered as growing threats because they are occurring more frequently in the last decade.

In addition, the main physical driver associated to losses is the raising up in the value exposure as the result of economic development, population concentrations in regions susceptible to natural hazards, that will be discussed in the next paragraph as well as for the impact of socio-economic factors[11].

1.2.3 The re/insurance underwriting cycle

The industry has experienced poor underwriting results following the increasing trend in natural catastrophe loss severity since 2017 and new risk drivers appear, as the pandemic and war in Ukraine including the increased value of insured property assets due to high inflation rates.

[11] Ibidem

Property reinsurance rates have been rising since 2018 and they rose significantly at the January 2023 renewals. A further indication is given by the Guy Carpenter Global Rate on Line (ROL) Index that has increased of 27.5%, mainly driven by pricing and attachment point adjustments in the US and Europe: it was the 6th consecutive year of increase, reaching a cumulative total increase of 65%[12]. The re/insurance underwriting cycle is characterized by periods of soft and hard market conditions: when there is a decreasing or stability condition for premium rates, the coverage is easily available, while when premium rates are increasing, the coverage could have problem in its availability.

The current market situation is passing through hard period, in which the market is finding a new equilibrium between supply and demand. On one hand, higher insurable values of buildings and other fixed assets have risen up the demand for coverage due to the increased trend in natural catastrophe activity. On the other hand, natural catastrophe-related claims payout have reduced the supply of capital, also worsen by the high interest rates and lower financial asset values. As consequence, risk appetite has declined due to poor property re/insurance underwriting results in recent years together with the perception that actual risk assessments are underestimating actual loss experience. This is originating hesitation among investors in insurance-linked securities (ILS) due to financial market uncertainty and traditional reinsurers engage new funds to replenish industry capital. The capital supply response has slowed: even if re/insurance industry has paid USD 650 billion since 2017 for weather claim events, the premium income has not been aligned with exposure growth resulting in declining profits for the insurance market. The re/insurance market is affected directly by natural catastrophes and indirectly by the fact that society is made more resilient thanks to insurance but payments to policyholders reduce profitability and capital availability.

The main drivers in re/insurance underwriting trend are:

1. Claims trends
    - remarkable impact on insurance prices caused by changes in expected losses
    - inflation wave has raised exposures and claims
    - modelling uncertainty is linked to economic inflation, social inflation, climate change, Ukraine war, pandemic, supply-chain risks, cyber;
2. Interest rates

[12] Guy Carpenter Global Rate on Line Index is a measure of the change in dollars paid for coverage year on year on a consistent program base. It reflects the impact of pricing of increasing (or decreasing) exposure base, evolving methods of measuring risk and changes in buying habits and market conditions. Definition is taken from www.guycarp.com.

- raising interest rates will improve portfolio yield generating a lag of losses in the short term
- they do not play a crucial role in explaining short-term changes in underwriting dynamics
- strong relationship between combined ratio and nominal interest rates in the long-term;

3. Industry capital
   - increasing the excess capital can lead to falling rates, while capital constraints can cause higher rates
   - accounting capital can be inflated by low interest rates and by deficit of claims reserves;
4. Catastrophe losses
   - unmodelled catastrophic risk have larger effect on supply and demand
   - the effect of natural catastrophes on price increase is smaller than assumed
   - lost industry capital can be replaced with fresh capital in case of availability of market opportunities.

These drivers are considered in the risk assessment and underwriting process of the re/insurance industry, which has been significantly improved for natural catastrophe risk modelling capabilities over the past 10 years. Further enhancements regarding:

- improvement in sufficient granularity for the collection and transmission of exposure data, specially for increasing role playing by secondary perils (floods, hail storms, wildfires, SCS) as the industry already does for primary peril risks;
- ensuring that exposure data is updated with the latest economic and inflation developments because costs of property rebuilds and reconstruction have been higher than those anticipated by re/insurers;
- models and risk assessments may reflect all changes in all relevant risk drivers (such as soil sealing, construction of new risk mitigation infrastructures, updates to building codes, social inflation and climate change effects) using a forward-looking prospective;
- selecting the peril-specific appropriate observation window limited to a more recent and forward-looking view to capture changes such as in weather regimes. Historical data points have always been the key input for natural catastrophes but they should be continuously updated in order to properly represent the current-day risk environment;

- regular model updates are usually made through small and digestible changes but sometimes bold changes are necessary for a better catching up of a fast evolving risk map of primary and, especially, secondary perils[13].

1.3 Main Loss drivers of natural catastrophes

1.3.1 Loss drivers are manifold

For each large natural catastrophes, there is a correspondent wide variety of risks across different perils around the world. It is also crucial to underline the main manifold loss drivers:

1. Hazard
2. Vulnerability
3. Exposure
4. Socio-economic effects

Starting from the analysis of Natural Hazards, which are defined "*as environmental phenomena that have the potential to impact societies and the human environment*", not caused by human activity. Natural hazards and natural disaster are related but they are different: the first is the treatment of an event that will likely have a negative impact, while the second is the negative impact originated from the actual occurrence of natural hazard[14]. The impact of large perils should be considered as well as the influence of El Niño and La Niña: they are two opposite climate patterns in the Pacific Ocean that can affect weather worldwide by occurring not on a regular schedule. During normal conditions in the Pacific Ocean, trade winds blow west along the equator, bringing warm water from South America towards Asia and the warm water is replaced by cold water rising from the depths through a process called upwelling. During El Niño, trade winds are wicker and warm water is pushed back to east, towards the west coast of the Americas leading to dryer conditions and increasing in flooding. While La Niña, known as "a cold event", has the opposite effect of El Niño: it pushes warm water toward Asia causing drought in southern U.S and flooding in Pacific Northwest and Canada. Even if El Niño occurs more frequently than La Niña, La Niña leads to warmer winter

[13] Ibidem

[14] FEMA – National Risk Index, *Natural Hazards*, in section Determining Risk / Expected Annual Loss, www.hazards.fema.gov

temperatures in the South and cooler than normal in the North giving birth also to more severe hurricane season[15].

The general concept of Vulnerability means "*the characteristics of a person or a group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard*". There is an implicit "differential vulnerability", meaning that different populations face different levels of risk and vulnerability. Although the sources of vulnerability are multiple, some of the most important factors include globalization, social diversity and population growth and distribution: urban earthquake are more dangerous due to the density and quality of the infrastructures, the growth of coastal populations raises concerns about increased human vulnerability to flooding, hurricanes, tsunamis and the increasing population in urban areas results in higher flood-prone areas. These are some major examples that underline how the analysis of buildings, new types of infrastructure and presence or absence of infrastructure protection from perils is playing an increasing role to prevent losses from weather events[16]. Another key loss driver is the Exposure, that is defined "*as the representative value of buildings, population or agriculture potentially exposed to a natural hazard occurrence*". Also, exposure loss driver is affected by the distribution of population: the rapid population increase, the growth in built areas and accumulation of physical assets in areas subjected to extreme weather events can massively affect the risk assessment process[17].

Another kind of storms come from the geopolitical and socio-economic factors that the entire world has to face. The stability of financial markets, the possible presence of pandemic, the outbreak of some conflicts, the evolution of the Gross Domestic Product, demographic aspects, inflation, and other factors have all a massive impact as loss drivers. In particular, the re/insurance industry prefers to "normalize" the economic losses triggered by natural catastrophes for nominal GDP growth effects: a past event would cause more economic damage today with equal magnitude than in the year of the occurrence due to the exposure value accumulation. A common approach is to apply real GDP and inflation factors to past economic losses[18].

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[15]NOAA – National Ocean Service, *What are El Niño and La Niña?,* in section Home/Facts www.oceanservice.noaa.gov

[16] PRB – Population Reference Bureau , *Disaster risk and vulnerability: the role and the impact of population and society*, William Donner and Havidán Rodrígues, January 8, 2011, www.prb.org

[17] FEMA – National Risk Index, *Exposure,* in section Determining Risk / Expected Annual Loss, www.hazards.fema.gov

[18] Swiss Re Institute, Sigma Report 1/2023: *Natural catastrophes and inflation in 2022: a perfect storm,* March 22, 2023

1.3.2 Trend for the main loss drivers

New risk drivers, together with the increase in loss severity, had a severe impact on renewals in the re/insurance industry. In particular, the unexpected spike in economic inflation not seen in four decades was a crucial aspect to consider in prices: inflation has the effect of raising the value of insurable assets and claims. The nominal value of buildings, motor vehicles and other fixed assets that insurers cover form the property insurance exposure has raised rapidly with respect headline inflation and economic growth: this leads to the increase in construction and vehicle sales sectors, which generate effects on the largest lines of insurance. Price inflation has caused difficulties for property underwriters, who expect that claim cost level will not go back to pre-pandemic times, but they will remain at high levels, even if inflation will reduce in 2024. It has affected directly exposures and demand for coverage and indirectly supply side. A tempestive intervention has been made by US Federal Reserve (Fed) and other central banks as European Central Bank (ECB) and Bank of England (BoE) in their monetary policy framework: they have risen short-term policy rates up to 4.37%, 3.5% and 2.5% respectively. A first consequence is the decline in financial asset values and shareholder equity: fixed income re/insurance portfolios have suffered significant mark-to-model losses. The combined effect on reinsurer balance sheets is relevant due to the reduction in reinsurance capital (traditional and alternative) of around 20-25% from year 2021.

As well as socio-economic factors can deeply affect the trend of insured losses, also all natural catastrophes events have underlined some specific aspects. Starting from loss potential power of a storm that produces more or less severe damages depending on the degree of density population present in the area where it makes landfall, and losses would have been much higher if new buildings have not been constructed following new standards and without storm-proofed roof. There is still a lack of investment in flood protection in existing infrastructures, which should be improved to contain possible property damage and high losses. Another aspect producing flood-related losses is the increase in soil sealing, especially in urbanized areas: urbanization and soil sealing effects should be considered in new models for floods. Also, the hail exposure is determined by considering new loss factors, such as changes in land use, claims behavior, assets exposed to hail damage, in addition to economic growth and urbanization. Additionally, winter storms in Europe are considered “sleeping giant” meant not to underestimate their lower activity but they are an ever-present risk. Besides, an increasing number of new regions in emerging economies, that are central to global supply chains, are exposed to these kinds of perils leading to future possible problems in loss estimation magnitude, especially for firms: lack of awareness and data transparency about the international connections within business' production sites can compromise risk assessment by underestimating the risk exposure. In addition, large natural disasters have not brought a significant influx of capital because investors are hesitating due to future possible heavy-loss year combined with high economic inflation and valuation price uncertainty. Some reinsures and ILS are expected to wait to see that re/insurance industry profits can increase its capacity by accurately quantifying and pricing natural catastrophe risks because January 2023 renewals are a sign that past prices were not able to capture the actual loss dynamics. Changing in exposure landscape risk and underlying loss distributions are key aspects to ensure the insurability of natural catastrophe-related insurance risk.

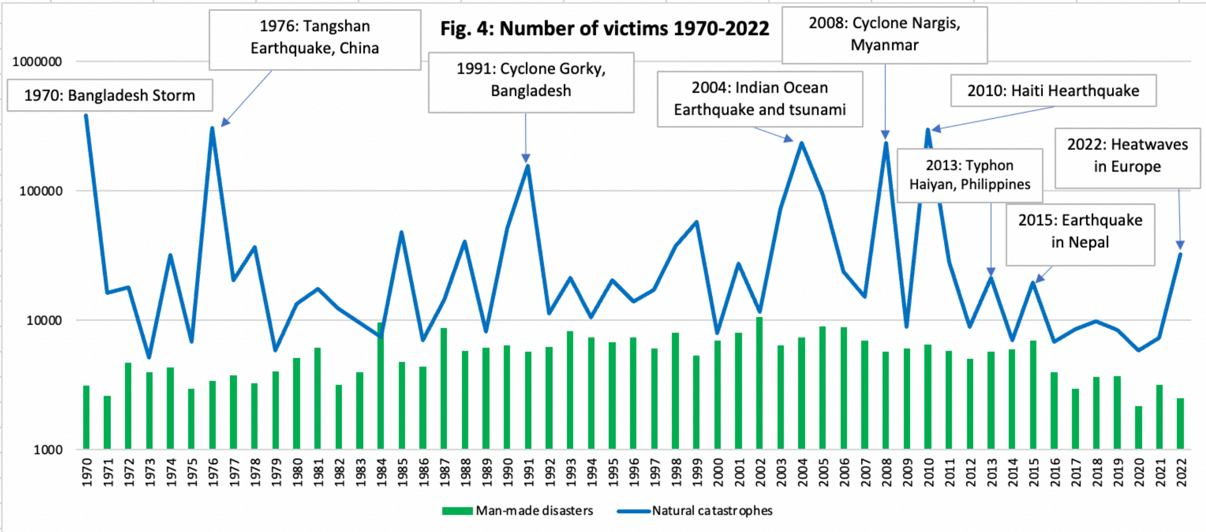
At the end, a crucial point for the re/insurance industry is to put major attention to the increasing presence of secondary perils from hereon. The industry has traditionally focused risk assessment on tail exposures and large capital disaster events, but the recent years' losses experience made evidence for the need on deeper attention to higher frequency end of loss distributions. The distinction between primary and secondary perils will be reduced considering "all perils as primary": underwriting cycle should give the same level of attention and resources to all perils as afforded primary hazard exposures[19].

1.3.3 What about Climate Change?

The main drivers of rising losses from natural catastrophes are rising populations in exposed area, growth, urbanization and social inflation pressure added in recent years. The question is: "can climate change effects be considered as one of the manifold loss drivers?". The answer is not clear. However, today it is evident how natural variability of extreme weather has become more significant than in the past, but property underwriters are still observant to extent climate change effects in risk models. In addition, the Intergovernmental Panel on Climate Change (IPCC) has supported the fact that climate change effects are likely to play a significant role, even if they are not a primary driver increasing losses, at least not yet. IPCC has observed how climate changes have been already present in different weather-related risks across all regions of the world. It has highlighted how the usage of burning fossil fuels for more than a century as well as unsustainable energy and land use have led to global warming of 1.1°C above the pre-industrial levels. This has affected the frequency and intensity of extreme weather events that have caused increasingly damages on nature and people around the world. "*Almost half of the*

[19] Ibidem

world's population lives in regions that are highly vulnerable to climate change. In the last decade, deaths from floods, droughts and storms were 15 times higher in highly vulnerable regions" is the statement pronounced by Aditi Mukherji, one of the 93 authors of the AR6 Synthesis Report: Climate Change 2023. **Figure 4** describes the devastating impact that climate change has had on people from weather perils during 1970-2022 period:



Source: Swiss Re Institute

This picture returns in terms of number of victims how every increment of warming results in rapidly escalating hazards: more intense heatwaves, heavier rainfall and other weather extreme events further increase dangers for human health, also for the rising insecurity linked to climate-driven food and water. When these risks are merged together with other socio-economic factors, as the above pandemic or wars, they become even harder to face. So, it can be said that taking action against climate change effects leads to reduce losses and damages both for ecosystem and for people, also providing wider benefits[20].

Climate risk is a systemic risk that has to be managed through global policy action. The first action universally taken by public institutions and corporate business all over the world is the Paris Agreement in 2015 during COP21, which is the first binding climate-related deal. The involved Parties are committed to reduce rising carbon emission up to 1.5°C by containing risks and impacts of climate changed within 2030. In addition, climate risk, in terms of exposure to severe weather risks, affects economies systematically through *physical* and *transition* risks. Physical risks are property damage, disruption to trade due to extreme weather events and lost

[20] IPCC, *Urgent climate action can secure a livable future for all*, March 20, 2023, www.ipcc.ch

productivity due to higher average temperatures, while transition risks come from the adjustment to a low-carbon economy by changes in technology use and society resource developments[21]. The impact of climate change on physical risks occurs at different levels of severity over a long time scale and with various outcomes: for example, the precipitation patterns and flood risk are direct consequence of rising globe average temperature and they have specific regional features for several areas of the world.

The two-dimension drivers, frequency and severity, used traditionally by re/insurance industry to model natural catastrophe risks are not any more enough because climate change introduces two new complexities to the risk equation: time horizon and level of confidence. Making projections about potential future changes is important to understand the timescale of changes because slow but steady changes improve adaptation measures to increase resilience, while severe and rare events are difficult to observe due to their low frequency of occurrence. It may require several years to prove changing trends because there is still a lack of evidence in considering climate change effects as relevant risk driver in insured losses and it can be the result of different causes:

- low frequency of peril occurrence in monitored areas (hailstorms)
- incomplete understanding of physical processes of weather events (hail formation, storm tracks), natural variability (tropical cyclones) or changes in precipitation patterns translate into flooding.

At the opposite, the re/insurance industry classify climate-change effects according to their relevance, where the highest confidence is now given to risks related to the increase in global temperatures because alarming trends are reported. Higher temperatures origin melting of glaciers and sea level rise that will directly impact the magnitude of storm affecting the long-term risk for coastal regions, that can be reduced by introducing some protection measures. There will be uncertainties concerning the speed and extent of sea level rise, longer heatwaves, droughts, and period of water scarcity: agriculture, productivity, infrastructure, health, mortality and political risks can be a possible consequence. Extreme rainfall and subsequent flooding can increase to the more water vapor hold by the atmosphere, pronounced with the outbreak of tropical cyclones. Since climate change combined with other loss drivers can massively affect the number of small-to-medium sized losses arising from secondary perils, the profitability of some lines of business can be drastically reduced if risks are not priced accurately. But

[21] Swiss Re Institute, *The economics of climate change: no action not an option*, April 22, 2021, www.swissre.com

currently, confidence in climate trends is lower for atmospheric and oceanographic circulation changes, affecting natural phenomena such as frequency and intensity of tropical cyclones or windstorms and hailstorms. Lower confidence levels are partially consequence of the lower frequency and because of difficult interplay with the climate system: re/insurers should lower the focus of frequency by increasing the confidence through additional research and quantifying uncertainties of climate risk on the occurrence of anomalously stationary weather patterns. The following **Table 3** summarizes the classification of climate change effects according to their relevance for the re/insurance industry:

Table 3: Classification climate change effects

DRIVER FOR CHANGE	EFFECTS / PERILS	TIME HORIZON	INSURANCE IMPACT
HIGH CONFIDENCE			
Increasing mean temperature	Sea-level rise and storm surge	Slow but steady increase over next decades	Low-med insurance impact: no sudden / unprecedented events
Increasing temperature extremes	More frequent heat waes, droguhts, water scarsicity, wildfires, potential politial conflicts, extreme rainfall and river floods	Observable increasing trends over next decades for heat waves / droughts	Frequency perils, mostly affecting primary insurance, quota-share and stop-loss reinsurance
Increases moisture capacity in atmosphere due to higher temperatures	More frequent severe tropical cyclones, winter storms	Regional trends already present with medium-severe impact likely by mid/end of century	Limited insurance impact for flood-related losses due to protection gap
Impact of climate cycles (e.g. ENSO)	Increased hail & tornado risks	Severe impact expected by mid/end of century	High impact on Poperty Damage and Business Interruption
Increased protection measures			
REDUCED CONFIDENCE			

Direct

Confidence barrier

Indirect

Source: Swiss Re Institute

In conclusion, climate change is a manageable risk for re/insurance industry but it should improve its risk modelling and benchmarking capabilities to capture the loss experience exacerbated by the connection between climate change and rising of extreme weather events because the insurability of assets exposed to weather-related events will be called into question. Furthermore, re/insurers should align their underwriting policies to facilitate transition to a low-carbon economy because unmitigated climate change will have severe consequences for the entire risk landscape, with dangerous impact on human life, health and poverty[22].

[22] Swiss Re Institute, *Insurance in a world of climate extremes: what latest science tells us*, by Michael Gloor, December 18, 2019, www.swissre.com

1.4 Protection Gap

1.4.1 Protection Gap definition

The Geneva Association offers two definitions of what it is a protection gap:

- The *risk protection gap* is the difference between total losses and insured losses.
- The *insurance protection gap* is the difference between the amount of insurance that is economically beneficial, and the amount of insurance actually purchased.

Both definitions are useful but with some differences. The risk protection gap identifies the issue to which insurance is not providing protection for potentially insured losses. The only advantage present is its relatively easy calculation, at both individual and societal levels: after a natural disaster, government and private entities can estimate the risk protection gap as the difference between the losses caused and the amount of insurance paid. The insurance protection gap focuses attention on the kind of insurance that should be provided and not just on the kind of insurance that is in place, adding normative element. This second definition pays attention on the process of evaluating types of insurance or insurance coverage decisions. But the above definitions can be considered incomplete for two reasons. Firstly, the definition should not consider the adequacy of amounts of insurance only at macro level, protection for a region of class of insureds after a disaster, but it should go in depth also at micro level by determining if a particular policyholder suffers from a protection gap. Secondly, the insurance protection gap suggests the presence of an optimal level of insurance that is "*economically beneficial*" but it is not necessarily true because the aim of insurance is to respond to risk aversion of a person or a firm to protect them against uncertain but potentially large losses. But the different levels of risk aversion present in each individual or groups are difficult to be measured and so, in the abstract, it is impossible to determine what is the economically beneficial level of insurance. In the end, the full definition of protection gap may be: "*it is the difference between the amount of insurance that is in place and the amount of insurance that should be in place*". The key term is the measurement of "how much insurance should be in place", either prospectively or related to occurred loss. The following steps are presented in order to determine the amount of insurance that "should be":

1. The insurance coverage must be related to a well-defined class of potential insureds and the context in which they are.
2. The insurance coverage should respond to the policyholders' reasonable expectations about the type of insurance at issue in terms of protection and security provided.

3. The risk must be insurable: calculable, non-correlated and adequate price covering all costs.
4. The insurance must avoid problems such as moral hazard, adverse selection, improper risk segmentation and high transaction costs.
5. The insurance must provide positive social effects and provide incentives for risk mitigation before the disaster occurs in order to limit the economic consequences in the community.

In conclusion, insurance plays a crucial role for the social and economic environment before and after the occurrence of perils by protecting individual and businesses. But to do this properly, the right amount and kind of insurance coverage needs to be in force because when insurance is inadequate, protection gap arises and makes economic losses from disasters high[23].

1.4.2 Closing the protections gap

According to Sigma Reports, the protection gap has reached the level of around 54% of the total losses uninsured in 2022. Even if there is still a large difference, the trend has improved by decreasing from the 10-year average of 61%. Main events hit areas characterized by higher insurance penetration proving that the scope of the re/insurance industry is to make households, firms and institutions more resilient[24].

Every year natural catastrophes events cause an enormous loss of lives and considerable economic costs both in industrialized and developing countries and, surprisingly, both are also materially underinsured. On average, from 2007 to 2017, only about 30% of catastrophes losses were covered by insurance and the remaining 70% have been borne by individuals, firms and governments. Traditionally, the financing gap is covered largely by public sector: governments have to shoulder the cost of relief and recovery, to pay for reconstruction of public infrastructures. It is expected to support also private rebuildings by providing transfer payment when individuals and firms are underinsured. However, many countries lack formal insurance programs for catastrophic losses and ask funds for the recovery only after a disaster has occurred. The typical measures taken by governments post-event are:

- Budget reallocation is a fast remedy, for which funds can be allocated autonomously but available funds are usually limited;

[23] SSRN, *What is a Protection Gap? Homeowners Insurance as a Case Study*, by Jay M. Feinman, April 12, 2021, www.papers.ssrn.com

[24] Ivi

- Raising taxes have a time lag during that it can hurt a fragile economy and people devasted by a natural disaster;
- Borrowing debt can be done using traditional instruments and it is potentially slow, unreliable, costly for countries with already high debt and low credit rating.

At the opposite, it is evident how financial preparedness through insurance helps to reduce responsibility on the government after a disaster: it lowers the volatility of state budget, it improves planning certainty for the public sector and it avoids long-term fiscal instability policy. The main pre-event measures that should be taken are:

- Incentive to a well-developed private insurance industry to which risk are transferred to stimulate price competition but legal framework, acceptance by population and increment of local insurance sector are required;
- Government can be seen as insurance buyer at macro level by providing financing when needed as innovation solution that requires time to be implemented;
- Guaranteed funding at pre-agreed terms with the disadvantage that additional loans can be restricted;
- Presence of reserve funds as positive signal to investors and at owners' discretion but it requires many year to reach critical size for the opportunity cost of holding liquidity.

The rating agency, such as Standard & Poor's (S&P), has emphasized the positive role of disaster insurance program on sovereign financial resilience: economies with lower protection gap recover more quickly and suffer lower GDP reduction than in absence of insurance coverage. But no industrialized or developing country or public organization can fully protect itself against extreme events. An integrated risk management approach should comprehend the transfer of catastrophic risk and climate risk insurance, as a risk transfer instrument, can contribute to building resilience to adverse consequences of extreme weather events.

Finally, governments should enable a working insurance market that will help to absorb the greatest part of disaster losses suffered by the community. The Sovereign and sub-sovereign insurance solutions can mitigate the remaining financial burden on governments and the post-disaster financing (such as debt) should only be used to cover residual losses once all risk transfer solutions have been considered. Public and private sectors can operate together to finance disaster risks by creating innovative solutions that can be applied to countries and regions. These new risk transfers solutions, used also to improve the protection gap, will be the main object of discussion in this thesis[25].

1.5 Focus on natural catastrophes in Italy

1.5.1 The numbers of disasters in 2022

Among the countries most prone to natural disasters, Italy is unfortunately at the top of the list for the numerous and frequent phenomena that have stuck and continue to hit its territory. Italy has historically been hit by a series of disasters, such as volcanic eruptions, earthquakes, landslides, floods, storm surges, that have caused significant social and economic damage, may victims and remarkable costs for the country. The gravity of these events has increased due the doubling of the population during years and its distribution from rural to urban areas with the consequence of the occupation of an increased number of potentially risky areas. In the 2022-year Italy has recorded a rising of natural catastrophes of 55% with respect the previous 2021 with 310 weather-related events causing the death of 29 people. In particular, there have been 104 floods (increased of 19% with respect 2021) and 11 landslides from heavy rainfalls, 81 severe connective storms (increased of 76% with respect 2021), 29 hailstorms (increased of 107% with respect 2021), 28 droughts (increased of 367% with respect 2021), 18 storm surges, 13 river floods, impacting also the cultural Italian heritage. The northern part of Italy has been the most affected zone, followed by south and center of the peninsula. These disasters are highlighting the increasing necessity to improve actions taken against the climate change effects in order to save 75% of resources used to repair incurred damages[26].

1.5.2 The current exposure of the Italian Insurance Industry for natural catastrophe

The most recent report of ANIA describes the overall exposure of the Italian insurance market during the period 2021-2022 for the catastrophic event risk exposure, counting for buildings, goods and incidental damage, is divided into:

- businesses:

[25] Swiss Re, *Closing the protection gap – disaster risk financing: smart solutions for the public sector*, in Our business / Public Sector Solutions / Thought leadership, www.swissre.com
[26] LEGAMBIENTE, *Emergenza clima: il 2022 anno nero*, December 30, 2022, www.legambiente.it

- €755 billion for earthquakes (decreased of 1.7% compared with 2021)
- €754 billion for floods (increased of 1.1% with respect 2021)

- homeowners:
    - €264 billion for earthquakes (increased for 17.8% from 2021)
    - €141 for floods (increased for 37.2% with respect 2021)

All € values are reported net of the contractual limits set by the insurance policies.
Around 1.4 millions of businesses are insured for both earthquake and flood risks, while a total of 906'000 residential units against earthquake and 435'000 against floods, so many dwellings with fire insurance are assumed to also have earthquake as extension. The regions that have contributed for the most to the increase in insurance are Marche and Valle d'Aosta for business, while Sicily, Umbria, Marche and Friuli-Venezia Giulia for homeowners. Geographically, total insurance exposure to natural catastrophe risk is concentrated mostly in the northern part of Italy, for almost two thirds of the total, and for neatly 20% of total exposures also the centra regions are becoming increasingly relevant.
To promote policy extension to natural disaster in Italy, with main focus on earthquake and flood perils, the *Law 205/2017* was introduced in accordance with the 2018 Budget Law, and it established a tax incentive for this coverage protection for dwellings. Traditionally, the Italian management approach to damage caused by natural disasters relies on ex-post state intervention: this has strengthened the belief that the public sector is a last-resort guarantor in charge of reconstruction and that is the reason why 88.7% of fire policies have no cat-nat coverage extension. Considering only policies with nat-cat extension subscribed from 2018 to March 2022 in order to see the impact of the law, this kind of policy was for 77% of the 1.4 million active policies, obtained as the sum of straight earthquake policies (579'000), straight flood policies (275'000) and combined earthquake and flood policies (496'000). Compared with 2020-year analysis, the number of straight earthquake policies decreases of 12.5% in favor of the increase in combined policies (+57.8%) and in flood policies (+18%). At national level, ANIA has estimated for 2021-2022 period, based on available data and regarding:

- **overall total exposure amounts** of roughly €393 billion as the sum of amounts insured of €198 billion from straight earthquake, of €56 billion from straight flood policies and additional part of €140 billion from combined policies covering both these risks;
- **the average policy premium** (net of taxes) of fire insurance is €167 and, after tax incentive, €142 for the extension to natural disasters. It is possible to calculate the average policy premium per dwelling that would be respectively €122 and €127.

Finally, since it is not more sustainable for both public sector and private sector separately to borne entirely the economic damages caused by extreme events, ANIA has underlined the need for a national insurance scheme based on an integrated public-private partnership to cover mainly damages from earthquakes and floods[27].

1.5.3 Current and historical protection gap

Among the European countries most highly exposed to catastrophic events, Italy has the biggest protection gap, amounted to 89% (€45 billion) in 2011-2021 according to Swiss Re estimates, among which the earthquake risk gap is one of the biggest in the world. Furthermore, earthquakes and floods are not the only major perils because, according to the European Severe Weather Database, extreme weather events in Italy have become four time more frequent in the last decade including also heavy rainfall, hail and tornadoes, which have increased from 348 in 2011 to 1'602 in 2021. In addition, EIOPA has confirmed this evidence by scoring the protection gap for natural catastrophe[28] in Italy: 2.5 for floods and 4 for earthquake, meaning a very high protection gap. This result is not surprising because Italy has historically been the country with the highest uninsured losses during 1980-2021 corresponding to 33% of the uninsured losses in whole Europe. Italian Earthquake and Italian Flood's insurance penetration was very low counting for 98% and 97% of uninsured losses in percentage of total economic losses. Another important outcome come from the fact that the actual protection gap can be the result of the business model used by the commercial property insurers: commercial insurance policies could differ significantly from residential ones for the amount of limits and deductibles that are more volatile and less standardized for the commercial line[29].

[27] ANIA*, Italian Insurance 2021-2022*, Chapter 6 – Other Non-life insurance, November 15, 2022, www.ania.it
[28] EIOPA Protection Gap scoring: 0-no, 1-low, 1.5, 2-medium, 2.5, 3-high, 3.5, 4-very high
[29] EIOPA, *The dashboard on insurance protection gap for natural catastrophes in a nutshell*, December 5, 2022, www.eiopa.europa.eu

CHAPTER 2

THE ARCHITECTURE OF CATASTROPHE RISK MODELS

Introduction

This chapter begins with the presentation of the catastrophe modelling fundamentals by recalling the brief history about catastrophe models and by explaining how they have become an important element in actuarial practice to predict future natural disasters. Then, it introduces the module-based mechanism behind the main catastrophe models and the growing concern for the insurance industry about the exposure data quality used as input into the models. After having presented the main three CAT models currently used in the worldwide, one section presents the main key output statistics obtained from the models used to manage risk and the most common distributions applied to the model claim count and to the model claim size in the catastrophe modelling. Finally, it gives an insight about the main advantages and disadvantages involved in the catastrophe risk models and it demonstrates how catastrophe model outputs can be used in several selected actuarial tasks.

2.1 Catastrophe modelling fundamentals

The human and financial consequences of natural disasters, whether these are earthquakes, hurricanes, or floods, can be devastating. Furthermore, risks are rising, as populations grow along exposed coastlines and mega-cities rapidly expand, merged with the global warming affecting the frequency and intensity of some extreme events. Consequently, over the past century, catastrophe modelling technology has developed itself from little more than a collection of maps to the cutting-edge application of nowadays. But in the modern world, issues such as exposure data quality and risk mitigation have moved forward requiring the urgent attention of both (re)insurers and policymakers. In such an environment, the future of catastrophe modelling with an ever-shifting spectrum of risk is most timely.

In a world of increasing uncertainty, one thing is sure: bigger and more frequently occurring catastrophes are set to test the reliability of modelling in a world of climate extremes. Catastrophic risks are inherently challenging to model due to the limited knowledge about what determines the probability of extreme events occurring, and the need to understand all the potential pathways to loss. But models provide a mechanism to integrate and summarize all the relevant science, data, engineering knowledge and even behavior of insurers in the aftermath of a catastrophe. The outputs provide a useful tool-set in which all this knowledge can be used by (re)insurers, property owners and policymakers to make informed risk management and mitigation. While originally catastrophe models were used mainly in countries with established insurance industries to manage risks, they are also being involved today in the creation of new risk transfer mechanisms in the developing world.

Finally, it is crucial to understand how catastrophe models are developed and calibrated, the quality and completeness of the exposure data fed into the models and, finally, the interpretation of model results to make informed decisions on how to stress pricing and accumulation strategies, which will be deeply analyzed in the subsequent sub-paragraphs[30].

2.1.1 Origins of catastrophe models

Since the 1800s, property insurers have been visualizing exposure by mapping covered property, but this common practice became too time consuming to be executed. The original aim of catastrophe models lies in the modern science of understanding the nature and impact of natural hazards. In particular, the common practice of measuring an earthquake's magnitude or a hurricane's intensity is one of the crucial elements in a catastrophe model. This measurement practice began in the 1800s and a standard set of metrics for a given hazard was established so that risks can be assessed and managed. In recent decades, many studies have published asserting that mapping risk and measuring hazard may come together in a definite way in the late 1980's and in early 1990's to create catastrophe models, also thanks to the increasing computer capabilities. Computer-based models were born for measuring catastrophe loss potential by linking scientific studies of natural hazard measurements and historical occurrences with advances in information technology and in geographic information system (GIS). Even if probabilistic catastrophe risk modelling occurred in the late 1980s, the usage of such tools was largely accepted only the aftermath landfall of Hurricane Andrew in 1992. After this catastrophe, it became clear how the actuarial approach relying on 5 to 25 years of historical catastrophe losses for pricing catastrophic risk was insufficient and how a probabilistic approach to loss analysis was the most appropriate way to manage catastrophe risk and its

[30] The Review Worldwide Reinsurance, *A guide to catastrophe modelling*, in association with RMS, 2008, www.rms.com

unexpected losses. In perils where losses are dominated by reasonably predictable and frequent events, actuarial practice can use recent historical loss experience, adjusted for inflation and other appropriate changes, to estimate future losses. Where losses are infrequent events, such as those arising from catastrophes, the available historical information may not be sufficient to reliably predict future loss potential. This problem has led to the development of sophisticated loss simulation models for perils such as hurricane, earthquake and flood. Today, catastrophe models are essential throughout the insurance industry, assisting (re)insurers and other stakeholders in managing their risk in a world of uncertainties.

Moreover, catastrophe models have expanded into many areas beyond those considered "traditional" of actuarial practice and are available for an increasing number of perils and potentially impacted regions. Even if there are several models dealing with different catastrophes, they have several similar components:

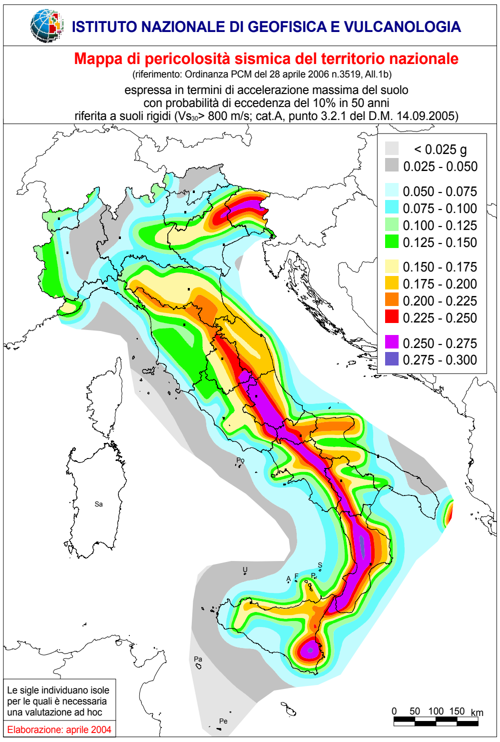
1. Probability of the particular catastrophe occurring;
2. Intensity of the catastrophe;
3. Corresponding damage;
4. Allocation of loss amounts among the various impacted entities.

Each of these previous components becomes a module in a catastrophe model, where each peril reflects multiple factors specific to the peril being modeled.

Historically, there are three main typologies of natural catastrophe models:

- **Deterministic models**

  They respond to the question "what could happen?" and provide a score (1-100) that represents the relative risk for a specific peril, at a specific location. They may only be relative to the hazard, while some include a measure of estimated loss based on the structure present. There is no need to run sophisticated model, but it is enough that a company can set its own thresholds for underwriting decisions depending on its risk appetite: the higher the score, the greater the risk. This score mechanism can be easily implemented into the underwriting risk and



pricing work stream, especially for homogenous lines of business.

- **Forensic models**

  They are used for the post event analysis of what occurred with the usage of advanced radar and aerial imagery: realistic, high-resolution footprints deriving from proprietary radar-based weather forensic algorithm, public data and social media reports.

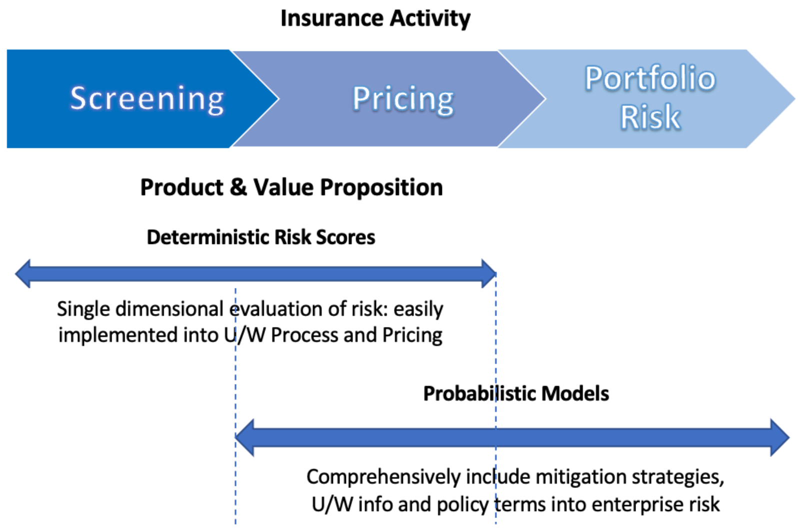
- **Probabilistic models**

  They start with a large event set (historical and simulated) and each event has a frequency of occurrence. Based on characteristics of the event at any location, the structure vulnerability and associated loss can be calculated with the relative outputs, which will be discussed after:

  - Event Loss Tables and Yearly Loss Tables
  - Average Annual Loss and Probable Maximum Loss[31].

The following **Figure 5** summarizes the natural catastrophe offerings to insurers in the creation of the appropriate suitable product for natural catastrophic risk:

Figure 5: A complete suite of products to cover the insurers' needs



Source: CoreLogic, Cat Modeling 101, March 25, 2018

[31] CoreLogic, Cat Modeling 101, Seminar CAS U/W Collaboration in Boston (MA), March 25, 2018

2.1.2 The structure of probabilistic catastrophe models

As it has been anticipated before, it is generally agreed that a probabilistic approach is the most appropriate method to model the complexity inherent in catastrophes. It requires simulating thousands of representative, or stochastic, catastrophic events in time and space; compiling detailed database of building inventories; estimating physical damage to various types of structures and their contents; translating physical damage to monetary loss; and summing over entire portfolios of buildings. The modeler's task is to simulate, realistically and adequately, the most important aspects of this complex system. Understanding the underlying assumptions of the models and their implications together with their output limitations is important in order to manage results effectively. Catastrophe models need substantial amounts of data for model construction and validation. The reliability of such models depends heavily on an understanding of the underlying physical mechanisms that control the occurrence and behavior of natural hazards, which have been accumulated by physical systems, scientists and engineers through sophisticated instrumentation and computing capabilities. The sophisticated theoretical and empirical models currently developed can reasonably simulate these complex phenomena and can be a useful tool for the entire (re)insurance industry[32].

In general, probabilistic catastrophe models capture two types of uncertainty:

- **Primary** (aleatory) uncertainty related to the likelihood of a certain event to occur;
- **Secondary** (epistemic) uncertainty defined as unsureness in the amount of loss, given that a particular event has occurred, and it is associated with:
    - *Hazard uncertainty* depending on the type of the event to be analyzed, such as the effect of soil types on the amount of ground shaking for earthquake or the wind speed at a particular location for windstorm;
    - *Vulnerability uncertainty* refers to the uncertainty in performance of the insured object coming from the modelling of building characteristics or from how buildings response to the intensity and duration of the hazard;
    - *Portfolio uncertainty* is linked to the level of detail of the input portfolio data as well as to the reliability of that information[33].

The basic framework for modelling the impacts of natural hazards can be divided into the following four modules:

[32] The Review Worldwide Reinsurance, *A guide to catastrophe modelling*, in association with RMS, 2008, www.rms.com

[33] SCOR, *From principle-based risk management to solvency requirements – analytical framework for the Swiss Solvency Test*, 2008, www.scor.com

- **Stochastic event module** – defining the hazard phenomena:

  The first stage of catastrophe modelling begins with the generation of a stochastic event set, which is a database of scenario events. Each event is defined by a specific strength or size, location or path, and probability of occurring or event rate by answering the question: What is the chance of this event occurring? Thousands of possible event scenarios are simulated based on realistic parameters and historical data to probabilistically model what could happen over time.
- **Hazard / Local intensity module** – assessing the level of hazard:

  This second stage assesses the level of physical hazard across a geographical area at risk. For example, an earthquake model estimates the level of ground motion across the region for each earthquake in the event set, considering the propagation of seismic energy. While for hurricanes, a model calculates the strength of the winds around a storm, considering the region's terrain and built environment.
- **Vulnerability / Engineering module** - quantifying the physical impact of hazard on properties at risk:

  This third stage calculates the amount of expected damage to the properties at risk. Vulnerability functions are region-specific and vary by a property's susceptibility to damage from earthquake ground shaking or hurricane winds. Parameters defining this susceptibility include a building's construction material, its occupancy type, its year of construction, and its height. In cat models for insurance applications, different vulnerability curves are used to damage for a structure, its contents, and time element coverages such as business interruption loss or relocation expenses. Damage is quantified as a mean damage ratio (MDR), which is the ratio of the average anticipated loss to the replacement value of the building. These are the average percentages of damage that are expected for a structure with the characteristics input into model. The uncertainty around the estimated property loss (sometimes referred to as *secondary uncertainty*) is often expressed in terms of standard deviation or a coefficient of variation (CV).

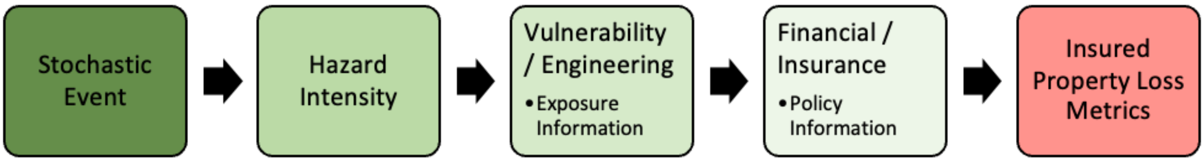
The stochastic event, hazard and vulnerability modules cover what is traditionally known as *a probabilistic risk analysis*.

- **Financial / Insurance Module** – measuring the monetary loss from various financial perspectives:

  Catastrophe loss models can be thought as one application of probabilistic risk analysis, characterized by their sophistication of the financial analysis module. This module translates physical damage into total monetary loss. Estimates of insured losses are then computed by applying policy conditions (e.g., deductibles, limits) to the total loss estimates.

Each module creates data, and some key information is passed sequentially to the next module to enable the process to continue. Some module output is useful on its own for validation and other purposes. The **Figure 6** below illustrates how the model components interact:

Figure 6: Model overview and components



Source: Uses of catastrophe model output, American Academy of Actuaries

In the complex and probabilistic world of catastrophe modelling, exposure data quality is the only element of uncertainty in the models that can be controlled. In fact, when missing or incorrect information is enhanced, it is not unusual to see loss estimates change from a building to another. Catastrophe models are now far more sensitive to higher resolution, location-specific exposure data, and results can change significantly based on the level of geographic resolution, property details and the characterization of hazard at a location. The main input used in probabilistic cat modelling are the following:

- **Time series**: essential data input for the simulations;
- **Geo Maps**: vectorial representation of territory, with evidence of urban areas, buildings, rivers, faults, …;
- **Vulnerability**: tables and functions that show construction's vulnerability such as construction, occupancy, year built, height, square footage, …;
- **Risk condition**: specific features of insured risks (localization with latitude and longitude, exposure, deductibles, …);
- **Geophysics models**: useful to estimate the impact of each simulated cat events, based on fault's characteristics, return period, …

Inserting all these data at their best quality into a model yields a loss distribution with a significantly lower spread measured by lower standard deviation with respect the case when all these features would be inadequate or partially unknown.

Improving data quality has become a pressing concern for many (re)insurers as well as rating agencies, which means that if a company does not have control over issues affecting the balance sheet such as data quality and modelling, they are unlikely to have rigorous internal controls. Many reinsurers are now differentiating cedants on the basis of the quality of their exposure data in order to benefit from reducing their operational risk, from improving their financial strength and securing the right level of capital for regulatory purposes. A simple comprehensive framework for exposure data quality assessment has been defined to incorporate the metrics into business decision-making:

- **Consistency** is to assess that data is presented in a consistent format and in the appropriate units for input into catastrophe risk models;
- **Completeness** is the assessment of the resolution (or granularity) of the data as well as amount and significance of unknown data;
- **Accuracy** measures the data correctness through:
  - *Credibility*: whether the data is believable and logical;
  - *Objectivity*: whether the data is coded in a manner that is unbiased, unprejudiced and impartial;
  - *Comparisons* with reputed sources: how well the data compares with data ascertained from reputed independent / third party sources.

On the opposite side, the main output of a probabilistic catastrophe model is the *Exceedance Probability* (EP) Curve, which illustrates the annual probability of exceeding a certain level of loss. Typically, EP curves are displayed graphically, but they can also be summarized by key *Return Period* (RP) loss levels. For example, a 0.4% annual probability of exceedance corresponds to a 250-year return period loss (1/250 = 0.4%). Conversely, for a given exceedance probability (Return Period), it is possible to define the corresponding *Probable Maximum Loss* (PML). Another important key risk metric coming from an EP curve is the *Annual Probability Distribution of the losses* with its mean known as *Average Annual Loss* (AAL) that is an estimate of the annual premium needed to cover losses from the modelled perils over time, assuming that the exposure remains constant. It can be calculated as the area under the EP curve o as the sum product of the mean loss and the annual likelihood of occurrence (the event rate) for each event in the event set, and can be used to evaluate the catastrophe load portion of an insurance rating function. AAL is often referred to as the pure premium of “burn cost” and its uncertainty plays a role in measuring risk: the coefficient of variation (CV), defined as the standard deviation divided by the mean (AAL), gives an indication of the variability around AAL estimates. This statistic is a normalized measurement and is appropriate for comparing the volatility of one exposure to another. From these metrics and from the resulting losses in the financial module, data available can be used to produce two relevant tables:

- *Event Loss Table* (ELT): a set of simulated synthetic catastrophic events, with information about the estimated frequency and loss of each event in the set;
- *Year Loss Table* (YLT): a list of years and a list of events that occur within each year and a single realization of loss for each event.

All these primary statistical metrics used in catastrophe modelling are described more precisely in the subsequent sub-paragraph to give also a separate discussion between the distribution of loss severities and the distribution of claim counts.

Finally, there are three CAT models that are mainly used today:

- **AIR Worldwide (AIR)** is the scientific leader and most respected provider of risk modeling software and consulting services with headquartered in Boston (U.S.A.) for catastrophe risk management, insurance-linked securities, detailed site-specific wind and seismic engineering analyses, and agricultural risk management;
- **Risk Management Solutions (RMS)** is the leading global provider of climate and natural disaster risk modeling and analytics for the global property and casualty (P&C) insurance and reinsurance activities, acquired by Moody's in 2021. It is the most used for retail insurers;
- **EQECAT** is a part of CoreLogic and is dedicated to the quantification and mitigation of the operational and financial consequences of extreme events related to natural and manmade risks for the insurance industry[34].

2.2 Primary output metrics and frequency analysis in catastrophe modelling

2.2.1 Exceedance Probability and relative statistical metrics in catastrophe modelling

It is evident how catastrophe modelling is a type of estimation technique used in the property and casualty (P&C) industry to predict and evaluate damage caused by natural disasters such as hurricanes, earthquakes, tornados, hail, winter storms, floods and wildfires.

[34] The Review Worldwide Reinsurance, *A guide to catastrophe modelling*, in association with RMS, 2008, www.rms.com

One of the most commonly used metrics in catastrophe modelling is the **Exceedance Probability** (EP), as it has been anticipated before: it is the probability that a certain loss value will be exceeded in a predefined future time period. EP is principally used in planning for potential hazards such as river and stream flooding, hurricane storm surges and droughts, reserving for reservoir storage levels and providing homeowners and community members with risk assessment. To define exceedance probability, let $D_1, D_2, ...$ be a set of natural disasters. Let p_i and X_i be an annual probability of occurrence and the corresponding total loss associated with a natural disaster D_i. Thus, D_i is a Bernoulli random variable with:

$$\mathbf{P}(D_i\ occurs) = p_i$$
$$\mathbf{P}(D_i\ does\ not\ occur) = 1 - p_i$$

If an event D_i does not occur, the loss is zero, while the expected loss for a given event D_i in a given year is $\mathbf{E}[X] = p_i X_i$.

As a consequent metric, the overall expected loss for the entire set of events is known as the **Average Annual Loss** (AAL) and is defined as the sum of the expected losses of each of the individual events for a given year:

$$AAL = \sum_{i=1}^{\infty} p_i X_i$$

The Exceedance Probability is sometimes denoted as $EP(x)$ and it is called the **Exceedance Probability Curve**, if X is a loss random variable, then:

$$\boldsymbol{EP}(x) = \boldsymbol{P}(X > x) = 1 - \boldsymbol{P}(X \leq x)$$

where using probabilistic terminology $EP(x)$ is the survival function of X.

In particular, if $x = X_i$, which is a loss associated with a disaster D_i, then:

$$\boldsymbol{EP}(X_i) = \boldsymbol{P}(X > X_i) = 1 - \boldsymbol{P}(X \leq X_i) = 1 - \prod_{j=1}^{i}(1 - p_j),$$

where $D_1, D_2, \dots, D_i$ are the events with higher level of losses such that $X_1 \geq X_2 \geq \cdots \geq X_i$.

The probability that all the other events with possible losses above the value X_i have not occurred is sometimes called the **Non-Exceedance Probability** (NEP):

$$P(X \leq X_i) = \prod_{j=1}^{i}(1 - p_j)$$

The **Return Period** of the Loss Return Period of a natural disaster is usually associated with the EP because it is calculated as a reciprocal of the EP itself:

$$RP = \frac{1}{EP}$$

An applicative example of an Exceedance Probability Curve in the following **Table 4** supposing that during a given year no more than one hurricane can occur:

Table 4: Summary of metrics: event loss data, annual probability of occurrence, EP, expected loss, RP

Event (D_i)	**Description**	**Annual Probability of occurrence (p_i)**	**Loss (X_i)**	**Exceedance Probability** $1-(1-p_i)(1-p_2)\ldots$	**E[X] $= p_i X_i$**	**Return Period (years) = $\frac{1}{EP}$**
1	Category 5 Hurricane	0.003	15,000,000	0.0030	45,000	333.33
2	Category 4 Hurricane	0.006	8,000,000	0.0090	48,000	111.33
3	Category 3 Hurricane	0.011	5,000,000	0.0199	55,000	50.29
4	Category 2 Hurricane	0.030	3,000,000	0.0493	90,000	20.29
5	Category 1 Hurricane	0.040	1,000,000	0.0873	40,000	11.45

Source: Exceedance Probability in Catastrophe Modeling, Casualty Actuarial Society E-Forum Winter 2021

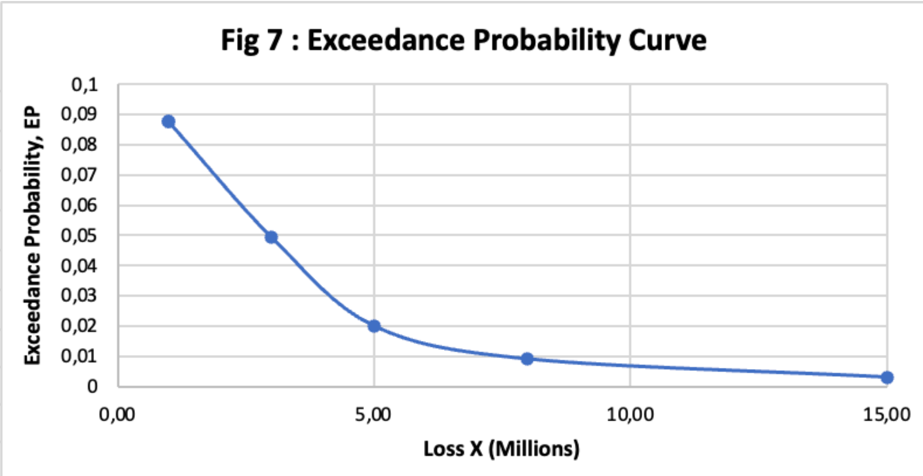
Note that the probability that no hurricane occurs is:

$$P(No\ Disaster) = 1 - \sum_{i=1}^{5} p_i = 1 - 0.09 = 0.91$$

While the Average Annual Loss is:

$$ALL = \sum_{i=1}^{\infty} p_i X_i = 45{,}000 + 48{,}000 + 55{,}000 + 90{,}000 + 40{,}000 = 278{,}000.$$

The Exceedance probability Curve in this example is shown in the following **Figure 7**:



Source: Exceedance Probability in Catastrophe Modeling, Casualty Actuarial Society E-Forum Winter 2021

*The Saffir/Simpson Hurricane Wind Scale provides specific wind values for each hurricane category in the following **Table 5**:

Table 5: The Saffir/Simpson Hurricane Wind Scale, 1974

Scale Number (category)	Winds Max 1-min (mph)
1	74 - 95
2	96 - 110
3	111 - 130
4	131- 155
5	>155

Source: Exceedance Probability in Catastrophe Modeling, Casualty Actuarial Society E-Forum Winter 2021

The Exceedance Probability can be further broken down into the **Occurrence Exceedance Probability** (OEP), which is the probability that the largest loss in a year exceeds a certain amount of loss, especially used for occurrence-based reinsurance structures such as quota share or working excess. It is denoted as $O(x)$ and is called the **Occurrence Exceedance Probability Curve**.

Let $X_1, X_2, \dots, X_N$ be losses in a given year. Then

$$O(x) = \boldsymbol{P}(max_{1\le i\le N}(X_i) > x) = 1 - \boldsymbol{P}(max_{1\le i\le N}(X_i) \le x) = 1 - \prod_{i=1}^{N} \boldsymbol{P}(X_i \le x)$$

Using probabilistic terminology, if $X_{(1)}, X_{(2)}, \dots, X_{(N)}$ is the ordered statistic with $X_{(N)} = max_{1\le i\le N} X_{(i)}$, then $O(x)$ is the survival function of $X_{(N)}$.

Let $F(x)$ be the cumulative distribution function (CDF) of X. Then for a fixed N the OEP is

$$O(x) = 1 - (F_x(x))^N.$$

If N is the random variable claim count with the probability mass function (p.m.f) P_N, then by the law of total probability,

$$O(x) = \sum_{n=0}^{\infty} \boldsymbol{P}(max_{1\le i\le N}(X_i) > x \mid N = n)\boldsymbol{P}(N = n) =$$

$$= 1 - \sum_{n=0}^{\infty} \boldsymbol{P}(max_{1\le i\le N}(X_i) \le x \mid N = n)\boldsymbol{P}(N = n) =$$

$$= 1 - \sum_{n=0}^{\infty} \left(\prod_{i=1}^{n} \boldsymbol{P}(X_i \le x) \right) \boldsymbol{P}(N = n) = 1 - \sum_{n=0}^{\infty} \left(F_X(x)\right)^n \boldsymbol{P}(N = n) =$$

$$= 1 - \boldsymbol{E}_N\left(\left(F_X(x)\right)^N\right) = 1 - \boldsymbol{PGF}\left(F_X(x)\right)$$

where $\boldsymbol{PGF}(x)$ is the probability generating function for N defined as

$$\boldsymbol{PGF}(t) = \boldsymbol{E}(t^N) = \sum_{n=0}^{\infty} t^n \cdot \boldsymbol{P}(N = n)$$

Thus,

$$O(x) = 1 - \boldsymbol{PGF}\big(F_X(x)\big).$$

Sometimes actuaries will refer to the **Occurrence Probable Maximum Loss** (PML) curve instead of the OEP curve because they are linked, since they are referring to the same thing: PML shows dollars, while the OEP shows probabilities. The PML is the dollar amount of loss x at return period r, thus:

$$\frac{1}{r} = O(x) = O(PML_{occ})$$

or

$$PML_{occ}(r) = O^{-1}\left(\frac{1}{r}\right)$$

where $O^{-1}(x)$ is the inverse OEP function.

The key outputs proposed above may be used to determine the distribution of the aggregate loss amount S but it is a difficult problem because it cannot be solved analytically. Generally, the distribution function F_S can be expressed as follows:

$$F_S(s) = \boldsymbol{P}(X_1 + X_2 + \cdots + X_N \leq s)$$

where the two main issues are:

- the sum of known independent random variables and the distribution of this sum is the convolution function of the individual distributions;
- the number of components of the sum N is itself a random variable, and hence one needs to take into account all possible values of N in the calculation.

Because the different values of N correspond to mutually exclusive cases, the distribution function F_S can be seen as a weighted sum of the probability of mutually exclusive events, given by:

$$F_S(s) = \boldsymbol{P}(X_1 + X_2 + \cdots + X_N \leq s) = \sum_{k=0}^{\infty} \boldsymbol{P}(N = k)\, F_X^{*k}(s)$$

where F_X^{*k} is the k-the convolution power of F_X.

This formula moves from the conditioning to N and from the fact that the distribution function of a sum of independent random variables is obtained by the convolution of the individual distribution functions: the problem has been reduced to calculating the distribution of the sum of a fixed number of variables. Furthermore, since there is an infinite sum of multi-dimensional integrals, it is hardly possible to obtain the aggregate loss process distribution with an analytical form and so the issue needs to be solved by numerical methods.

From this brief introduction, it has be noted that the Exceedance Probability can be further split into the **Aggregate Exceedance Probability** (AEP), which is the probability that the sum of losses in a year exceeds a certain amount of loss and it is mainly used for aggregated based reinsurance contracts such as stop loss and reinstatements. This probability is denoted as $A(x)$ and is called the **Aggregate Exceedance Probability Curve**.

Let $X_1, X_2, \dots, X_N$ be losses in a given year. Then

$$A(x) = \boldsymbol{P}(X_1 + X_2 + \cdots + X_N > x) = 1 - \boldsymbol{P}(X_1 + X_2 + \cdots + X_N \leq x)$$

Using the terminology of the aggregated loss models, if S is the collective risk model, defined as $S = \sum_{i=1}^{N} X_i$, then $A(x)$ is the survival function of S.

For a fixed N this probability is

$$A(x) = 1 - F_X^{(N)}(x)$$

where $F_X^{(N)}$ is an N-fold convolution of $F_X(x)$, defined as

$$F_X^{(N)}(x) = \int_0^x F_X^{(N-1)}(x - y)\, f_x(y)\, d_y \quad \text{for} \quad N = 2,3, \dots$$

For $N = 1$ this equation reduces to $F_X^{(1)}(x) = F_X(x)$.

If N is the random claim count with the probability mass function (p.m.f) P_N, then by the law of total probability,

$$A(x) = \sum_{n=0}^{\infty} \boldsymbol{P}(S > x | N = n)\, \boldsymbol{P}(N = n) =$$

$$= 1 - \sum_{n=0}^{\infty} \boldsymbol{P}(S \leq x | N = n)\, \boldsymbol{P}(N = n) =$$

$$= 1 - \sum_{n=0}^{\infty} F_X^{(n)}\,(x)\boldsymbol{P}(N = n) = 1 - \ \boldsymbol{E}_N\left(F_X^{(N)}\right)$$

The expected value of S is by definition

$$\boldsymbol{E}[S] = \ \int_0^{\infty} A(x) d_x \ = \boldsymbol{E}[X]\boldsymbol{E}[N].$$

Sometimes modelers may use the **Aggregate Probable Maximum Loss** which is defined in a manner similar to the occurrence OML but with the aggregate distribution. The Aggregated PML is essentially the inverse function of the AEP:

$$PML_{agg}(r) = \ A^{-1}\left(\frac{1}{r}\right)$$

It should be appointed that PML is often used informally, and its meaning is not always clear. There can be an issue that the AEP is occasionally confused with the OEP, but they are not the same thing: the AEP can be very different from the OEP when the probability of two or more events is significant, while they can be very similar when the probability of two or more events is very small and, finally, they are identical when there is zero probability of two or more events. But the comparison between the OEP and the AEP underlines two main propositions:

- **First Proposition**: *let X be the severity of loss random variable and N be the number of claims random variable. Suppose that X and N are mutually independent. Then for any $\epsilon > 0$ there exists a $\delta > 0$ such that*

$$if \sum_{n=2}^{\infty} P_N(n) < \ \delta \ \ then \ \ |A(x) - O(x)| < \epsilon$$

Proof: Let $X_1, X_2, \dots, X_N$ be losses in a given year. By definition,

$$O(x) = \boldsymbol{P}(max_{1\leq i \leq N}(X_i) > x) \ \ and \ \ A(x) = P\left(\sum_{i=1}^{N} X_i > x\right)$$

and it has been shown previously that

$$O(x) = 1 - \sum_{n=0}^{\infty} \left(F_X(x)\right)^n \boldsymbol{P}(N = n)$$

$$A(x) = 1 - \sum_{n=0}^{\infty} F_X^{(n)}(x)\, \boldsymbol{P}(N = n)$$

where $F_X^{(n)}$ is an n-fold convultion of $F_X(x)$.

If $P_N(n) = \boldsymbol{P}(N = n) = 0$ for $n > 1,$ then $A(x) = O(x)$. Otherwise, let $\epsilon > 0$. Choose $\delta = \frac{\epsilon}{2}$. Suppose that

$$\sum_{n=2}^{\infty} P_N(n) < \delta$$

Then,

$$|A(x) - O(x)| \leq \sum_{n=2}^{\infty} \boldsymbol{P}(N = n) \left| F_X^{(n)}(x) - \left(F_X(x)\right)^n \right| \leq 2 \sum_{n=2}^{\infty} P_N(n) < 2\delta = \epsilon$$

The following inequality is always true:

$$max_{1 \leq i \leq N}(X_i) \leq \sum_{i=1}^{N} X_i$$

- **Second proposition** shows a connection between the OEP and the AEP with their corresponding survival function of the loss severity random variable.
  It states that: *let $X_1, X_2, \ldots, X_N$ be losses in a given year, $F_X(x)$ and $S_X(x)$ be the cumulative distribution and survival functions of a loss random variable X. Then*

$$O(x) \geq 1 - F_X(x) = S_X(x)$$

$$A(x) \geq 1 - F_X(x) = S_X(x)$$

Proof: For any N, we have:

$$O(x) = 1 - \left(F_X(x)\right)^N \geq 1 - F_X(x) = S_X(x)$$

$$A(x) = 1 - F_X^{(N)}(x) \geq 1 - \int_0^X F_X^{(N-1)}(x - y)\, f_X(y)\, dy \geq$$

$$\geq 1 - \int_0^x f_X(y)\, dy = 1 - F_X(x) = S_X(x)$$ [35].

2.2.2 Main statistical distributions for claim count and severity of natural extreme events

A reinsurance actuary will receive an OEP table or even part of one and be asked to apply reinsurance terms for pricing. In this context, it is useful to be able to reverse a claim count distribution $F_N(n)$ and a severity distribution $F_X(x)$ from the OEP curve. Using the claim count and severity distributions one can then simulate individual losses and apply reinsurance terms to the simulated data because it is easier to start with detailed event loss data and compute the OEP curve. In other situations, an actuary starts with the claim count distribution and claim size distribution, and it may be convenient to compute the OEP curve directly, without simulating. An important simplification is represented by the assumption in the collective risk model that considers independent claim counts and independent and identically distributed claim sizes. Thus, it is interesting to evaluate the main severity distribution using the OEP because it can be used to estimate the claim size cumulative distribution function F_X of losses X:

$$F_X(x) = \boldsymbol{PGF}^{-1}(1 - O(x))$$

where $\boldsymbol{PGF}^{-1}(x)$ indicates the inverse function of the probability generating function for N. This process does not generally produce a unique size distribution $F_X(x)$ because it is needed to select the claim count distribution $F_N(n)$ and its parameters: different $F_N(n)$ will yield a different $F_X(x)$. However, the size distributions computed this way will be consistent with the starting OEPs and the claim count assumption.

An important property of the probability generating function must be recalled and it is outlined in the following **Lemma 1**: *If N and M are independent random variables, then*

$$\boldsymbol{PGF}_{N+M}(t) = \boldsymbol{PGF}_N(t) \cdot \boldsymbol{PGF}_M(t)$$

[35] Casualty Actuarial Society E-Forum, Exceedance Probability in Catastrophe Modeling, Winter 2021, www.casact.org

with **Proof**: by definition,

$$\boldsymbol{PGF}_{N+M}(t) = \boldsymbol{E}(t^{N+M}) = \boldsymbol{E}(t^N \cdot t^M) = \boldsymbol{E}(t^N) \cdot \boldsymbol{E}(t^M) = \boldsymbol{PGF}_N(t) \cdot \boldsymbol{PGF}_M(t).$$

Following is the presentation of the main discrete distributions for claim counts:

- **Poisson Distribution**

  The common assumption when modelling a number of catastrophes is to suppose that claim counts N have a Poisson distribution with mean parameter λ. The probability mass function is defined as

$$p_n = \boldsymbol{P}(N = n) = e^{-\lambda} \frac{\lambda^n}{n!}$$

Calculating the **PGF**, we obtain

$$PGF(t) = \sum_{n=0}^{\infty} t^n \cdot P(N = n) = \sum_{n=0}^{\infty} t^n \cdot e^{-\lambda} \frac{\lambda^n}{n!} = e^{-\lambda} \sum_{n=0}^{\infty} t^n \frac{\lambda^n}{n!} = e^{-\lambda} \sum_{n=0}^{\infty} \frac{(t\lambda)^n}{n!}$$
$$= e^{-\lambda} \cdot e^{t\lambda} = e^{\lambda(t-1)} .$$

And the Occurrence Exceedance Probability is:

$$O(x) = 1 - e^{\lambda(F(x)-1)}$$

Then the inverse function is

$$y = e^{\lambda(t-1)} \Leftrightarrow \lambda(t-1) = \ln y \Leftrightarrow t = \frac{\ln y}{\lambda} + 1 \Leftrightarrow \boldsymbol{PGF}^{-1}(x) = \frac{\ln y}{\lambda} + 1$$

Using the formula of Poisson distribution, the cumulative distribution F_X is

$$F_X(x) = \boldsymbol{PGF^{-1}}\big(1 - O(x)\big) = \frac{\ln(1 - O(x))}{\lambda} + 1$$

This distribution is useful for large n and small p, or if the expected number of events is much smaller than the theoretically possible maximum number of events. It is also applicable to situations in which the event arrivals can be assumed to be independent, with expected number λ per time unit (typically a year).

- **Binomial Distribution**

Supposing that claim counts N have a binomial distribution with parameters q and m. The probability mass function is defined as

$$p_n = \boldsymbol{P}(N = n) = \binom{m}{n} q^n (1-q)^{m-n}$$

Calculating the **PGF**, we obtain

$$\boldsymbol{PGF}(t) = \sum_{n=0}^{m} t^n \cdot \boldsymbol{P}(N = n) = \sum_{n=0}^{m} t^n \cdot \binom{m}{n} q^n (1-q)^{m-n} =$$

$$= \sum_{n=0}^{\infty} \binom{m}{n} (qt)^n (1-q)^{m-n} = \big((1-q) + qt\big)^m = (1 + q(t-1))^m$$

Note that the same **PGF** can be obtained using one of the properties of a probability generating function. Since Binomial (q, m) random variable N can be expressed as a sum of $m\ i.i.d.$ Bernoulli (q),

$$N = N_1 + N_2 + \cdots + N_m$$

and using Lemma 1, its **PGF** is:

$$PGF_N(t) = \prod_{i=1}^{m} PGF_{N_i}(t) = ((1-q) + qt)^m$$

The inverse function is:

$$y = \left((1-q)+qt\right)^m \Leftrightarrow (1-q)+qt = y^{\frac{1}{m}} \Leftrightarrow t = \frac{y^{\frac{1}{m}}-1+q}{q} = \frac{y^{\frac{1}{m}}-1}{q}+1$$

$$\Leftrightarrow \boldsymbol{PGF^{-1}}(x) = \frac{x^{\frac{1}{m}}-1}{q}+1.$$

Using the cumulative distribution function F_X is:

$$F_X(x) = \boldsymbol{PGF^{-1}}\left(1-O(x)\right) = \frac{(1-O(x))^{\frac{1}{m}}-1}{q}+1$$

The Binomial case is appropriate for portfolio with (finite) small number of risks that create small homogenous events with equal probability p: it is not so suitable for modelling big catastrophe events.

- **Negative Binomial Distribution**

Supposing that claim counts N have a negative binomial distribution with parameters p and r. The probability mass function is defined as

$$p_n = \boldsymbol{P}(N=n) = \binom{n+r-1}{n} p^r (1-p)^n$$

For an integer r, since a Negative Binomial (p, r) random variable N can be expressed as a sum of r $i.i.d.$ geometric (p),

$$N = N_1 + N_2 + \cdots + N_r$$

by the same Lemma 1, its **PGF** is:

$$\boldsymbol{PGF}_N(t) = \prod_{i=1}^{m} PGF_{N_i}(t) = \left(\frac{p}{1-t(1-p)}\right)^r$$

Then the inverse function is:

$$\mathcal{y} = \left(\frac{p}{1-t(1-p)}\right)^r \Leftrightarrow \frac{p}{1-t(1-p)} = \mathcal{y}^{\frac{1}{r}} \Leftrightarrow \mathcal{y}^{\frac{1}{r}} - \mathcal{y}^{\frac{1}{r}}t(1-p) = p \Leftrightarrow$$

$$\mathcal{y}^{\frac{1}{r}}t(1-p) = \mathcal{y}^{\frac{1}{r}} - p \Leftrightarrow t = \frac{\mathcal{y}^{\frac{1}{r}} - p}{\mathcal{y}^{\frac{1}{r}}(1-p)} \Leftrightarrow \boldsymbol{PGF}^{-1}(x) = \frac{x^{\frac{1}{r}} - p}{x^{\frac{1}{r}}(1-p)}$$

Using still Lemma 1, the cumulative distribution function F_X is:

$$F_X(x) = \boldsymbol{PGF}^{-1}\big(1 - O(x)\big) = \frac{(1-O(x))^{\frac{1}{r}} - p}{(1-O(x))^{\frac{1}{r}}(1-p)}$$

It is a proper frequency distribution if there is a systemic "risk driver" in the background which affects the conditional expectation. For example, the frequency of hurricanes is often modelled with a negative binomial distribution with rate driven by sea surface temperature. This distribution is not a "more conservative version" of Poisson and there are different parametrizations and interpretations of this distribution in literature.

These distributions are known to model the number of losses in a portfolio and to sum up, they cover the following values for the variance/mean ratio:

$$\frac{Var(N)}{E(N)} = \begin{cases} < 1 & if\ Binomial \\ = 1 & if\ Poisson \\ > 1 & if\ Negative\ Binomial \end{cases}$$

Generally, it is not possible to rely completely on empirical data to select a frequency distribution because catastrophe modelling deals with rare and extreme events assuming at least 5-20 years of data and 0.1-3 events per year[36].

Instead, for modelling the loss amount, there are many probability distributions with heavy and fat tails which can be used: Pareto, Lognormal, Log-Gamma, Beta and Weibull. In general, these severity or loss distributions used in traditional insurance branches are the same adopted in catastrophe reinsurance modelling context.

The Pareto distribution can be considered as the basic and fundamental distribution for excess-of-loss severity modelling.

[36] Casualty Actuarial Society E-Forum, *Exceedance Probability in Catastrophe Modeling*, Winter 2021, www.casact.org

- **Pareto Distribution with two parameters**

A random variable $X: \Omega \to \mathbb{R}$ has a Pareto (α, x_0) distribution with $x_0 > 0, \alpha > 0$, if:

$$\mathbb{P}(X \leq x) = 1 - \left(\frac{x}{x_0}\right)^{-\alpha}$$

where a minimum loss amount /threshold is determined by x_0 for which this distribution existing having a positive support, while the parameter α defines the tail behavior of the distribution.

Some remarks about this distribution:

a. Moments are given by:

$$E(X^k) = \begin{cases} \dfrac{\alpha\, x_0^k}{\alpha - k} & 0 < k < \alpha \\ +\infty & k \geq \alpha \end{cases}$$

It states that the order-k moments exist only for $k < \alpha$, otherwise they do not exist.

b. Conditionally on being larger than a certain threshold, Pareto is again Pareto with the same parameter α. If $X \backsim Pareto(\alpha, x_0)$ and $d > x_0$, then:

$$X|X > d \backsim Pareto\ (d, \alpha)$$

or equivalently

$$\mathbb{P}(X > t|X > d) = \begin{cases} \left(\dfrac{t}{d}\right)^{-\alpha} & if\ t > d, \\ 1 & else. \end{cases}$$

This property is linked to the fact that the Pareto distribution can be seen as a *truncated distribution*: it is a conditional distribution obtained from restricting the domain of some other probability distribution when the ability of record occurrences is limited to values which lie above or below a certain threshold or within a specific range.

c. Exceedance Probabilities, i.e. $\mathbb{P}(X > x)$, for Pareto distributions scale with power α. If $X \backsim Pareto(\alpha, x_0)$, then:

$$\frac{\mathbb{P}(X > kt)}{\mathbb{P}(X > t)} = k^{-\alpha}$$

Pareto distribution is largely known and used in reinsurance business to such an extent that the following **Table 6** containing α parameter values, for different lines of business, have been established[37]:

Table 6: Loss potential with related α parameter values

Loss Potential	α
Earthquake / storm	∽ 1
Fire	∽ 2
Fire in industry	∽ 1.5
Motor Liability	∽ 2.5
General liability	∽ 1.8
Occupational injury	∽ 2

Source: Non-life Course Documents at Catholic University, *Reinsurance Pricing Analytics*, by Edoardo Luini

2.3. Advantages and limitations of catastrophe models

Catastrophe models were initially developed to address the shortcoming inherent in using historical data to project potential losses from infrequent, severe events that impacted many properties that were not geographically diverse. But frequency and severity of catastrophe activity has not been constant over time and the 5 to 25 years' experience is not nearly enough to evaluate the expected catastrophe costs. The limitation of relying on historical data is affected also by the fact that historical events may be quite different from future events, geographical patterns and physical characteristics of the historical record do not reflect the full range of possible catastrophe events, especially many areas may not have had any historical losses at all, but are clearly at risk. Focusing only on historical damage would overstate the loss potential in some areas and understate the potential in areas that are in very close proximity and equally

[37] Non-life Course Documents at Catholic University, *Reinsurance Pricing Analytics*, by Edoardo Luini

likely to experience a loss. Furthermore, property distributions have changed as well as population and housing units have increased in high-risk areas near the coast, lakes and rivers. Since construction methods and building codes have positively changed leading to a reduction in the likelihood of damage aftermath a catastrophe, historical losses based on old exposure distribution cannot be used without appropriate actuarial adjustments, which introduce more uncertainties to the process. Also claim payment records may be limited or inaccurate and claim practices may have changed over time. In particular, exposure information about properties exposed to loss but not damaged or having only negligible damage (especially below the deductible) may not be available. For these reasons and others, while historical data does bring valuable insight about catastrophe losses, it is insufficient in many current cases to make proper projections for future catastrophe losses. This had led to extensive effort to develop catastrophe models, which are a better alternative for estimating catastrophe losses for the following advantages:

1. Catastrophe models use a comprehensive and realistic database of scenario events to simulate significantly more realistically plausible events than what is contained in the historical records. The frequency of each event is calibrated to reflect the scientific view of the likelihood of that event: event parameters are smoothed to minimize the gaps in the historical records.
2. Catastrophe models allows users to import and analyze the current exposure and settlement terms, therefore avoiding problems related to the adjustment of historical experience to reflect changes in the number, types, building practices, building code, loss-mitigation features, and values of structures exposed to the hazard.
3. Catastrophe models are updated regularly and often to incorporate the most advanced science in meteorology, hydrology, seismology, statistics, and structural engineering. They are fed with the most current information on land use/land cover, surface roughness, soil type, flood defense, flood control measures, ZIP code boundary, etc.
4. Catastrophe models encourage sensitivity testing, which leads to more frequent testing in order to provide valuable information about characteristics to investigate more deeply, provide additional viewpoints to consider, and stress-test scenarios.
5. There are several catastrophe models available to the insurance industry that can provide several viewpoints with valuable information related to risk management.

To sum up catastrophe models offer many advantages compared to historical loss-based projections - more accurate premiums can be determined, the potential benefit of mitigation features can be quantified, and changes to exposure characteristics and policy terms can be assessed – but they still have some important limitations to be considered:

1. Since many assumptions are involved in creating catastrophe models, there are significant uncertainties around model estimates and large ranges of output values among different models. The uncertainty is not linked to the inaccurateness or unreliableness of model outputs, but to the usage of alternate methods of estimating catastrophe damage that can be even more difficult or impossible to quantify. However, a wide range of model outputs can cause concerns with consumers, regulators, and executives.
2. A substantial financial output is required to collect important building characteristics because it is not an easy task for an insurance company.
3. Damages or causes of loss that happen due to or concurrent with a catastrophic event are not included in model outputs and they need to be treated separately. This is not a big deal, but it underlines how important is understanding what the model assumptions are.
4. Stability concerns can be originated from software updates: modelling vendors have opportunities to incorporate new sciences and learnings into the models as well as more data becomes available. As a result, the industry may experience large swings in the estimates from year to year, but these changes are far smaller than what could happen when relying on historical experience.
5. Given the complexity of catastrophe models, they require either reliance on a company's reinsurance broker or other third party, or significant investment in training, software, and hardware to develop and maintain internal expertise.
6. Some core assumptions are considered proprietary and are not readily accessible to users because a catastrophe model is usually developed by a group of scientists with specialized knowledge in different fields[38].

[38] American Academy of Actuaries, *Uses of catastrophe model output*, Extreme Events and Property Lines Committee, July 2018, www.actuary.org

2.4 Application of catastrophe model output in several actuarial tasks

Modelled loss results provide valuable insight into the potential severity and frequency of catastrophic losses, and into the volatility of the analyzed risks. Metrics from catastrophe models are used by private insurance companies, public policy experts, and others in the fields of ratemaking, portfolio management and optimization, underwriting and risk selection, loss mitigation strategies, risk transfer analysis, enterprise risk management, capital adequacy and reinsurance. Among these several applications for catastrophic model output, the main typical actuarial tasks are presented in the following sub-paragraphs.

2.4.1 Ratemaking

The annual cost of catastrophic events needs to be determined because most policy terms are for a year. The cost of an insurance policy is comprised of Average Annual Loss (AAL) generated by models to cover expected loss, expenses, and risk load, which depends on the variability (i,e., standard deviation or CV) or uncertainty in the loss estimates.. Some appropriate reinsurance must be included, and their assignment to an expense category depends on what those costs consist of and how they are treated by the primary company.

To adequately insure a risk, an insurer must commit a certain level of capital beyond the expected annual loss to cover the potential for catastrophic loss. This risk load should be sufficient to cover the cost of capital including a profit provision. Because catastrophe risk is volatile, the risk load can be multiples of AAL: the higher the volatilities, the higher the likelihood of insolvency, therefore the higher the risk load. As it has been anticipated before, the most common way to develop the risk load is using the standard deviation of the modeled losses (σ):

$$\sigma = \sqrt{\sum_i (p_i X_i^2) - AAL^2}$$

Catastrophe models use rating factors such as construction, year built, occupancy, and territory relativities to evaluate the insured risk's potential insured loss propensity in a catastrophic event, including also geographic location, physical characteristics of the building and policy terms.

The presence of some deductibles from an insured loss before payment are an essential part of insurance contracts as sharing tool of the risk between the insurance company and the policyholder: the amount of deductible would come from policyholder's own wealth to repair a damage. Deductible relatives can be estimated by models using gross losses (loss after application of the deductible) divided by ground up losses (total amount of loss without any adjustments):

$$Deductible\ loss\ elimination\ ratio = 1 - \left(\frac{Gross\ Loss}{Ground\ Up\ Loss}\right)$$

More accurate premium can be determined and charged for all risks.

2.4.2 Underwriting and Risk Selection

Insurance premiums commensurate with risk are critical to a robust insurance market and to the continuing ability of companies to remain solvent and provide needed protection to policyholders. Any property can be insured only if an appropriate rate can be calculated and charged but, while a price is commensurate with expected loss is critical, there are other factors to be considered. Along with adequate rate, an insurance company must consider the financial health of its entire book business and the impact of adding a given property on it, which depends on how the property's potential for loss interacts with existing policies. Here measures such as Probable Maximum Losses (PML) and the Return Period Loss (RPL) are taken into consideration. Besides the business need for accurate premiums, insurance undertakings can inform individuals on how safe or exposed they are and can promote mitigating behavior. Underwriting can me managed with the aggregation of risks that minimizes the risk of insolvency and reducing the concentration of risk may help to lower reinsurance costs and to limit the number of claims after an event. Risk selection was used as a binary decision tool: a property was acceptable to insure based only on its characteristics, or it was not acceptable. Nowadays, catastrophe models allow a property to be evaluated based on its risk in the context of company's entire book of business. Also uninsurable properties can obtain coverage thanks to premium changes or coverage adjustments made through catastrophe models to make the premium commensurate with the associated risk.

Underwriters and risk selection algorithms can use several metrics, or combinations of them, to provide additional information to help understand the risk for an individual insured property location. Companies may set up guidelines around various ranges of these metrics, with these ranges set based on the risk tolerance that the company has decide to follow. A few examples of these metrics are:

1. **AAL / TIV**: the ratio between the AAL and the *Total Insured Value* (TIV) provides a metric that shows the long-term risk at a location. It is used to evaluate how properties that are close geographically can have significantly different expected losses AAL. It also shows the relevance of having accurate detailed geographic information: for each catastrophic peril, ZIP-level AALs vary notably from state-level, and location-level information within a ZIP also varies.
2. **PML / TIV**: the ratio of a PML at a specified return period, to the TIV gives an indication of the possible severity at a location. This view jointly with locations that have a similar AAL/TIV ratios gives an insight of the variability of risk at a location.

These metrics can allow portfolio metrics to see the effects of adding or removing a property: a property could have a relatively high AAL, but if it is in an area with low concentration in the current book, it does not impact the total book's PML and resulting reinsurance costs, the property could still be acceptable to an insurer, especially if capital allocated to writing property insurance is limited. Considering two separate insurance companies in a state having similar 100-years PMLs but with different distribution of risk across the state, both are considering acquiring a portfolio of locations, even though their acquisition could cause significantly different marginal changes to their PMLs. It could be also useful for companies to review their Tail Value at Risk (TVaR) to see if adding locations has a significant impact on the tail/extreme risk at various return periods. An extension of this process is portfolio optimization: the insurance company chooses the modeled metric and then builds a geographically distributed portfolio that optimizes that metric relative to premium or insurance values (exposure). For example, if a company has the capital allocated to be able to write $100 million in premiums in a state, it may design a portfolio that minimizes a specified return period PML (like a 100-year PML).

2.4.3 Loss Mitigation and Catastrophe Reinsurance

Mitigation involves efforts to prevent hazard from developing into a disaster and to reduce the effects of such events when they occur: the effects from the introduction of some mitigation features can be evaluated by seeing how AALs and other measures react to the presence or absence of these features. Strategies to encourage desired choices can be tied to potential loss dollar change and some are applied to individuals and others to communities being structural (e.g., window shutters, flood levees) or non-structural (e.g., land-use planning). Many companies can decide to reduce expenses and to adjust the *Loss Elimination Ratios* (LER), which is the ratio of the decrease in the expected loss for an insurer writing a policy with a deductible and/or policy limit to the expected loss for an insurer writing a full-coverage policy. Since there are more minor losses than extreme losses, more relative weight would be in the LER leading to the realization of additional savings. A community can also use a catastrophe model to quantify the costs and benefits of these strategies in order to weigh public policy decisions.

The risk of insolvency increases for primary insurance companies when many policies are likely to have a claim at the same time because catastrophes increase the likelihood of many claims in close geographic proximity occurring all at once. Since primary insurers need large sums of money quickly, they manage this risk making usage of reinsurance and other risk transfer mechanisms that play a valuable role in the insurance market. Many reinsurers and reinsurance contracts rely heavily on model results and are not focused on individual properties or everyday losses, but instead look at providing loss coverage to portfolios of policies. Reinsurance pricing begins with the AAL plus a factor times the standard deviation for the layer, from which this factor can vary over time and under different circumstances but factors from similarly exposed companies and/or similar market conditions can serve as useful benchmarks. Catastrophe modelling provides an importance source of quantitative knowledge to evaluate risk and objectively evaluate reinsurance pricing together with valuable information to financial markets in developing catastrophe bonds and other risk-linked securities[39].

This last point is going to be presented in the following chapter because it is having an increasing relevance in the (re)insurance industry and in how catastrophe risk is managed.

[39] American Academy of Actuaries, *Uses of catastrophe model output*, Extreme Events and Property Lines Committee, July 2018, www.actuary.org

CHAPTER 3

INSURABILITY OF CATASTROPHE RISK BETWEEN CAPITAL MARKETS, CATASTROPHE INSURANCE AND GOVERNMENTS

Introduction

This chapter offers an overview about the (im)possibility to ensure catastrophe risk with the related general insurability criteria passing through the legal, actuarial, and economic insurability issues. Subsequently, it is presented the main problem for primary insurance companies related to the quantification of the additional accumulated capital for catastrophe losses with a focus on the principal regulatory constraints present around the world. Since natural events have increased during the past decades leading to make the natural catastrophes hardly insurable, this section presents the major Alternative Risk Transfer Solutions available to diversify large risks: from transferring catastrophe risk to the capital markets throughout the Insurance-linked Securities, passing then to the analysis of the main traditional reinsurance products and finally explaining the growing presence of collaboration between the public and private sectors thanks to some government programs in order to face catastrophic events in a changing environment.

3.1 Insurability: when can we sell / buy insurance for catastrophe risk?

When assessing risks, any insurer or reinsurer must take into account the fundamental principles, also with the limitations, of insurability: it is not a strict formula but rather a common approach frequently used for differentiating insurable and uninsurable risks. As it has been anticipated in the first chapter, if on one hand it is difficult to find risks covering all the insurability requirements, on the other hand more risks are insured and more the insurance activity can rely on mutualization. The fundamental concept of mutualization of risks by the insurer is the basis on which the insurance market is based for its solvency capacity and its obligations honorability: it is the process of dividing up exposure to potential financial losses among several insurance policyholders. Hence, insurance can be defined as "the contribution of the many to the misfortune of the few" meaning that risk adverse agents, the *insured*, are willing to pay even more than the actual value of predictable risk to transfer its consequences to another agent, the *insurer*. It is possible to define a criterion in order to ensure a risk by following **Berliner's** (1982) insurability criteria idea, which is one of the most famous approaches used in the literature. Berliner has established nine insurability criteria covering five actuarial, two market-specific and two societal aspects of insurability. The following **Table 7** summarizes the insurability criteria with the related requirements[40]:

Table 7: Insurability Criteria and requirements defined by Berliner

	Insurability Criteria	**Requirements**
Actuarial	(1) Randomness of loss occurrence	Independence and predictability of loss exposure
	(2) Maximum possible loss	Manageable
	(3) Average loss per event	Moderate
	(4) Loss exposure	Loss exposure must be large enough
	(5) Information asymmetry	Moral hazard and adverse selection not excessive
Market	(6) Insurance premium	Cost recovery (insurer) and affordability (policyholder)
	(7) Cover limits	Acceptable
Society	(8) Public policy	Consistent with social values
	(9) Legal restrictions	Allows the coverage

Source: The impact of artificial intelligence along the insurance value chain and on the insurability of risks, Martin Eling, Davide Nuessle, julian Staubli, The Geneva Papers on Risk and Insurance

This approach has been used by **Charpentier** (2007) to analyze the insurability of climate risks. He has merged the nine points into six, which are still split between the three macro-areas:

1. An insurance contract can be valid only if the claim occurrence satisfies some randomness property;
2. The possible maximum loss should not be huge with respect to insurer's solvency capacity;
3. The average cost should be identifiable and quantifiable;
4. Risks should be pooled so that the law of large numbers can be used, except for catastrophe risk;
5. Moral hazard and adverse selection should be absent;
6. There must exist an insurance market from which an equilibrium price should rise by the meeting between supply and offer.

[40] The Geneva Papers on Risk and Insurance, *The impact of artificial intelligence along the insurance value chain and on the insurability of risks*, by Martin Eling, Davide Nuessle, julian Staubli, February 8, 2021, www.onlinelibrary.wiley.com

The first point belongs to the legal insurability, from the second to the fourth points are under the actuarial insurability and the last two points are linked to the economic insurability: these three categories are specifically analyzed in the following sub-paragraphs.

3.1.1 Legal Insurability: randomness properties

The insured event must be unpredictable in its time and location, while the occurrence itself must be independent from the will of the insured. Especially for the natural catastrophes to be in line with the randomness properties, "*the consequences of natural catastrophes are considered as all direct damages caused by abnormal intensity of natural hazard, when standard measures usually taken to prevent those events did not prevent its occurrence*". This definition has been mentioned by French Law 82-600 of 13 July 1982 and it is a particular case of interaction between private and public involvement in the scheme of natural disaster protection, which will be analyzed after. Here, the problem is the identification of what "abnormal intensity of natural hazard" means, from which the question can be easily related to the notion of "known risks"[41]. The concept is to invest or insure only what we can understand – risk and not uncertainty – because the risk can be defined as the randomness with knowable probabilities (*measurable uncertainty*). Obviously, one of the real issues for insurers is the increasing destructive power of natural disasters due to the climate change, which is increasing as well both intensity and frequency of climate hazards, from which even the uncertainty can be very large[42].

3.1.2 Actuarial Insurability: the problem of large risks non-diversifiable

The assessability and mutuality criteria must be satisfied: on one side the frequency and severity of claimable events can be estimated and quantified within reasonable confidence limits, on the other side it must be possible to build a risk pool in which risk is shared and diversified at economically fair terms. The ability to identity and quantify the chances of an event to occur as well as the extent of losses might not be satisfied in the case of natural disasters. The second

[41] Arthur Charpentier, *Insurability of Climate Risks*, The Geneva Papers, 2008, www.palgrave-journals.com/gpp
[42] Michel M. Dacorogna, *The Price of Risk in Insurance*, Master of Actuarial Science, Università Cattolica, Milan, Feb.-Mar. 2023

and third points of Charpentier's insurability criteria refer to the fact that losses can be extremely large, but they must be properly quantified. They are related to the concept that risk should be based on probabilistic uncertainty but with known probabilities. In order to fulfil this aim, the losses must be properly modelled by specific probabilistic distributions with positive asymmetry and fat tails, as it has been presented in the Chapter 2.

The fourth point refers to the issue that the Central Limit Theorem, as it has been anticipated in the Chapter 1, cannot be used for natural catastrophes. It helps to derive confidence intervals to assess additional capital required for solvency purposes of safety margins in premium calculation. Since this theorem is based on independence of claims, the natural catastrophe events have usually positive dependence due to geographical dependence, where thousands of claimed policies are from a common event, and strong correlation for several lines of business such as property, car insurance, life insurance for casualties, business interruption, … From a probabilistic distribution point of view, the positive dependence makes the capital increases, since quantiles will increase, while the pure premium will remain unchanged and the diversification for the single insurer is no longer possible because catastrophe risks appear to be hardly diversifiable.

3.1.3 Economic Insurability: the problem of finding a fair price

It is hard to find an equilibrium price that both the insured and the insurer accept. The problem is related to the fact that the perspective view of policyholders and insurers are completely different. In the first case, many individuals perceive the probability of a disaster as a very low-probability event, and therefore find it unnecessary to invest in protective measures. While from the (re)insurer's perspective, the price covers the expected cost of acquiring and administering the business as well as claims costs. In addition, the price must allow for an appropriate return on the capital allocated to the risk, a return which meets shareholder's return requirements[43].

Regarding this point, adverse selection and moral hazard are two additional difficulties that have been generated by the information asymmetry between insurer and insured, especially in the case of natural catastrophes. Adverse selection is the situation when one counterparty is not sure about the quality of the good of service object of the negotiation. The insurer is uncertain about the quality of the insured person due to the lack of available information used to better

[43] Swiss Re, *The essential guide to reinsurance*, 2015, www.swissre.com

estimate the risk profile of the customer. If the risk estimation is affected by the adverse selection, it implies the following negative effects:

- anti-selection is the phenomena for which the insurer underwrites contracts with insured subjects, who are on average worse than those of the population;
- higher premium on average with fewer contracts;
- transfer of wealth from better quality subjects (who pay a higher premium than they should) to worst quality subjects (who pay a lower premium than they should).

Adverse selection is a difficult issue, since major natural events can be covered only when pooling a large number of insured, but risks are hardly homogenous depending on the geographical location of the events (non-coastal regions being usually less risky for instance). This problem can be managed through the intervention of the Regulation to prevent from problems caused by the insurer and using market or contractual solutions

The moral hazard problem can be split into two distinct opportunistic behaviors: moral hazard ex-ante and ex-post. The first case is when the insurance coverage limits policyholder's incentive to adopt actions or measures capable of preventing accidents or mitigating their injurious effects. The second case is present after the occurrence of the claim, when the insured tends to use insurance services more than he would do in case he would be uninsured. The mitigation of problems originated from adverse selection and moral hazard are solved using two instruments:

a) intervention of the Regulation to prevent from insurer's opportunistic behaviors;
b) application of market or contractual solutions against issues created by insured people[44].

3.2 Limits to quantify capitals inside private insurance companies: is catastrophe risk uninsurable?

After having presented the principal insurability criteria and the main problems related to them, the insurance literature has often identified three main factors as impediment to the successful operation of private insurance market related to natural disaster events: problems of adverse selection and moral hazard, the insured risk is "too large" and the probability of loss is not susceptible to precise actuarial calculation. First, the ex-ante risk of catastrophic loss is not

[44] Alberto Floreani, *Economia delle imprese di assicurazione,* Il Mulino, Bologna, 2019, p. 63, 65

private information of the insured and the insured agent has no control over the event creating the risk. Since losses are difficult to be estimated and to be verified, claims may be inflated producing the ex-post moral hazard problems with catastrophes. Second, the accurate assessment of the probability of weather-related risks has only become available recently.

Subsequently, the major question for modern catastrophe insurers in terms of insurability has become how upper layers of catastrophic risk can be financed through additional sources of capital – beyond the active capital provided by current investors – to enable the market to operate completely, even in the case in which high losses are expected. Private insurance markets are currently having a difficult time providing coverage for catastrophe risk because they must not solve a "point in time" risk spreading problem, but rather an intertemporal problem of how to match a smooth flow of annual premium receipts to a highly non-smooth flow of annual loss payments. The fundamental problem of catastrophe appears to be clear, and it seems to be more a capital market problem: how to smooth large losses over time. Unlike every other line of business, the seller of catastrophe insurance contracts must have access to a large pool of liquid capital in every year in which the contract stands. This capital pool can be required by an insurance company to cover the largest possible catastrophe loss that might occur. For example, if one extreme event is estimated with a 1 percent annual probability, the expected loss (or the annual premium) would approximately equal to 1 percent of the required capital. Equivalently, the required capital can be approximately equal one hundred times the expected annual loss. Since such large pools are difficult to arrange and they currently do not exist, hence companies cannot bear the risk in such a way: firms have preferred to withdraw from this procedure rather than bearing the risk of insolvency[45].

The liquidity risk can be considered as one main cause of insolvency and it must be monitored and actively managed in order to have sufficient liquidity in extreme situations. (Re)insurer's capital and its liquidity management must respond to various and partially conflicting stakeholder interests:

- **Customers** such as policyholders and primary insurers care about the prompt payment of claims to honor obligations and debt holders;
- **Regulators** have focus on policyholder protection and on the overall systemic stability;
- **Investors** look for attractive risk-adjusted returns to maximize capital efficiency.

[45] Wight M. Jaffee and Thomas Russell, *Catastrophe Insurance, Capital Markets, and Uninsurable Risks*, The Journal of Risk and Insurance, 1997, Vol. 64, N°2, 205-230, www.onlinelibrary.wiley.com

These different needs reflect the dynamics of the actuarial, regulatory, accounting, and competitive environments by adding complexity to arrange for the required capital[46].

3.2.1 Main institutional features of the modern insurance contract against the accumulation of additional capital for catastrophe losses

Before presenting the different ways used to measure the capital adequacy, there are several institutional features of the modern insurance contract working against the accumulation of capital from which to pay future catastrophe losses, which are going to be listed in this paragraph.

The first limitation regards the **Accounting Requirements**, in particular, the accounting practices in property-liability insurance avoid an insurance firm from earmarking capital surplus to pay for future catastrophe loss (i.e., one that has not yet occurred), even though the occurrence of that loss at some time is highly likely. According to Zenith National Insurance Corporation (1994), in the event of major adverse natural phenomena, the line of business of property insurance is exposed to the risk of significant loss because these catastrophes may cause significant simultaneous financial statement losses, since natural disaster losses may be accrued in advance of the event. The provision of reference is the Financial Accounting Standards Board (FASB) Statement N° 5 Accounting for Contingencies. "A contingency is defined as an existing condition, situation, or set of circumstances involving uncertainty as to possible gain (a *gain contingency*) or loss (a *loss contingency*) to an enterprise that will ultimately be resolved when one or more future events occur or fail to occur. Resolution of the uncertainty may confirm the acquisition of an asset or the reduction of a liability or the loss or impairment of an asset of the incurrence of a liability"[47]. To identify the existence of a loss contingency, which means that the likelihood of a future event or events will confirm the loss or impairment of an asset of the incurrence of a liability can range from probable to remote, this Statement uses specific terms such as:

- *Probable* when the future event or events are likely to occur;
- *Reasonably possible* when the chance of the future event or events occurring is more than remote but less than likely;
- *Remote* when the chance of the future event or events occurring is slight.

[46] Swiss Re, *The essential guide to reinsurance*, 2015, www.swissre.com

[47] FASB, Statement N° 5 Accounting for Contingencies (issued 3/1975), FASB HOME/Reference Library/Superseded Standards, www. fasb.org

The main examples of loss contingencies include:

- Collectibility of receivables
- Obligations related to product warranties and product defects
- Risk of loss or damage of enterprise property by fire, explosion, or other hazards
- Actual or possible claims and assessments
- Risk of loss from catastrophes assumed by property and casualty insurance companies including reinsurance companies
- Guarantees of indebtedness of others
- Obligations of commercial banks under "standby letters of credit".

This Statement establishes standards of financial accounting and reporting for an estimated loss from a loss contingency, and it implies accrual by a charge to income if two conditions are met:

a) information available prior to issuance of the financial statements indicates that it is probable that an asset had been impaired, or a liability had been incurred at the date of the financial statements, and
b) the amount of loss can be reasonably estimated.

Since this Statement implies that the disclosure of a loss contingencies shall be made when there is at least a reasonable possibility that a loss or an additional loss may have been incurred and when there is a reasonable possibility that the outcome will be unfavorable[48].

The view implicitly present in this accounting rule is reporting the realistic insurance company's financial situation when catastrophe income and losses are registered for one year at time, rather than over a longer term with the usage of capital accumulated in good years being used to smooth out losses in future bad years. The insurance undertakings can allocate retained earnings to a capital surplus account prior to regulatory approval, but there is no possibility that the companies can irrevocably transfer this surplus towards payment of a catastrophe risk. In principle, all unassigned surplus is not only available to pay such losses, but also for other purposes, such as premium growth. In addition, even if this Statement puts evidence on the disclosure procedure, this accounting rule does not include to provide policyholders with a clear picture of the funds available from their insurance company to mee their catastrophes losses[49].

The second impediment against the accumulation of capital refers to **Tax Provisions** and it is linked to the accounting rules just presented. The tax loss carry-forward and backward code

[48] FASB, *Statement N° 5 Accounting for Contingencies (issued 3/1975),* FASB HOME/Reference Library/Superseded Standards, www. fasb.org

[49] Wight M. Jaffee and Thomas Russell, *Catastrophe Insurance, Capital Markets, and Uninsurable Risks*, The Journal of Risk and Insurance, 1997, Vol. 64, N°2, 205-230, www.onlinelibrary.wiley.com

provision is an accounting technique that applies the current year's net operating loss (NOL) to future year's net income to reduce tax liability: for example, if a company experiences negative net operating income (NOI) in the first year, but positive NOI in the subsequent years, it can reduce future profits using NOL carryforward to record partially or totally the loss from the first year in the following years. This operation makes taxable income lower in positive NOI years, reducing the amount of taxes transferred from the company to the government[50]. Consequently, on one hand the tax code offers insurance companies no incentive to appoint funds "for a rainy day" because the retained earnings would be taxed as corporate income in the years in which they are put aside, and the interest income on these reserves would be also taxed. Furthermore, these tax provisions are absent if the company goes on bankrupt because of a catastrophic loss exceeding the company's available financial resources. On another hand, these funds used to meet inevitable claims are a business expenses, and such monies and the interests on them should be allowed tax free status. The situation present in many European countries implies the presence of verified funds that must be only available to meet future catastrophe losses and it must be demonstrated that insurance companies do not use these funds for other purposes, such as to cross-subsize other lines of business[51]. Italy can be seen as an example of State, which has established the assessment of a specific reserve called "Riserve di perequazione per i rischi di calamità naturale e per i danni derivanti dall'energia nucleare" for non-life insurance companies from the Ministerial Decree n. 705 of November 19th, 1996. This reserve aims to compensate over time the trend of claim ratios for extremely variable risks, such as the catastrophe ones, which have a relatively low probability of occurrence with respect to the ordinary risks and their recurrence produces significant damages compared to the economic dimension of a single insurance company[52].

The union of **cash surplus, myopic behavior of stock market investors and takeovers** represents the last obstacle to collect additional capital from an economic and financial point of view. The accumulated capital to pay for future catastrophe losses is subjected to the risk that myopic managers can face unfriendly takeovers, which can be considered both as agency-cost aspects of surplus cash and as imprudent stock market investors' behavior. This danger is more evident in publicly traded companies: managers may reduce their company's reported earnings in the short run when they undertake policies that maximize the firm's long-term value in order

[50] Alicia Tuovila, *Loss Carryforward: definition, example, and tax rules,* October 30, 2020, www.investoipedia.com

[51] Wight M. Jaffee and Thomas Russell, *Catastrophe Insurance, Capital Markets, and Uninsurable Risks*, The Journal of Risk and Insurance, 1997, Vol. 64, N°2, 205-230, www.onlinelibrary.wiley.com

[52] Stefano Miani, *La gestione dei rischi climatici e catastrofali*, G. Giappichelli Editore, Torino, 2004, p. 40

to give the opportunity to well-informed traders to take over the company at a low price, reflecting the low short-run earnings. In addition, they can distribute catastrophe premiums as dividends in case of no loss, then they might declare insolvency if a catastrophe occurs. There is also the possibility that a parent company may allocate surplus from its subsidiary to any other corporate purposes. Liquid assets allocated for future catastrophe losses are not actually "free cash" for a company with a long-term horizon and the recent prompt intervention of the Regulatory Framework avoids these dangerous situations that might have been generated by takeovers of cash-rich insurance companies, which cause insolvency problems towards policyholders[53].

3.2.2 Regulatory Constraints

The (re)insurance world is a highly regulated industry because it must match several interests among companies, policyholders, and consumer activities. The main purpose of Insurance Supervisory Authorities is the regulation and supervision of insurance and reinsurance company's activities to protect policyholders and to ensure the stability of the market by calculating adequate capital requirements, which take into account the specific features of the (re)insurance business model. All aspects related to insurer's operations are subject to regulatory oversight: capital requirements, claims practices, policy provisions and even premium rates. It is essential to safeguard the solvency of primary insurers by imposing such robust regulatory conditions to ensure that they can pay legitimate claims made by policyholders. Even if most reinsurers do not have direct contact with retail clients, the default of a reinsurance company could have still an indirect impact on retail customers due to the subsequent default of a primary insurance company. A reinsurer's strong financial health is a crucial element to take into consideration for the solidity of the entire insurance industry.

Before passing to the main different regulatory frameworks present all over the world for managing the catastrophe risk, which are traditionally almost the same requirements either for primary insurers or for reinsurers, another point linked to the accumulation of capital is the identification of the appropriate level for a fair premium. According to what will be presented at the end of this chapter regarding the advantage of having a government-public program, some market agents can complain about the fact that presence of some surplus capital inside an

[53] Wight M. Jaffee and Thomas Russell, *Catastrophe Insurance, Capital Markets, and Uninsurable Risks*, The Journal of Risk and Insurance, 1997, Vol. 64, N°2, 205-230, www.onlinelibrary.wiley.com

insurance company is caused by a too high-level premium. Because of scientific disagreements about the probabilities of various natural disasters, a certain quantity of accumulated capital might appear conservative from a regulatory perspective but excessive for consumer activists. This issue can discourage insurers to raise premiums to the level necessary to accumulated adequate capital on the grounds that this increase may be seen “unfair” by customers. This conflict may appear by looking at the strategies followed by insurers to set catastrophe line premiums: they typically raise rates substantially after a catastrophic event. The questions asked by commissioners in states where a prior approval for premium rate is requested by the National Authority is: “What kind of (dynamic) premium strategy has the insurance company been using before the catastrophe? And what is the contribution of the new relevant information to this strategy after the occurrence of the catastrophe?”. The answer is connected to the fact that a rate change may be justified if the occurrence of a major events can be shown to provide new information regarding the shape of the insurer’s loss distribution. If the (dynamic) premium strategy already reflects the new information, there can be no justification for a rate increase just because the event has happened. On the opposite situation, new information could also generate a rate reduction in case the event shows a lower average loss exposure[54].

Passing to the main regulatory constraints, the **Solvency II Framework (SII)**, the **Swiss Solvency Test (SST)** and the **Risk-based Capital (RBC)** are the three main regulatory frameworks used for the identification of the appropriate capital requirement calculation methodologies, focusing on the effect of climate change.

1. **Nat-Cat risk in Solvency II**

   “The Solvency Framework requires that the Solvency Capital Requirement (SCR) may be determined by considering the main types of risks (market and technical – such as non-life underwriting risk and, within that, *catastrophe risk*) to which an insurance company is typically exposed in the conduct of its business”.

   Specifically, “The natural catastrophe risk (Nat-cat risk module) quantifies the risk of loss of unfavorable change in the value of insurance liabilities arising from non-life insurance obligations due to significant uncertainty of assumptions about premiums and reserves referring to extreme or exceptional events identifiable as “natural catastrophes”.

[54] Wight M. Jaffee and Thomas Russell, *Catastrophe Insurance, Capital Markets, and Uninsurable Risks*, The Journal of Risk and Insurance, 1997, Vol. 64, N°2, 205-230, www.onlinelibrary.wiley.com

From the growing significance of climate-related risks, the European Commission asked recently to review, at least every three years, the scope and calibration of the standards parameters of the natural catastrophes risk-submodule for non-life companies.

Article 120 of the Delegated Acts states that the calculation of the Nat-cat risk sub-module shall be based on five types of natural disasters (perils) summarized in the following **Table 8**:

Table 8: Types of natural disasters present in Article 120 of the Delegated Acts

Peril	Type of disaster	Description
Earthquake	Geophysical	Includes ground motions not resulting from tsunamis or fires
Flood	Hydrological	Includes river and rain floods (caused by rainfall), not including storm surges
Windstorm	Meteorological	Includes cyclonic storms (extra-tropical and tropical cyclones) and excludes convective storms
Hail	Meteorological	Includes hail as the dominant sub-peril
Subsidence	Geophysical	Refers to the swelling or shrinkage of clay soils (characteristics of French and neighboring territories)

Source: ANIA documents

The Nat-Cat SCR is calculated by considering all risks to which the company is exposed based on the country/geographical region and the province/administrative area (called CRESTA zone/risk zone[55]) in which the risk is located.

For each of the listed risks, the capital requirement is calculated based on the sums insured by the following steps:

STEP 1 – calculation of the Weighted Sums Insured $\mathbf{WSI_{(i,r,k)}}$.

$$\mathbf{WSI_{(i,r,k)}} = \mathbf{SI_{(i,r,k)}}\ \mathbf{Q_{i,r}}\ \mathbf{W_{(i,r,k)}}$$

WSI calculation is made for each country and risk zone, obtained by multiplying the sums insured $\mathbf{SI_{(i,r,k)}}$ exposed to peril *i* located in region *r*: a risk factor $\mathbf{Q_{i,r}}$ specific to each risk *i* and region *r* combination (representing the loss of an average industry portfolio for the country *r* of policies affected by an adverse event with probability of

[55] CRESTA zones has been created by CRESTA (*Catastrophe Risk Evaluation and Standardizing target Accumulations*) to establish a global uniform system for the accumulation risk control of natural hazard regarding the distribution of insured values within a region or country.

occurrence 1/200) and a weighting factor $\mathbf{W}_{(\mathbf{i,r,k})}$ specific to each peril i, region r and zone k (measuring the risk distance of risk zone k with respect to the region under consideration).

STEP 2 – calculation of $\mathbf{SCR}_{(\mathbf{i,r})}$ for each region r, aggregating using correlation matrix $\mathbf{Corr}_{(\mathbf{i,r,s})}$.

The capital requirement for each country, equal to the loss of basic Own Funds that would result from an instantaneous loss of an amount calculated by:

(i) aggregating the insured sums calculated in the previous step through risk-zone correlation matrices and

(ii) taking into account specific scenarios defined by the Delegated Regulation.

$$\mathbf{SCR}_{(\mathbf{i,r})} = \sqrt{\left(\sum_{(\mathbf{i,k,j})} \mathbf{Corr}_{(\mathbf{i,r,k,j})}\, \mathbf{WSI}_{(\mathbf{i,r,k})} \mathbf{WSI}_{(\mathbf{i,r,j})}\right)}$$

- the sum includes all possible combinations of cresta-zones (k, j) of region r, referred to the risk i;
- $\mathbf{Corr}_{(\mathbf{i,r,k,j})}$ is the correlation coefficient for peril i in cresta-zone k and j or region r;
- $\mathbf{WSI}_{(\mathbf{i,r,k})} \mathbf{WSI}_{(\mathbf{i,r,j})}$ are the weighted sums insured for peril i in cresta-zone k and j of region r.

STEP 3 – calculation of $\mathbf{SCR}_{\mathbf{cat\,i}}$ for each risk i using the specific risk correlation matrix.

Calculating capital requirement for each peril, obtained by aggregating the values derived from the previous step using cross-country correlation matrices.

$$\mathbf{SCR}_{\mathbf{cat\,i}} = \sqrt{\left(\sum_{(\mathbf{r,s})} \mathbf{CorrCAT}_{\mathbf{i(r,S)}}\, \mathbf{SCR}_{(\mathbf{cat\,i,r})} \mathbf{SCR}_{(\mathbf{cat\,i,s})}\right) + \mathbf{SCR}^2_{(\mathbf{cat\,i,other})}}$$

- $\mathbf{SCR}_{\mathbf{cat\,i}}$ denotes the Solvency Capital Requirement for each natural catastrophe risks ***cat_i = {Earthquake, Flood, Hail, Windstorm, Subsidence};***
- $\mathbf{CorrCAT}_{\mathbf{i(r,S)}}$ is the correlation coefficient between **cat_*i*** risk for region r and s;

- $\mathbf{SCR}_{(\text{cat i,r})}\mathbf{SCR}_{(\text{cat i,s})}$ are the Solvency Capital Requirement for **cat_i** risk for region *r* and *s*;
- $\mathbf{SCR}^{2}_{(\text{cat i,other})}$ is the Solvency Capital Requirement for other regions not included in the correlation matrix.

The previous review phase took place with the Review 2018 and decided for an increase in the country risk factor for flood risk from 0.10% to 0.15%, a reduction for earthquake risk factor from 0.80% to 0.77% and the 2010 calibration of 0.03% is still in forced for hail risk. Additional important elements to be considered to ensure adequate calibration of the risks under consideration include:

(i) the need to consider the evolution of the scientific literature in this area and the new catastrophe models available for some specific risks, as well as the most recent data on insured losses;

(ii) critical issues related to the use of insured sums as a basis for calculation and the need to reflect, in the parametrization of the formula, the different national practices in terms of loss limits[56].

2. Nat-Cat risk in Swiss Solvency Test

The Swiss Solvency Test defines the minimum amount of economic capital an insurance company must have available: the higher the risks, the larger its capital requirements will be. The capital requirement defined by the Swiss Financial Market Supervisory Authority FINMA is under the form of **Target Capital** (TC), which is calculated in such a way that an insurance company will remain financially safe even when it faces with a once-in-a-century negative event. It is the result from the sum of two components:

a. The *one-year risk capital*, which is the Swiss correspondent SCR, that is computed by considering all the relevant risks present in the insurance company's balance sheet (market risk, credit risk between of outward retro and of other assets, insurance risk between life and non-life, additional scenarios and other risks) and their effect on the *Available Capital*, which is obtained by giving value to each assets and liabilities on its balance sheet on a market-consistent basis, in the event of a worst-case scenario;

[56] ANIA, *TRENDS-Solvency,* Solvency department, Year IV, Number 3, March 30 2023, www.ania.it

b. The *discounted market value margin* (dMVM) for non-life insurance risk, credit risk of outward retrocession (specificity of reinsurers) and scenarios in scope, except for non-hedgeable market risk, that is calculated through the Cost of Capital Approach as in SII.

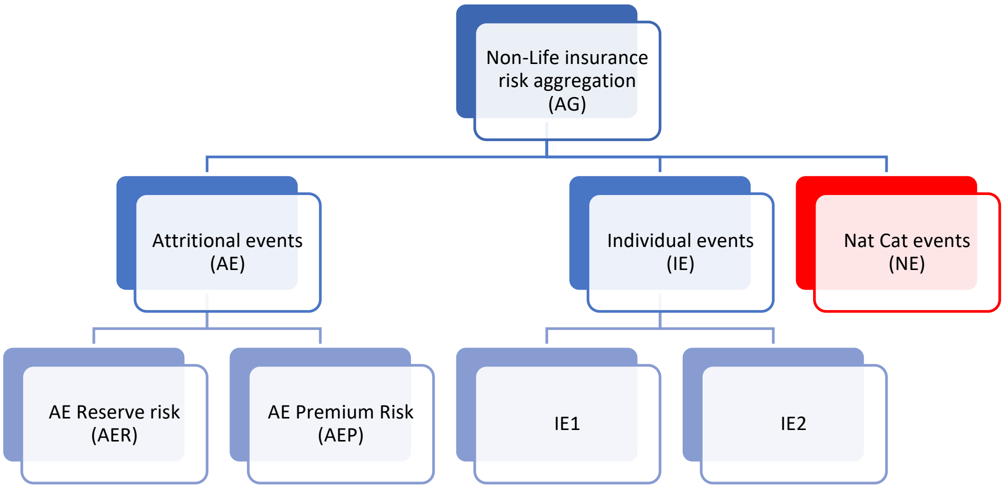
FINMA proposes guidelines for insurance companies on the treatment of natural catastrophe risks in the SST for the scope of a (partial) internal model. "A natural catastrophe risk (**nat cat risk**) is the risk of financial losses to the insurance industry caused by a natural catastrophe event, while a natural catastrophe event (**nat cat event**) is an event caused by a non-anthropogenic mechanism and which generally has an impact on a large continuous area for an uninterrupted period of time lasting from a few second to several weeks". Modelling nat cat risks by insurance companies should follow:

1. it is assumed that the insurance company will follow its own business plan covering all relevant losses in the current year from in-force business, including new business, for the one-year period;
2. all nat cat event risks are modelled fully by a nat cat existing model, which must be adjusted to cover risks that would not otherwise be covered, including model-specific effects such as secondary uncertainty;
3. it is permitted to make use of models/software, typically stochastic event set based models (vendor models), justified in terms of the insurance company's risk profile[57].

Since the best practice in the Swiss insurance industry for the treatment of Nat-Cat risk is the development of full or partial internal model, a further detailed technical description is given by **StandRe**, the SST standard model for non-life insurance risk for reinsurance and insurance companies writing reinsurance business. Here, the Nat-Cat risk is included in the non-life insurance risk module obtained from the aggregation of different components illustrated by the following **Table 9**:

[57] FINMA, *Guidelines for insurance companies subject to the Swiss Solvency Test regarding the treatment of natural catastrophe risks in SST*, October 31, 2017, www.finma.ch

Table 9: StandRe Non-life insurance risk module



Source: Technical description of the SST standard model reinsurance (StandRe), FINMA

- **Attritional events (AE)** are info events that measure the impact on the reinsurer over the one-year period and they can be modelled by lognormal distributions parameterized by mean and standard deviation. It is composed by:
  - **AE Reserve Risk (AER):** the risk from AE info events for the business from the prior accident years (i.e., the business earned at t=0). It covers info events affecting nat cat business from prior accident years.
  - **AE Premium Risk (AEP)**: the risk from AE into events for the business from the current accident year and the business written but not earned at t=1.
- **Individual events (EI)** cover all info events that are not in the scope of NE and AE. They should be modelled individually, not primarily by extrapolation from historical experience of the reinsurer, and explicitly considering actual exposures and inward reinsurance structures. It is composed by:
  - **IE1:** covers info events in IE that only impact the current accident year;
  - **IE2:** covers all info events in IE that are not covered by IE1 having also impact on prior accident years.
- **Nat Cat events (NE)** are info events assumed to only affect the current accident year. Here NE is referred to the usage of internal model by the reinsurer, otherwise this component would be absent[58].

[58] FINMA, *Technical description of the SST standard model reinsurance (StandRe),* October 31, 2022, www.finma.ch

3. Nat-Cat Risk in US Risk-Based Capital

The US Risk-Based Capital, which has been created by National Association of Insurance Commissioners (NAIC) measures the minimum amount of capital a company must hold based on its level of risk to not trigger regulatory action.

The RBC splits the risks a company can take in four major classes:

- **Asset risk**: it refers to risks associated with investments held by the insurer including the possibility of default of bonds or loss of market value for equities;
- **Credit risk**: it is the risk that a counterparty to an agreement will be unable or unwilling to make payments back;
- **Underwriting risk**: it reflects the amount of surplus (assets-liabilities) available to offset possible losses from excess claims;
- all other business risks and such other relevant risks as are set in RBC instructions that reflect the general health of insurer.

The RBC is, then, obtained through the subsequent formula by adding new ingredients for Cat Risk:

$$R0 + \sqrt[2]{(R1)^2 + (R2)^2 + (R3)^2 + (R4)^2 + (R5)^2 + (R6)^2 + (R7)^2}$$

R0 Insurance affiliate investment and (non-derivative) off-balance sheet risk

R1 Invested asset risk – fixed income investments

R2 Invested asset risk – equity investments

R3 Credit risk (non-reinsurance plus one half reinsurance credit risk)

R4 Loss reserve risk, one half reinsurance credit risk, growth risk

R5 Premium risk, growth risk

R6 Catastrophe Risk - Earthquake

R7 Catastrophe Risk - Hurricane

The risks inside the formula are adjusted for covariance, meaning that all the four risks categories will not occur at the same time[59].

[59] American Academy of Actuaries, *Comparison of the NAIC Life, P&C and health RBC Formulas*, www.actuary.org

Focusing on the catastrophe risk charges, it is composed by the sum of the following two components:

1. net catastrophe loss
2. additional component intended to address the risk of ceded reinsurance being uncollectible, for the worst year in 100.

For example, for the risk of hurricanes, the calculation of the charge is as follows:

R7 = Net Catastrophic Loss + Risk Factor x Ceded Reinsurance Amounts, based on "worst years in 100" modeled losses.

A larger number of scenarios, denoted as *simulated years*, are generated by catastrophe modeling software, each of them showing catastrophe insurance losses realized in that year. These losses are then aggregated to calculate the totals for each of the simulated years (scenarios) and the level of P&C RBC is calculated by taking the 99th percentile of the distribution obtained[60].

3.3 Alternative Risk Transfer Solutions for the diversification of large risks

Both the frequency and strength of hurricanes, floods, and droughts such as other natural events have increased during the past decades leading to make the natural catastrophes hardly insurable:

- losses can be huge and, as a consequence, the actuarial premium might be even infinite;
- the diversification from the Central Limit Theorem is not applicable because of geographical correlation and a lot of additional capital is required to strength the solvency position;
- there might exist no adequate insurance market because the short-term horizon of policyholder might not match the high prices asked by insurance companies;
- the climate change causes more uncertainty translated in additional risk bear both by the insurance companies in terms of additional capital and by policyholders in terms of premium.

[60] Navigation Advisors LLC, *RE: Catastrophe Risk Charge in the P/C Risk-based Capital Requirements to National Association of Insurance Commissioners*, www.navigateadvisors.com.au

In conclusion, insurance can always exist only if risk can be transferred, not only to the classical reinsurance markets but also, due to the lack of capacities, to capital markets. In recent decades, new Risk Transfer Techniques from classical reinsurance world have been developed to securitizing insurable risks and tapping capital market investors as an additional source of underwriting capacity. The Alternative Risks Transfer Solutions can be used to solve the following issues:

1. They are additional sources for insurance and reinsurance market capacities, especially in case of a hard market, where traditional capacities of reinsurance market are constrained;
2. Avoiding the credit risk of reinsurers, since liabilities are collateralized in bonds;
3. Getting a consistent actuarial price for (re)insurance products over time because reinsurance markets are very sensitive to catastrophes, while financial markets react more softly.

Climate risk, and more specifically natural disasters, has become a challenging issue for the insurance industry, since it involves potential extremely large losses. **Kleindorfer** and **Kunreuther** (1999) have already observed that "the private insurance industry feels that it cannot continue to provide coverage against hurricanes and earthquakes, such as other natural catastrophes, as it has done in the past without opening itself up to the possibility of insolvency of a significant loss of surplus". Moreover, any discrepancy between (re)insurer's risk profile and its capital need to be addressed by raising additional capital, transferring risk to third parties (through retrocessions or insurance-linked securities) or reducing the amount of risk assumed in underwriting and investment activities.

Furthermore, there are often discussions between cedents and reinsurers complaining about the clear identification without any ambiguity of the event generating a natural catastrophe. For example, in December 1999, two major winter storms Lothar and Martin crossed Europe within 48 hours and the reinsurer was arguing that this was a single event, and they therefore should pay for a single layer, not two. On the opposite, in case of smaller events, they would have argued that there were several events, of which none may have reached the priority. Four main techniques have been developed to define the trigger, and so the event:

1. **Indemnity trigger**: they are directly connected to the experienced damage for classical reinsurance;
2. **Industry-based index trigger**: they are connected to the accumulated loss of the industry;

3. **Environmental-based index trigger**: they are connected to some climate index (rainfall, windspeed, Richter scale, …) measured by national authorities and meteorological offices;
4. **Parametric trigger**: a loss event is given a cat-software, using climate inputs and exposure data.

The main focus of this document is to analyze the features and mechanism of the Parametric trigger technique, which will be the major object of the Chapter 4[61].

3.3.1 Insurance-linked securities: transferring risks to capital markets

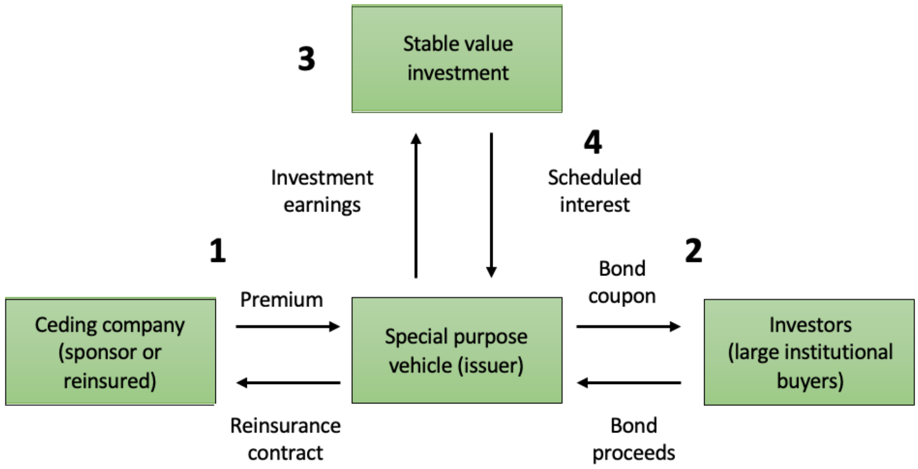
Insurance-linked Securities (ILS) are a means of ceding insurance-related risks to the capital markets representing a convergence of the insurance industry and capital markets. ILS have been used to transfer a wide range of risks from natural catastrophes to life insurance risks: for example, to reduce the peak risks of a severe natural catastrophe event of the risk of extreme mortality. The benefit from the unique features of an ILS transaction compared to traditional reinsurance makes this instrument more attractive. For example, a typical ILS structure for catastrophe bonds is composed by several steps:

1. The insurer or reinsurer (sponsor) enters into a financial contract with a Special Purpose Vehicle (SPV), which provides conventional reinsurance;
2. The SPV capitalizes itself through the issuance of interest-bearing notes to investors in the capital markets;
3. The SPV invests the proceeds from the notes offering investments in high-quality securities such as government bonds held in a collateral trust;
4. Investment returns are swapped to a LIBOR-based rate by the swap counterparty;
5. The SPV's funds are paid out to the sponsoring insurer or reinsurer if the bond's specified catastrophe event (e.g., the magnitude of an earthquake on the Richter scale) is triggered. Investor's principal is reduced by the amount of loss payment.

The ILS procedure is summarized in the following **Table 10**:

[61] Arthur Charpentier, *Insurability of Climate Risks*, The Geneva Papers, 2008, www.palgrave-journals.com/gpp

Table 10: A typical insurance-linked security (ILS) structure



Source: The essential guide to reinsurance, Swiss Re

The main advantages offered by ILS from the sponsor's perspective are:

- ability to transfer peak risks which might be difficult to place through traditional reinsurance as well as additional underwriting capacity;
- multi-year ILS duration makes the sponsor distance from the common pricing cycles present in the insurance and reinsurance industries;
- reinsurer's counter-party credit risk is very limited as the proceeds from the securities issued are held in a collateral trust.

Insurance-linked securities are particularly attractive for investors seeking diversification because they give access to a source of higher-yield fixed income securities with little correlation to other financial markets: changes in inflation of interest rates and the implications for equity and bond markets have no influence on the frequency and severity of natural catastrophes. In addition, the claims settlement process can be easily simplified with the ILS transactions because they are based on actual losses or are in the most cases tied to pre-specified measurements such as the intensity of a disaster in a particular location. One of the principal tasks in building such index-based contracts or parametric triggers is to minimize basic risk, which is the risk that the actual losses of the sponsor differ from the losses implied by the index or parametric trigger. This aspect will be covered in the next Chapter 4[62].

The Insurance-Linked Securities market, also known as Cat Bond market, was born during one of the most difficult periods for the property and casualty (P&C) insurance industry due to the

[62] Swiss Re, *The essential guide to reinsurance*, 2015, www.swissre.com

strike of Hurricane Andrew on Florida causing $27 billion in damages, of which only $15.5 billion was covered by insurance. It led to the failure of eight insurance companies and pushed others near to insolvency. Many large insurers and reinsurers initially reduced their exposure to catastrophic events in coastal regions. However, the demand for natural disaster-related insurance by households and business was increasing meaning that new capital had to flow into reinsurance. To increase the available capital, the insurance industry created a new financial instrument called *Catastrophe Bond* and the first CAT bonds were issued in 1997, giving insurers access to broader financial markets and offering institutional investors (such as hedge funds, pension funds and mutual funds) the opportunity to earn an attractive return on investment uncorrelated with the returns of other financial market instruments in exchange for assuming catastrophe insurance risks[63]. The growth of ILS market was indeed limited in the early years due to several factors:

- lack of sophisticated knowledge of both issuers of and investors in these risk transfer instruments;
- relative immaturity of catastrophe models, which are the basis for the pricing of many cat bonds;
- length of time to take a deal to market;
- high transactional costs since they are multi-year rather than one-year instruments to deal with the minimization of the impact of these high costs.

Then, the volume of outstanding catastrophe bonds started to grow steadily until when Hurricane Katrina in 2005, which caused an additional increase in ILS/cat bond issuance, but this changed suddenly with the collapse of Lehman Brothers in 2008. The only temporary set-back suffered by ILS market was during this global financial market dislocation, even if they were one of the very few asset classes which generated positive return during this period. Investors were concerned that the underlying collateral structures as total return swaps, with investment banks (such as Lehman Brothers that was the guarantor of total return swaps for four cat bonds at the time) often being the guarantor: cat bond investors were exposed to both insurance risk and investment risk. New issuance of ILS dropped sharply but quickly recovered thanks to the low-risk stable vehicles such as Treasury money market funds that were used as another underlying collateral structures. Then, during the several years of low interest rates following the financial crisis of 2008, investors were particularly attracted to cat bonds because

[63] Federal Reserve Bank of Chicago, Catastrophe Bonds: A Primer and Retrospective, by Andy Polacek, Chicago Fed Letter N°405, 2018, www.chicagofed.org

they gave relatively higher yields among all the ILS instruments. In 2011, the ILS market began to attract new and non-traditional issuers, such as publicly owned service providers and utilities. Since many of these issuers were at least partially self-insured, they considered ILS as a beneficial addition to their risk management programs because ILS react to large tail risk events that might create stress for more traditional reinsurance while being less of a stress to the overall capital markets results in more stability. The insurance industry has increased its capital availability thanks to ILS and traditional reinsurance markets. In the past 20 years, ILS have gained popularity and had a major influence on market price, terms, conditions and competitivity. For example, traditional reinsurance adapts to stay competitive by starting to offer multi-year capacity of insurers who prefer the stability, since cat bonds are multi-year agreements. Future developments of ILS are expected to be favorable, since they have proved their worth as an effective tool for diversification.

The main Insurance-linked Securities are the Catastrophe Bonds, Catastrophe Futures, Catastrophe Options and Catastrophes Swaps.

1. **Catastrophe bonds**

Catastrophe bonds (cat bonds) are a subset of insurance-linked securities, which are debt-like investment instruments providing risks coverage to insurance and reinsurance entities. ILS are principally funded by funds and supplemented by "insurance premium" paid by the entity obtaining the risk protection (cedant), which works to enhance the yield on these investments.

From a sponsor's perspective, there are two features present in cat bonds. The first element states that a cat bond mimics the default rates of corporate bonds, typically high-yield corporate bonds, that restricts the risk protection on the tail of the distribution away from the "working layers", which are a dollar range in which an insured or, in the case of an insurer's book of business, a group of insureds is expected to experience a fairly high level of loss frequency. Secondly, this instrument is mainly used by a sponsor to investigate for the coverage of tail risks (e.g., 1-in-50 to 1-in-100-year events) due to the high transaction costs that restricts the usage of cat bonds to large amounts of coverage and to multi-year agreements. Pricing for tail risks via cat bond markets returns a potential greater stability with respect to traditional reinsurance markets. Typically, cat bonds respond more to financial market trends, whereas traditional reinsurance prices respond more to recent catastrophe activity: natural events that are likely to drive up the cost of traditional reinsurance may not impact the cost of cat bonds. Another consideration that should be made by a sponsor is the relative cost of cat bonds versus traditional reinsurance. This relative cost can vary over time, but in general the cost of cat bond protection has come down over time thanks to two elements: capital markets have become more familiar to this concept, while catastrophe models have been much more developed and expanded to additional perils. The high cost of setting up an SPV for a cat bond can be the only remaining barrier to entry for a first-time sponsor. On the other hand, most sponsors already have familiarity with the placement of traditional reinsurance making the process shorter and less complex with generally locked-in terms for the full period, even if a large amount of documentation and potential disclosure of company-specific information are required. Cat bonds are often issued over multiple years during which coverage and price are locked, and the level of customization is reduced with respect the annual basis traditional reinsurance coverages. Since tail events are unlikely to have multiple occurrences in the same year by producing a lack of reinstatements, it can be mitigated by setting a cat bond triggers on an aggregate basis. Differently from traditional reinsurance that pays claims on indemnity basis, cat bonds may use different payout triggers, as it has been anticipated in the introduction of this paragraph. How to recover from the cat bon principal is chosen by the sponsor, who will select triggers based on many factors, including:

- *basic risk*: the payout might not fully cover the losses incurred or could pay more than the actual loss;
- *transparency*: the investor can assess the risks assumed;
- length of time between an event and the claim settlement;
- accounting implications.

The main types are the following:

a) **Indemnity triggers** are the most commonly used trigger type by insurer sponsors because of their low basic risk with perfect alignment between sponsor's losses and recoveries, favorable accounting treatment, and growing popularity among investors. Sponsor's catastrophe losses are required to be public disclosure but the transparency for investors is minimum because, since payouts depend on sponsor losses, investors should have a good understanding of sponsor's underwriting operations and claims handling to properly value the cat bond investments. This trigger can be time-consuming because it relies on the claim verification, which might be difficult, and the payout settlement is the longest. As a result, to be more attracted, cat bonds have commutation provisions at the end of the final risk period if covered events have occurred, even if open claims and reserves reaming from the triggering event. This clause allows for payment of cash by one party to release the other from all future obligations to pay claims after a certain time period.

b) **Industry Loss Index Triggers** work when the insurance industry loss from a covered event reaches a specified threshold by specifying the source of the industry loss estimate or amount. They are commonly used by reinsurer sponsors who are more likely to accept basis risk and, since their portfolios are well diversified, they are not as likely to have peaks of exposure concentrations where their own incurred losses are not proportional to their industry market share. Any information about sponsor's portfolios is needed to be disclosure and the index can be customized to a company's own book of business. The basic risk is high due to potential disconnects between portfolio's incurred losses and the industry loss.

c) **Modeled Loss** is based on sponsor's portfolio exposure with specified catastrophe modeling software, and when there is a catastrophe event, the event parameters are run against the exposure database in the cat model. If the modeled losses are above a specified threshold, the cat bond is triggered. The basic risk is higher with respect indemnity triggers because these models are not perfectly aligned with incurred losses. Since modeled losses are not dependent on claims settlement, they reduce the time to determine recoveries, but investor transparency is limited and privy only to sponsor related to understanding cat model.

d) **Parametric** works by using specific parameters of natural hazard, such as windspeed for hurricane or magnitude for earthquake. Parameter data are often collected at multiple reporting stations as inputs into an index formula. If the results exceed a predefined threshold in a predefined geographical region, then the cat bond is triggered. The potentially low correlation with actual loss can be a danger for pure parametric bonds. To mitigate this risk, sponsors can use models to obtain an approximation of loss as a function of the speed at differing locations, which then can be used to determine a payout function for the bond. Key advantages are transparency and shorter payout settlement after an event.

In the early 2000s, parametric and industry loss indexes were popular because they were easier to understand by investors who did not have familiarity with insurance and catastrophe modeling. As ILS and cat bond's market grew over the past two decades, indemnity triggers became more widely used and now they are the most common type of trigger. Since triggers can be on a per occurrence or aggregated basis, a decade ago the majority of cat bonds were on a per occurrence basis, but now the market has shifted towards aggregate triggers.

From the investor's perspective, this investment vehicle is mainly chosen from who is seeking diversification and potentially high returns. Cat bond evaluation is similar to reinsurance underwriting: assessing sponsor's operations and exposure portfolios, or judging whether modeling results are conservative or aggressive, and then using the analysis to determine the fair price for the cat bond. Further comparisons are made by investors between the returns of cat bonds and from other fixed income investments, or between the price of cat bonds and the corresponding traditional reinsurance layers to evaluate the risk-return trade-off. The great advantage of cat bonds is their high diversification capacity resulting in lower volatility and lower correlation with the general capital market. It has been demonstrated by the fact that S&P 500 Total return index was significantly impacted by the financial crisis of 2008-2009, while the Swiss Re Global Cat Bond Index Total Return[64] (which consists of price and coupon components) was much less affected. In addition, catastrophe events are often regionalized, and they do not have as much correlation with the global financial markets as do non-insurance events keeping the cat bond returns stable, even if cat bonds have generated higher returns than similarly risky fixed income assets. The payout calculation for catastrophe bonds depends on the terms specified in the bond's document, but generally it can be calculated using a formula like this:

$$Payout = Notional\ Amount\ x\ (\ 1 - \text{Loss Percentage})$$

where:

- **Notional Amount** is the initial principal amount of the bond
- **Loss Percentage** is the percentage of loss due to the catastrophic event as determined by a predefined trigger.

In summary, can bonds are collateral structures providing price stability over multi-year period, especially during hard reinsurance market, coverage for layers and amounts that may not be available from the traditional market with minimal credit risk. They involve investments in stable, conservative, short-term instruments, such as treasury money market

[64] This index was established by Swiss Re in 2007 and it tracks the aggregate performance of all catastrophe bonds issued in any currency, all rated and unrated cat bonds, outstanding perils, and triggers.

funds, and have become safer leading to a broader pool of investors, who can diversify their exposure to catastrophe risks by peril and geography[65].

2. Catastrophe Futures

Catastrophe Futures (Cat Futures) are derivative contracts first traded on the Chicago Board of Trade (CBOT) in 1992 in the aftermath of Hurricane Andrew used by primarily by insurance and reinsurance companies to hedge themselves against catastrophe losses. In 2007, the Chicago Mercantile Exchange (CME) acquired the CBOT and announced that catastrophe futures would continue trading through its NYMEX (New York Mercantile Exchange) division. They work similarly to a financial future used by both hedgers and speculators to protect against or to profit from price fluctuations of the underlying asset in future: a futures contract is an agreement specifying that a buyer purchases or a seller sells and underlying asset at a specified quantity, price, and date in the future. Catastrophe futures are forward contracts based on an underwriting catastrophic loss ratio that estimates the potential of catastrophe losses borne by the American insurance industry for policies written that cover a particular geographical region over a specified period of time[66]. These contracts are indexed to the "CME hurricane index (CHI), which determines a numerical measure of the potential for damage from a hurricane, using publicly data from the National Hurricane Center of the national Weather Service"[67]. Payoffs are based on potential catastrophe losses as predicted by a catastrophe loss index calculated by the exchange. When a catastrophe futures contract was launched, its value was initially $25,000 multiplied by the catastrophe ratio, which is a numerical value provided by the exchanged every quarter, to obtain the base value of the contract (Final Price), as it can be shown in the following formula:

$$\mathrm{FP_b} = \frac{\text{Incurred Catastrophe Losses}}{\text{Estimated Property Premium}} \text{ x } \$25{,}000$$

Since the change in the Cat Futures price is directly linked to the trend in claims, in the event of a catastrophe:

[65] American Academy of Actuaries, *Insurance-Linked Securities and Catastrophe Bonds*, June 2022, www.actuary.org

[66] Investopedia, *Catastrophe Futures,* by Julia Kagan, July 24 2022, www.investopedia.com

[67] CME Group, *CME Hurricane Index Futures and Options,* www.cmegroup.com

- if losses are high, the value of the contract goes up and the insurer makes a gain that hopefully offsets whatever losses might be incurred;
- if losses are lower than expected, the value of the contract decreases, and the insurer (buyer) loses money.

This reasoning is applied to Cat Futures because they are acquired by (re)insurers as hedging instruments and the (re)insurance companies may estimate for each quarter the Maximum Possible Loss (MPL), which is its maximum portfolio loss ratio for the catastrophe risks with respect to USA regions where risks are located. This value is then compared with the underlying spot price of the Cat Future for the same period: if the first value is less than the second, the company is willing to buy futures. In this way, if at maturity the buy price is lower than the definitive value communicated by NYMEX, the company will collect the difference between these two values that allow to cover costs of catastrophic events suffered. On the opposite situation, the company will endure what it has not lost on its portfolio. It makes sense that the company buys Cat Futures to protect itself against the risk of a significant worsening of the accidents, when it is expected to have an increasing trend in claims. Contrary, the firm has convenience to sell Cat Futures when it is expected to have a decreasing trend in claims, since they are not more a hedging instrument. If on the expiry date this decreasing tendence has been confirmed, the company will achieve a profit equal to the difference between sale price and price communicated by the NYMEX; while if the trend has been different, the undertaking will suffer a loss equal to price communicated by NYMEX and sale price[68].

3. Catastrophe Insurance Options

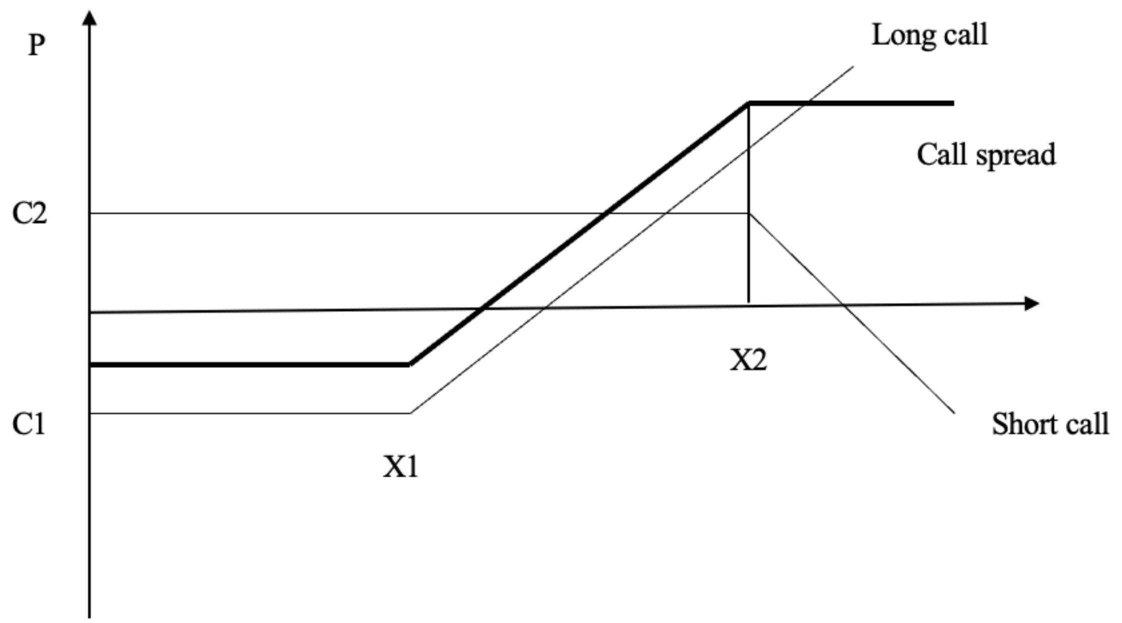
Catastrophe Insurance Options (Cat Options) are financial contracts, which give the right, but not the obligation, to the buyer upon a payment of a price (premium), to exercise or not the right to buy (call) or sell (put) a given quantity of an underlying, or before a given expiry date or at maturity and at a given strike price. Cat Options, traded on the Chicago Board of Trade (CBOT), are on European type with underlying the Property Claim Service Index (PCS) that is the international authority for aggregate insured losses of the US insurance sector in the property and casualty lines of business. These investment instruments provide the right of the purchaser to demand payment under an option contract: if the claims index

[68] Luigi Selleri, *I rischi catastrofali e ambientali,* Milano, Edizioni Angelo Guerini e Associati Spa, 1996, p. 210,211

surpasses a pre-specified level (strike price). The indexes are regional to permit hedging against large risks in specified areas, even if a national index also exits. Investors can profit from selling options in diversified territories which are unlikely to suffer losses simultaneously. A drawback can be the presence of basic risk when specific claims obligations do not necessarily exactly match the compensation amount from the option pay out and, in addition, this cost cannot be deducted as premium equivalents.

Cat Options can be structured for more complex buying strategies by implementing different positions. One of the main popular strategies for the insurance derivatives is the *Call Spread Options or Stellage* on the strike price. It is based on the combination between a long position on a call option with strike price k1 and a short position on another call option having strike price $k2$, where $k1 >$ k2 and the maturity date T is the same for both the options. The following **Figure 8** shows the strategy just described:

Figure 8: Profit from a call-spread strategy



Source: La gestione dei rischi climatici e catastrofali, Stefano Miani

The light black lines represent profits of the two options independently: the first (long) call determines a profit for spot prices higher than X1, while the second (short) call establishes a loss for spot prices higher than X2. The solid black line is the total profit of a call spread obtained by summing together the two positions. The minimum result is the difference between premiums of the two options. Since the premium of an option decreases as the strike price grows, the paid premium on the long option is greater than the one received on the short option, and the minimum result is negative. When the final value of the activity reaches the strike price of the long call, the result increases proportionally to the final value. Reaching the strike price of the short call, profits of two positions cancel themselves and the overall profit remains fixed. This economic structure is similar to a reinsurance CatXL, which will be explained in the subsequent paragraph. A call spread is equal to a reinsurance contract that has strike price of the long call as attachment point, the strike price of the short call as exit point and the difference between the two prices as premium. The loss range chosen should reflect the layer of risk to be transferred and it depends on the relationship between the losses of the insurer and the losses of the index on which the contract is signed. The theoretical number of contracts that the insurer may subscribe is equal to the ratio between the desired coverage amount and the maximum profit from a single call spread contract. The ratio between loss variations of a specific sector and the loss changes of a single insurer measures the basis risk: if the correlation is lower, the hedge through cat options is less effective. Given the great influence that the correlation has on the number of signed contracts and in order to maximize the efficiency of the protection, the number of contracts should be equal to their theoretical number multiplied with the hedging ratio obtained with the following formula:

$$\mathrm{h} = \rho \text{ x } \frac{\sigma_{\mathrm{A}}}{\sigma_{\mathrm{I}}}$$

where:

- h is the hedging ratio
- A is the activity to cover
- I is the asset on which the option is written
- ρ is the correlation coefficient between the variations of A and I
- σ_{A} is the standard deviation of the variations of A
- σ_{I} is the standard deviation of the variations of I[69].

4. Catastrophe Swaps

Catastrophe swaps are another method for paying catastrophe reinsurance by using capital market players as counterparties. It is a customizable financial instrument traded in the over the counter (OTC) derivatives market that enables insurers to guard against massive

[69] Luigi Selleri, *I rischi catastrofali e ambientali,* Milano, Edizioni Angelo Guerini e Associati Spa, 1996, p. 210,211
Stefano Miani, *La gestione dei rischi climatici e catastrofali*, G. Giappichelli Editore, Torino, 2004, p. 108-111

potential losses resulting from a major natural disaster. Since swap is a private contractual agreement between two parties to exchange cash flows for a given period at predetermined conditions, a catastrophe swap involves an insurer and an investor to exchange streams of periodic payments where policies are traded from different regions of a country to diversify better insurers' portfolios. The insurer's payments are based on a portfolio with potential payment liabilities of investor's securities, and the investor's payments are based on potential catastrophe losses as predicted by a *Catastrophe Loss Index* (CLI), which is an index created by third-party-firms that research natural disasters and used in the insurance industry to quantify the magnitude of insurance claims expected from major disasters. An insurer would take on the obligation to pay an investor period payment on a specified security (or portfolio of securities) which the investor was liable for, while conversely, the investor would take on the potential liabilities under an insured portfolio by making payments for catastrophe losses based on agreed measures of magnitude or severity. For the insurer, payments made on the investor's securities are equivalent to a reinsurance premium. This instrument protects (re)insurance companies when numerous policyholders have been hit by a claim within a short time frame[70]. Trading units are standardized in terms of equivalent risks and exposures, where the risk is classified according to the type and geographic area. The change refers to proportional relationships between different risks called *relativities,* for example, an exposure unit to Los Angeles earthquake can be equivalent to two exposure units of winter storms in Long Island. Catastrophe swaps are exposed to the credit-default risk of the counterparty because it does not exist a Clearing House to guarantee the exchanges. The basis risk, dependent on the contractual conditions, can be deleted if each indemnity payment from the two parties results in payments by both counterparties, otherwise the basis risk is present for both parties when payments refer to aggregated insurance industry payments. In addition, both adverse selection and moral hazard are reduced. Firstly, the potential risk that a price does not reflect average terms linked to adverse selection issue has been minimized because swap participants are required to provide policy and claims data to their counterparties. Secondly, policies that are part of the swap operation are randomly selected to prevent insurers from exchanging only their highest risk contracts[71].

[70] Investopedia, *Catastrophe Swap*, by the Investopedia Team, February 19, 2021, www.investipedia.com
[71] Stefano Miani, *La gestione dei rischi climatici e catastrofali*, G. Giappichelli Editore, Torino, 2004, p. 188, 189

3.3.2 The contribution of traditional reinsurance markets to managing catastrophe risk in a changing environment

The increasing severity and frequency of major natural disasters and innovations in recent years have supported the development of the international reinsurance markets as an additional risk management tool to enhance primary insurance markets' capacity to offer coverage and supporting their ability to manage catastrophe risks. Primary insurers are facing a significant deterioration in underwriting performance, resulting in the increase of claims ratio, can address that this deterioration by tightening their underwriting standards with extending less coverage or by increasing premium pricing. This last point of increasing premium pricing in the aftermath of a catastrophe event could provide an indicator of the extent to which reinsurance coverage has mitigated the level of insurance market disruption. The contribution of reinsurance to risk management across four areas thanks to the usage of a unique set of data on property reinsurance premiums and claims:

i. increasing primary market capacity;
ii. managing catastrophe risks;
iii. reducing economic disruption in the aftermath of catastrophe events;
iv. reducing primary insurance market disruption from catastrophe events.

Since they are long-term investors in equities, bonds and other asset classes, reinsurers are shock absorbers for the global economy and thus give companies the means necessary to grow and prosper, especially for insurers with a significant exposure to highly volatile lines of business such as natural catastrophe risks. Primary insurers (or cedants) may look for insurance coverage, which is a contractual agreement to indemnify losses or otherwise provide a payout to themselves based on the occurrence of a triggering event, such as a loss incurred by the cedants. The main reasons to seek reinsurance coverage include:

- **Risk transfer function**
  - reducing uncertainties and volatility in underwriting results which could be high in business lines subject to catastrophe risk;
  - protection against model risk;
  - increasing underwriting capacity, either for a given policyholder/risk or for a portfolio of policies/risks;
  - reducing timing risks with earlier recognition of profit.
- **Risk finance / capital market function**
  - reduction in the cost of holding reserves of capital required by clients, rating agencies and regulators;

    - establish an appropriate level of risk diversification with access to decrease in profits but increase in RoE (Return on Equity);
    - reducing tax payments.
- **Information function**
    - support in risk assessment, pricing, management;
    - allowing start-up companies to build business and accelerate profitable growth;
    - support entry into a new line of business or market (or exit), including for the purposes of leveraging the market knowledge and/or market presence of reinsurance companies.

The transfer of risk from cedant to the reinsurer can lead to risks to the cedant's ability to meet its obligations to its policyholders and they include:

- **Counterparty (credit) risk** is the risk that the reinsurer will not be able to meet its future obligations to the cedant, but it can be reduced by:
    - securing reinsurance coverage from multiple reinsurance companies or by accessing multiple forms of reinsurance coverage both traditional and alternative reinsurance in order to reduce the concentration risk for one single provider;
    - choosing to place reinsurance only with reinsurance companies that have a minimum level of financial strength:
    - requiring that some form of security be placed by the reinsurer to back the obligations assumed.
- **Execution risk** is the issue that reinsurer to not respond as expected by the cedant, especially present in case of triggering based on non-indemnity trigger (e.g., parametric, modelled loss or industry loss) by resulting in a mismatch between the payout and cedant's actual losses. It can be mitigated by ensuring close alignment between the coverage provided to policyholders and the coverage secured through reinsurance arrangements.
- **Liquidity risk** happens when cedants may be faced with liquidity problems in cases where payouts on reinsurance coverage are not made in advance of the cedant's payments to policyholders and it can be reduced by including allowances for advance payment or through collateralization or deposit arrangements.

The providers of reinsurance also include independent reinsurance companies, small and large with regional and/or global presence, as well as many reinsurance companies established within insurance groups to provide coverage to other group entities. The global nature of international reinsurance markets allows for some portion of the losses from an event to be absorbed by international markets (and investors), thereby diversifying the burden away from the domestic financial system. The pooling of risks faced by many insurers leads to diversification across populations, regions, risks, and time, leading to a reduction in the aggregate cost of protection and providing individuals and businesses with the financial protection necessary for making longer-term planning and to provide additional layer of risk absorption capacity at a lower cost than can be achieved in aggregated by insurance companies individually.

Reinsurers themselves may also acquire insurance coverage ("retrocession") for their exposures, typically covering catastrophe or tail risk (i.e., low frequency/high severity events). A reinsurer (retrocedent) purchases retrocession from retrocessionaries, which may constitute other reinsurers or capital market investors or even primary insurers. Retrocession can provide cover on a portfolio-wide or pillar basis and provides many of the same benefits to reinsurers as reinsurance provides to primary insurers, such as allowing more business to be written and providing risk diversification.

Most jurisdictions impose some regulatory or supervisory requirements on the use of reinsurance aimed at ensuring that counterparty and execution risks are appropriately managed. The primary aim of reinsurance regulation and supervision is ensuring that reinsurance companies are able to meet their obligations to their policyholders, who are the cedants. Reinsurance key role is in supporting earnings stability and solvency of primary insurers by applying regulatory measures to the transfer of risk by cedants, with the scope of ensuring that the transfer of domestic risks to reinsurance markets does not lead to significant risks for cedants, and ultimately their policyholders. For this purpose, regulators and supervisors may find an appropriate balance between allowing cedants to leverage the potential benefits of international reinsurance markets while ensuring that their risk transfer to international reinsurers does not lead to significant risks to their ability to meet their obligations to policyholders. Improving supervisory cooperation, information exchange and recognition could provide a better approach to manage the risks of international property catastrophe reinsurance markets[72].

Traditional reinsurance coverage to cedants is in exchange for a premium and the coverage is normally provided on an indemnity basis: providing payments based on the actual levels of losses incurred. The reinsurer's obligations to the cedant are backed by reserves and capital held by the reinsurer (or retrocedent in case of retrocession) or is backed by collateral posted by the reinsurer, where required. Traditionally, there are two basic forms of reinsurance:

[72] OECD, *The contribution of Reinsurance Markets to managing Catastrophe Risk*, 2018, www.oecd.org

- **Obligatory (treaty) reinsurance**

  It is mainly used to reinsurer entire portfolios meaning that a primary insurer agrees to cede a portion of its overall risk exposure to the reinsurer, and they are both obliged to cede or accept any risk covered in the treaty concluded. The reinsurer is bound by the treaty to accept its share of the risks, and it cannot refuse to provide insurance protection for an individual risk or policy that falls within the scope of the cover, while the insurer is likewise obliged to cede the agreed-upon risks. That's why this coverage is also often called *treaty* or *automatic* reinsurance. Non-life reinsurance treaties are usually renewed on an annual basis to underline the efficient in terms of administration of this form. In addition, because reinsurers do not analyze each policy relating to the reinsured business before accepting the cession, reinsurers are dependent on the cedant's underwriting and claims management ability.

- **Facultative reinsurance**

  It is the oldest form of reinsurance that is known as "reinsurance of individual risks" because, even if the primary insurer is free to choose which risks are reinsured, the reinsurer retains the option, of the *faculty*, to accept or refuse all or any policy offered to it. It adopts a case-by-case approach to transferring risks that are exposed to many different perils and represent a complex situation that requires individual treatment. This type of reinsurance coverage is mostly used by the primary insurer as a complement to obligatory reinsurance, covering additional complex and large individual risks above and beyond what has already been covered by the obligatory reinsurance treaty. Since the risk is analyzed on a policy-by-policy basis, the administrative process is more burdensome than treaty reinsurance.

There is also a hybrid form of **Facultative-Obligatory reinsurance** where the direct insurer can select which individual risks to cede to the reinsurer through a treaty, however the reinsurer must accept all business that the insurer wishes to cede subject to the scope of the treaty.

Both treaty and facultative reinsurance can be structured as proportional or non-proportional leading to different forms of reinsurance with their advantages in terms of meeting the various objectives for the use of reinsurance:

- **Proportional reinsurance**

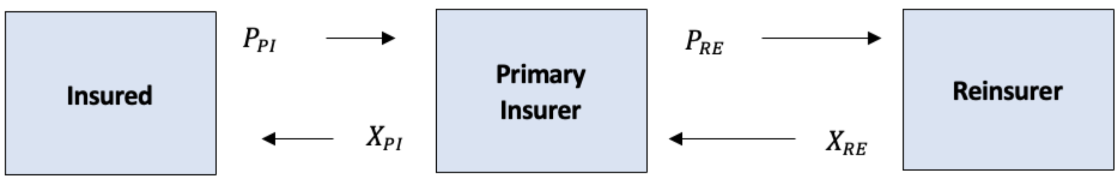
  Premiums and losses are shared between the primary insurer and the reinsurer by a ratio defined in their contract. The reinsurer's share of the premiums is directly proportional to its obligation to pay any losses. Then the reinsurer compensates the primary insurer for a portion of its acquisition and administrative costs through a reinsurance commission. This commission also can be seen as the price for the reinsurance: it is reduced or increased according to the quality of the portfolio, and it is calculated independently on the primary insurer's original premium.

- **Non-proportional reinsurance**

  Premiums and losses have no pre-determined split and it requires only that all losses up to a certain amount are borne by the primary insurer. This amount is called *deductible* D*, net retention, excess point, or priority*. Losses or amount X exceeding this deductible are assumed by the reinsurer up to a pre-agreed cover limit C. Here the loss amount plays a relevant role in contrast with relevance of the sum insured as in the proportional coverage. They were born in the 1970s as an alternative and complementary solution to traditional proportional forms of cover against biggest and accumulated losses, those which could potentially affect primary insurer's solvency. The main advantages from primary insurer's point of view are:

  - limitation of reinsurer liabilities with the presence of a deductible that reflects its willingness and capacity to bear risk;
  - smaller losses within primary insurer's net retention are no longer covered by the reinsurer who retains higher proportion of its gross premiums on its own account;
  - lower administration costs for both parties because the primary insurer has no longer needs to calculate his proportion of a loss for each risk;

  The cash flows present in non-proportional reinsurance contracts are simpler with respect the proportional ones:



  From the reinsurer perspective, it is able to determine the pricing of the risk, regardless of how the risk was originally priced by the insurance company. Reinsurer demands a suitable portion of the original premium defined through an *experience rating strategy* by considering the loss experience of recent years or *exposure rating strategy* by estimating the losses expected from type and composition of risk.

The fundamental functions present are:

- **Proportion function** of X: $\alpha \cdot$ X operating *vertically*

- **Layer function** of X: $\min(\mathrm{C}, \max(\mathrm{X}-\mathrm{D}, 0))$ operates *horizontally*

where $\alpha \in (0,1), 0 < \mathrm{D} \leq \mathrm{D} + \mathrm{C} < \infty$.

In the subsequent **Table 11**, the main reinsurance contract types available on the market are briefly introduced and divided for their type:

Table 11: Classification of contract for type and application of functions

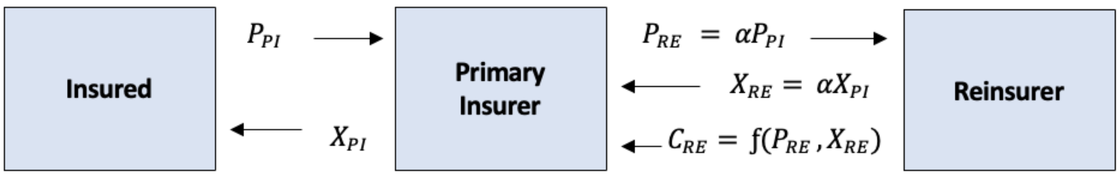
Contract	Type	Quantity		
		Exposure	**Premiums**	**Claims**
Quota Share (QS)	Proportional	Proportion	Proportion	Proportion
Surplus (SP)	Proportional	Layer	Proportion	Proportion
Excess-of-loss (XL)	Non-proportional			Layer
Stop Loss (SL)	Non-proportional			Layer

Source: Non-life Course Documents at Catholic University, *Reinsurance Pricing Analytics*, by Edoardo Luini

There are two main types of proportional reinsurance agreements:

- **Quota Share Reinsurance**

  It is the simplest form of proportional reinsurance because original premiums and losses are transferred from the cedant to the reinsurer based on a fixed quota or percentage α of policies written, generally applied to the entire portfolio of risks. The primary insurer retains a fixed percentage of each policy's premiums and cedes the remaining, as well as for the losses, while the reinsurer participates proportionally both in losses and in receiving the corresponding portion of premiums. The following picture shows the main cash flows present:



  Even if the original premiums are calculated in such a way that the direct insurer can pay for the losses as well as costs incurred, the reinsurer always have a better result than the direct insurer, since reinsurer's costs are lower. However, to truly "share the fortunes" a part of the reinsurer premium is repaid to the direct insurer through the reinsurance commission $\mathrm{C_{RE}}$. In theory C_{RE} compensates the cedant for incurred expenses (e.g., acquisition costs) but in practice it determines the expected cost of profit/loss of the quota share contract, since C_{RE} is a fixed commission rate c_{α}:

$$C_{RE} = c_{\alpha}\, \mathrm{P_{PI}}$$

Normally, a cedant would use quota share for any of the following reasons:

i. entry into a new market where it faces higher levels of uncertainty;

ii. to address liquidity needs related to fast growth as reinsurers will provide upfront funding for the acquisition of business;

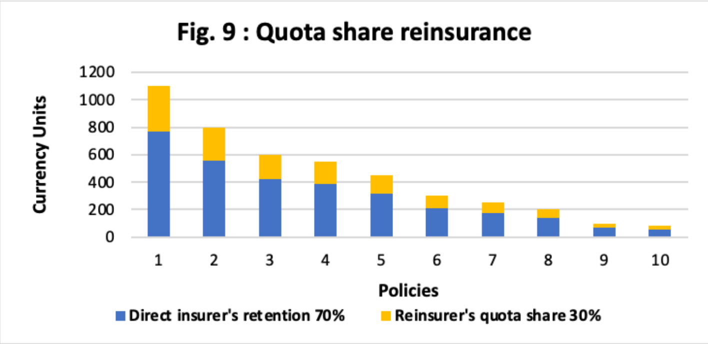
iii. to increase underwriting capacity as an alternative to issuing new equity;

iv. to incentivize reinsurers to accept highly-exposed risks by offering a share of a profitable book of business.

To sum up, it is ideal for homogenous portfolios like motor and household insurance where all the risks are fairly similar. Quota share reinsurance treaties are suitable for young, fast-growing insurers or established companies which are new to a certain class of business. It is also useful for primary insurers who are seeking capital relief for solvency purpose or protection against random fluctuations across an entire portfolio. Another reason might be changes triggered by unexpected legal developments or economic factors, such as inflation. On contrary, this proportional reinsurance agreement has also its drawbacks: it is based on relatively crude notion of proportional sharing of premiums and losses without effectively protecting the insurer against extreme loss scenarios, such as an accumulation of losses as a result of a natural disaster. A solution to solve this issue might be to combine a quota share agreement with another type of reinsurance contract, such as the surplus reinsurance agreement. Additionally, there are potential imbalances due to its inflexibility due to the fact that a primary insurer could cede too much and retain too little, possibly at the expense of profitability.

An example of how a quota share reinsurance is illustrated in the subsequent **Figure 9**, where the reinsurer's quota share is 30% reflected with losses and premiums shared at the same rate:

The primary insurer retains:	70%
The reinsurer accepts:	30%
Sum insured:	10 m
Primary insurer retains:	7 m
Reinsurer accepts:	3 m
Premium is 2‰ of the sum:	20.000
Primary insurer retains:	14.000
Reinsurer accepts:	6.000
Losses:	6 m
Primary insurer retains:	4.2 m
Reinsurer accepts:	1.8 m

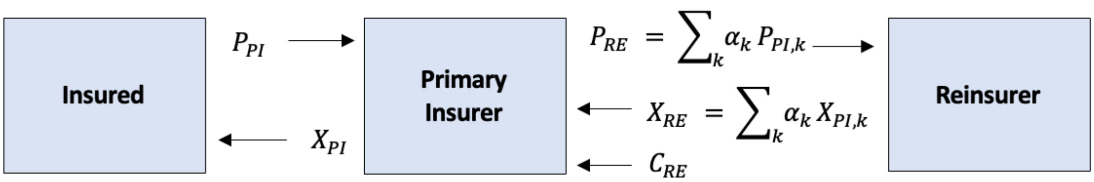


Source: The essential guide to reinsurance, Swiss Re

- **Surplus Reinsurance**

It is the most common form of proportional reinsurance coverage: the reinsurer does not participate in all risks because the primary insurer retains all risks for its own account up to a specific amount. This feature is in contrast with the quota share agreement, in which the retention is defined as a percentage from the conclusion of the contract. Here the reinsurer is obliged to accept the surplus of the amount which exceeds the primary insurer's retention. More in details, it can be seen as a modified quota share where α can vary across the different risks in the portfolio. Typically, α is a function of the sum insured of each risk and the surplus retention. Herein a deductible M is first of all determined, known also as retention line, where risks having sum insured V smaller than M remain entirely with the direct insurer (i.e., $\alpha = 0$) and for other risks, premiums and losses are divided between reinsurer and direct insurer in the ratio $\mathrm{V} - \mathrm{M}$ to M: here $\alpha = \frac{(\mathrm{V}-\mathrm{M})}{\mathrm{M}}$. In case of a total loss ($X_0 = V$) the direct insurer pays M and the reinsurer $V - M$. The limit of a surplus agreement is based on the maximum amount of liability a reinsurer is prepared to take on and it is usually expressed as a multiple of the primary insurer's retention. For example, a three-line surplus means the reinsurer assumes coverage up to three times the primary insurer's retention. Retentions can be set at various levels depending on the type of risks, the size of a risk and the company's overall risk appetite. This flexibility, however, comes at the price of more complicated and costly treaty administration.

The commission rate is determined in the same way as in quota share contract: the reinsurer pays a commission to the insurer. Originally, the commission was intended to compensate the insurer for the costs incurred in writing business in the first place, but this premium is often insufficient due to the competition present in the primary insurance market: after the direct insurer deducts his operating costs, the remaining original premium is less than the total losses incurred. More and more reinsurers are thus adopting the procedure of returning to the direct insurer only that part of the original premium that was not paid out for losses. At the end, the reinsurance commission is increasingly defined by commercial reasons rather than the direct insurer's actual operating costs. The following picture shows the main cash flows present:



The surplus reinsurance is a useful tool for balancing a primary insurer's portfolio by limiting its exposure to the single largest risks in its portfolio to make the resulting retained portfolio more homogenous and it can be used to calibrate a primary insurer's reinsurance needs much more accurately than a quota share can.

The following **Table 12** shows an example of insurance portfolio containing three different policies and, in each case, the total amount insured is shown, followed by the amount that the insurer wishes or is able to retain. Here, the insurer has a retention line of 300.000 and takes the surplus between the retention and the total insured sum, in this case up to a maximum multiple of 9 times the retention. The premium is 1.50 ‰ of the sum insured in all cases.

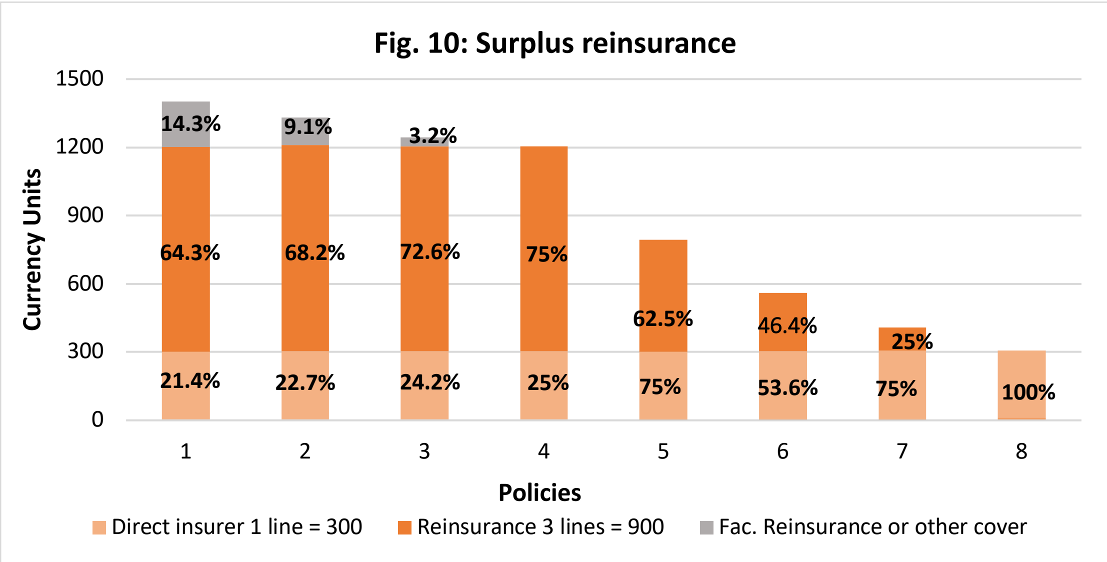
Table 12: Surplus reinsurance – treatment of a portfolio of risks

Policy I	Total	Insurer retains (1 line)	Reinsurer's surplus (9 lines max)
Sum insured	3.000.000	300.000 = 10%	2.700.000 = 90%
Premium	4.500	450 = 10%	4.050 = 90%
Losses	1.500.000	150.000 = 10%	1.350.000 = 90%
Policy II			
Sum insured	130.000	130.000 = 100%	0 = 0%
Premium	195	195 = 100%	0 = 0%
Losses	80.000	80.000 = 100%	0 = 0%
Policy III			
Sum insured	3.500.000	300.000 = 8.57% + 500.000 = 14.20% = 22.86%	2.700.000 = 77.14%
Premium	5.250	1.200 = 22.86%	4.050 = 77.14%
Losses	2.000.000	457.200 = 22.86%	1.542.800 = 77.14%

Source: The essential guide to reinsurance, Swiss Re

Policy I is the simple case of a surplus reinsurance contract, Policy II shows that reinsurer does not participate in risks given the retention and Policy III shows that the reinsurer takes its maximum surplus, while the primary insurer must either bear the additional respective losses (here 14.29% of the sum insured or 500.000).

An additional graphical illustration is presented just below in the **Figure 10**, in which insurer must bear additional costs over 3 lines of retention for policies 1,2,3 and the entire cost for policy 8 that does not exceed the first line of retention at 300:



Source: The essential guide to reinsurance, Swiss Re

There are three main types of non-proportional reinsurance:

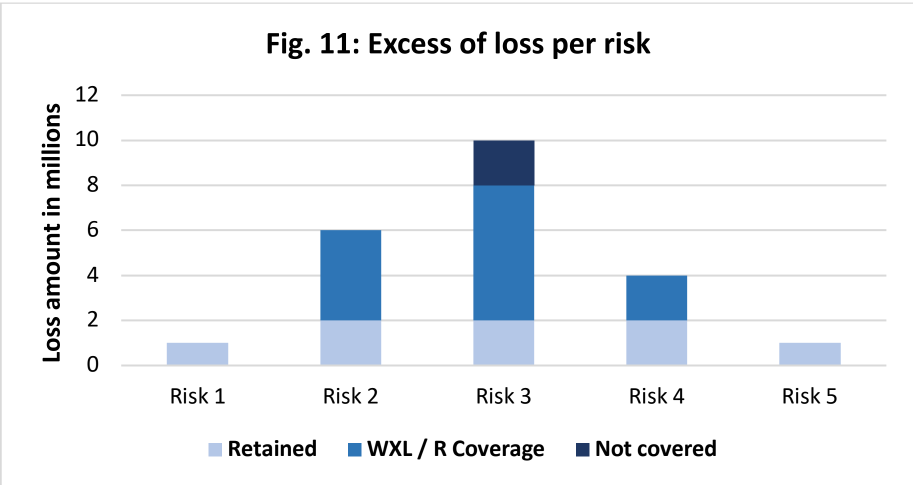
- **Excess of Loss per Risk (or per policy)**

  It is the traditional form of non-proportional reinsurance effective for risk mitigation against large single risk losses, such as large fire claim in property insurance, and risks that are particularly prone to total losses. It is often referred to as Working Excess of Loss (WXL), where "per risk" means for each insured object. Only the actual amount of loss incurred with respect to the specific risk is used to determine the amount of the claim for the purpose of reinsurance. The reinsurer indemnifies the primary insurer for the loss amounts of all the individual policies affected, which are defined in the treaty terms and conditions, and which exceed the contractually fixed deductible D and up to a cover C, while the primary insurer retains all the amounts up to the deductible.

$$X_{RE} = \sum_{r} L_{D,C}\,(X_r)$$

where X_r denotes the claim costs of risk r.

Unfortunately, this product does not offer adequate protection against frequency or against cumulative losses, where many policies are affected by the same loss event such as a major natural catastrophe.
There is a graphical illustration on how a coverage of 6 million in excess of 2 million (6 million xs 2 million) works, while the primary insurer retains 8 million in the following **Figure 11**:



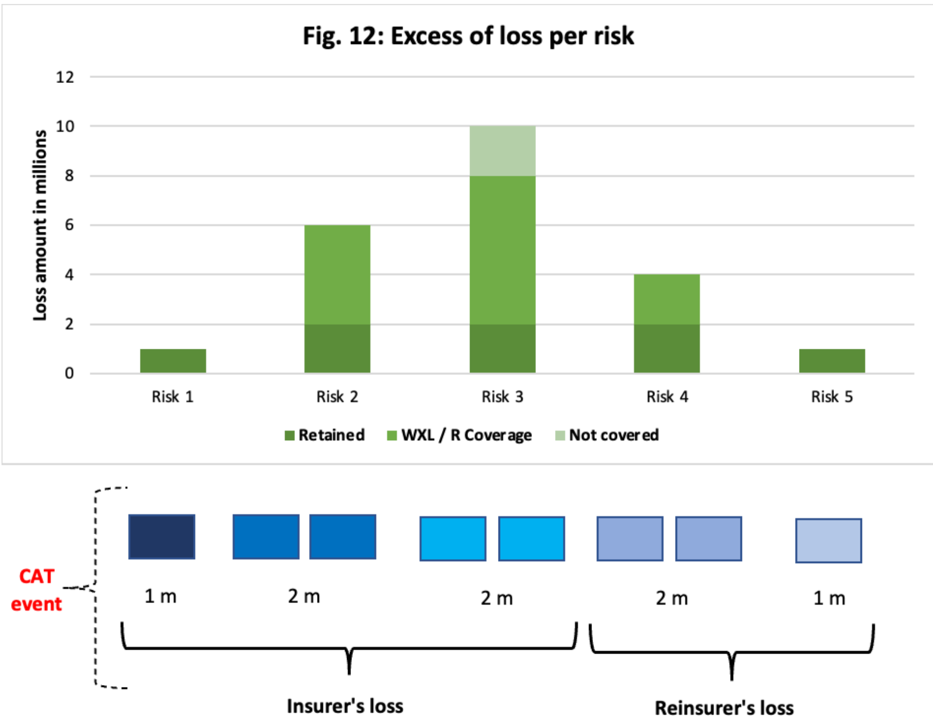
Source: The essential guide to reinsurance, Swiss Re

- **Catastrophe Excess of Loss (per event / occurrence and aggregate) reinsurance**
  It is a more suitable product to limit an accumulation of losses from a single event (e.g., a natural disaster or large-scale loss event) by representing the effective risk mitigation against large catastrophe losses made up of the sum of potentially hundreds or thousands of small losses created by the same cause. This coverage is commonly used in property reinsurance after an earthquake or windstorm and for moto policies after a hailstorm. The main difference to excess of loss per risk is that the unit of loss is not the individual loss per policy, but the aggregate loss caused by one event within the insurance portfolio covered by the reinsurance treaty.

$$X_{RE} = \sum_{e} L_{D,C}\left(\sum_{i^e} X_{i^e}^{e}\right)$$

where X_{i^e} denotes the claim costs of risk i associated to event e.

There is typically present a time limitation clause related to the occurrence of the peril depending on the peril and treaty (e.g., losses occurring within 96 hours for wind or 168 hours for earthquake are considered a single event). CatXL often allows for a reinstatement against the payment of an additional premium which provides cedants that the reinsurance coverage will be again available after a significant event.
The subsequent **Figure 12** illustrates the example of a CatXL coverage with the limits 4 million xs 5 million meaning that the direct insurer's net loss from the catastrophic event is 5 million, while CatXL reinsurer's net loss is 3 million.



Source: The essential guide to reinsurance, Swiss Re

The reinsurer's participation in each claim is limited by the reinsurance cover and there is usually an additional annual limitation of the total amount of all claims that the reinsurer pays. Excess of loss contracts specifies an *Annual Aggregate Deductible (AAD)* or an *Annual Aggregate Limit (AAL)* working aa a layer applied to the aggregated reinsurer losses:

$$X_{RE} = L_{AAD,AAL}\left(\sum_{r} L_{D,C}\,(X_r)\right)$$

The idea behind this procedure is that the direct insurer retains a large deductible for the "first" loss, namely $D + AAD$, where AAD is the *aggregate retention*, and a small deductible D in the case of future losses. AAL is the maximum loss exposure for the reinsurer.

- **Stop Loss**

  It helps primary insurer to smooth its earnings by protecting itself against unfavorable frequency of large claims fluctuations from year-to-year, even if it is not a so frequent form of non-proportional cover because it is mainly used when the direct insurer has suffered a technical loss (e.g., when claims and administration costs exceed premiums) by ensuring the most comprehensive level of coverage. Anyway, this product discourages the primary insurer to take on excessively risky underwriting because it makes the direct insurer still responsible, since he is not relieved of all entrepreneurial risk. It is mainly applied to a cedant's "net retention", the liability remaining after a combination of other reinsurance forms and it does not offer extra commitments for reinstatement coverages. The reinsurer covers any part of the total annual loss burden which exceeds the agreed deductible D, usually expressed as a percentage of annual premiums or loss ratio, or a specified absolute amount by allowing the. The layer function is applied to the whole loss of a portfolio, typically on an early basis

  Considering a portfolio with N losses $X_1, \dots, X_N$ that have occurred in a given year, the total reinsured losses with deductible D and cover C are the following:

$$X_{RE} = L_{D,C}\left(\sum_{i=1}^{N} X_i\right)$$

  where X_i denotes the single claim cost of risk i of the cedent portfolio.

In any case, the economic damage caused by catastrophic events requires such considerable compensation that not even the reinsurance market can efficiently fulfill. Only transferring the management of catastrophic risks to the financial market, that is nearly 50 times the capital of the world insurance markets, could suitably absorb some of the risks and financial payouts generated by catastrophic events. However, it is not enough to make use of financial market mechanisms because new products should be thought to proper manage the underlying damage assessment with accessibility and transparency in the risk assessment process. Indeed, the main purpose of this document is to analyze innovative products which are a combination between the financial and reinsurance world: the parametric disaster insurance products[73].

3.3.3 Short insight of Government Programs for managing catastrophic events

In many countries the management of catastrophic risks has always been committed to the State, which acts as an ex-post guarantor of last resort and therefore willing to take responsibility for remedying the damage. Individuals are induced to take moral hazard behavior because they request public intervention ex-post rather than adopting ex-ante prevention measures against natural risks. This behavior has led to a low diffusion of insurance coverage in the past because the only individuals asking for insurance policies covering catastrophic events were policyholders who are the most exposed to the risk of natural disasters. This issue has caused a problem of adverse selection of customers leading to a significant increase in insurance premiums and, as a consequence, in the costs of insurance coverage: dangerous circle of excessively high insurance premiums and low demand for individual coverage have signed an insurance market failure in this particular sector. One of the possible solutions to break this vicious circle is the presence of public intervention that will take on a considerable part of insurance premiums through tax relief and subsidized loans to reduce individual cost of insurance coverage.

In addition, several discussions among insurers and governments within some countries about whether or not natural disaster risks are insurable with current arrangements have shown the three main reasons why insurers in many countries have difficulties to offer natural disaster at low cost:

1. difficult estimation of uncertain low-frequency but high-impact risks and, hence, the premium;
2. property and casualties (P&C) insurers have limited capacity to over the potentially large and correlated natural disaster losses;

[73] Swiss Re, *The essential guide to reinsurance*, 2015, www.swissre.com
Non-life Course Documents at Catholic University, *Reinsurance Pricing Analytics*, by Edoardo Luini, December 2022

3. in the absence of significant premium differentiation, there could be a problem of adverse selection for only individuals with a high natural disaster risk exposure.

On the other hand, fully public natural disaster insurance, which is the main traditionally way of ex-post intervention, have some drawbacks linked to:

- it moves away financial resources from other important public projects;
- it works against the free market principle;
- it disincentives risk preventions measures for individuals who are often limited in the absence of risk-based insurance premiums.

Most of the existing international catastrophe insurance systems, such as those for flood risk, have developed a sort of involvement of the government, either through private markets or by providing compensation through public reinsurance or a state guarantee. These systems are commonly set up as Public-Private (PP) partnership with the participation of private insurance companies with varying degrees of roles and responsibilities for the involved participants. The main objective in PP insurance systems is the cooperation between government and private sector in sharing or selling insurance policies with the aim of achieving a high market share. PP makes optimal use of the expertise and capacity to carry risks of public and private sectors, while the government's role in fully private system is very limited to a regulatory role.

Particularly, Mysiak and Pérez-Blanco (2016) proposed a classification of the different forms of partnership between the State and insurance companies on the basis of three aspects:

1. robust or poor regulation of the insurance market by the public operator;
2. mandatory nature of insurance coverage;
3. possibility that policyholders cover part of the risk (mutuality) inversely related to the amount of insurance premiums.

Nowadays, countries can be divided into the following scheme:

a) France, Switzerland, Spain, Chile and New Zealand are characterized by massive state intervention, by compulsory insurance coverage with premiums set by law and strong mutuality;
b) countries like Japan and Turkey have a lower incidence of point 2 and 3;
c) United Kingdom and United States have a weaker presence of the State in the sector with non-mandatory nature of insurance coverage with premiums that are no longer constant but calculated from time to time according to the level of risk to be managed.

Reasons behind this differentiation in the diffusion of insurance risk management tools to protect against natural disasters are multiple and complex from granularity of regulation, presence-absence of the State in the insurance systems, the nature of catastrophic risks to be insured to the culture in the field of prevention. In any case, it is evident how the current ex-post method of state intervention in the management of catastrophic risk is increasingly unsustainable as well as economically inconvenient due to the greater frequency and intensity of natural disasters.

The recent natural disasters have underlined the reduced degree of exposure of families and businesses to catastrophic risks and the awareness of individuals in facing these events is increasing as well as the timid, constant public demand for insurance products, especially in some countries. This phenomenon is still limited in Italy, considering the substantial increase in natural disasters that have occurred in the past months, even though insurance coverage plays an important role from a macroeconomic point of view leading to a decrease in negative effects of natural disasters on public spending and GDP growth. As it has been shown before, insurance companies manage properly technical and financial risks by calibrating their exposure to overall risk by insuring themselves against these natural risks, already suitably diversified in advance, that they have taken on by transferring part of the risk both through traditional reinsurance products and new hedging instruments[74]. Governments can also use ILS to obtain a quick inflow of needed cash given a catastrophic event, although ILS transactions do not normally replace other reinsurance arrangements but are used as an additional source of capital for catastrophic events. On the opposite, governments in the developed economies in Europe and thew U.S. have already witnessed the "exit" of insurers from private markets due to natural catastrophes and have established a public-private collaborative scheme to insure catastrophic risks through risk pooling.

If funding and achievement of risk reduction are two main characteristics to determine the financial viability and long-term robustness of an insurance system, there are four additional aspects for establishing a well-functioning natural disaster compensation arrangement:

- mandatory vs voluntary participation;
- the costs of the insurance:
- the role of the private insurance market and the government in financing the insurance;
- incentives and policies for mitigation.

Firstly, the insurance systems have usually low market penetration rates if there are not, or only weak, mandatory purchase requirements, as in the case of private insurance system, and the reason is linked to the fact that the provision of large amounts after a disaster to compensate

[74] Springer, *Catastrophic risks and the pricing of catastrophe equity put options*, by Massimo Arnone, Michele Leonardo Bianchi, Anna Grazia Quaranta, Gian Luca Tassinari, 2021, www.doi.org

uninsured damages comes from government relief, which reduces incentives moral hazard selection. Thus, government may establish and enforce a strict mandatory purchase requirement for resulting in high market penetration and a large pool of insured, which facilitates risk spreading and may reduce costs while its limits the need for ad hoc government relief.

Secondly, fully private insurance systems have the highest premium levels, fully public insurance systems have lower premiums, while PP insurance systems lays in the middle of the two regimes. The fully public and PP mandatory systems are driven by social and collective risk-sharing principles based on mandatory participation, which leads to a large pool of policyholders among which administrative costs and claims can be spread.

Another advantage in public or PP insurance systems is that a damage, which have passed above a certain level to the government intervention, is financed either by a state guarantee of state backed reinsurance or a combination of both. The private insurers sell and administer policies, make available their knowledge to assess catastrophe damages and offer coverage limited to only "common" perils. This division of tasks is cost-efficient because it makes optimal use of available expertise of private insurers in providing insurance coverage for the medium-sized damage provoked by catastrophic events under some public sector regulations. There are usually integrated form of risk-transferring mechanism inside public and PP insurance systems with the aim of making insurance available for extreme risks that would often be uninsurable for a wide public at an affordable price. The integration of risk-transferring mechanisms in PP insurance schemes are important for three main reasons:

1. The absence of a state guarantee, reinsurance or reserve with tax-exemptions in a PP natural disaster insurance scheme may induce private insurers to not offer insurance against catastrophe risk because they are usually reluctant to cover uncertain risks with potentially large damages;
2. Premiums can be kept more affordable if the government covers part of the extreme damage and the system can be able to diversify the extreme catastrophe risk across insurers by pooling risk or by purchasing reinsurance in the local and international market that can be translated in the reduction of the costs of holding large amounts of internal capital with the consequence of lowering premiums;
3. A risk-transferring system allows insurers to build technical or equalization reserves with a specific level of tax-exemption to prevent from a lack of cash flow in the event of a catastrophe.

Especially, developing countries and small economies have difficulties in properly funding potential catastrophic risks because they suffer not only the devasting effects of disasters, but also from market imperfections and constraints which generate disincentives to better risk management. The domestic capacity constraints are present in:

a. high exposures to perils ;
b. limited fiscal capacities to fund major disaster reconstruction for low-income communities and public properties;
c. insufficient vulnerability reduction measures taken for properties and physical assets;
d. limited reserves of domestic insurance capital;
e. resulting under-insurance in the economy.

Also, the features of the international (re)insurance markets have influenced the development of local risk management practices through:

a. past premium rate volatility which has limited insurance coverage to only middle/higher income sectors;
b. lengthy past delays in rate adjustments and capacity to rebuilding following global disaster events;
c. high levels of reinsurance provided to local insurers with high premiums;
d. proportionately higher insurance costs for catastrophic-level risks given insurer's needs to retain high and costly levels of capital.

The potentially devasting effects can be faced at country level, if governments control "exposure" through regulatory actions aimed at vulnerability reduction programs also for the low-income sectors, and by assuring that the local insurance sector has sufficient capital, net of reinsurance cover, to withstand large losses. Including regional diversification and exploiting the latest risk transfer technologies, governments can help in arranging the requisite inter-country and market collaboration for setting the basis for ex-ante regulatory requirements to ensure financial solvency and risk reduction. The combination of public, private, international and multilateral resources can jointly increase broader cost-effective risk management tools which will begin to minimize the economic and financial disruptions of future disaster events[75].

A particular case in the middle of the axis of private/public involvement in the scheme of natural disaster protection is the France case: the *French Régime d'Indemnisation des catastrophes Naturelles*, also known as CatNat Regime, founded in 1982 on the basis of solidarity, prevention and responsibility. The combination of the principle of national solidarity emerged

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[75] World Bank, *Catastrophe Risk Management – using alternative risk financing and insurance pooling mechanisms*, by Caribbean Country Department – Latin America and the Caribbean Region, www.worldbank.org
The Geneva Paper, *A comparative study of Public-private catastrophe Insurance Systems: lessons form current practices*, by Youbaraj Paudel, 2012, www.genevaassociation.org

with modern nation-states together with private insurance takes the form of the so-called "mandatory extension of guarantee": a policyholder buys insurance for their home or office, vehicle, or in the case of businesses for operating loss, under the policy name of "*baseline contract*" ("contract socle"), which includes a mandatory amount dedicated to natural disasters called "ad*ditional premium*" or "*surpremium*" ("prime additionelle" or "surprime") that is a percentage of the premium. This additional premium gives the policyholder a right to insurance in the event of natural catastrophe and its level is defined and periodically updated by the state. At the creation of the regime, the additional premium amounted at 5.5% of the home-owning contract, while today it is 12% and 6% for vehicles. Since, in France, insurance for certain natural risks is mandatory, state-defined, it is, however, implemented by private insurance companies, which collect the additional premiums, as a specific class of premiums. One peculiar aspect of CatNat Regime is the non-differentiation of the additional premium, which is indiscriminately flat as expression of the national solidarity principle under which all citizens or companies living or operating in France pay the same rate regardless of their risk exposure. Obviously, the premium itself varies: if a house is insured in a flood-prone area, the premium will cost more than in other areas but the surpremium remains flat.

Although premiums are collected by private insurers, the decision to trigger the regime and compensate victims is made by a governmental committee, on which insurers do not participate. What counts as a natural disaster is ultimately defined by the French law, under which the inter-ministerial committee is sovereign in this decision. The CatNat regime covers major disasters that cause damages considered uninsurable by the insurance market, even if some natural events would be "normal" in other countries, i.e., ones that do not necessarily have large-scale disruptive consequences, such as snow, hail or storms of "normal" intensity are covered by private insurance. The list of natural disasters covered by the regime is open-ended meaning that there is no exhaustive list of climatic events specified in the law, despite that the increasing tendency to include new risks is getting worse with climate change.

The French state is reinsured by a public reinsurer CCR standing for *Caisse centrale de reassurance* founded in 1946, which is backed by a state guarantee. It has become a liability-limited company in 1993, even if it remains state-owned even today, it partly operates as a private reinsurer in France and in other countries. The NatCat Regime relies on two levels of risk transfer. First, private insurers transfer part of the risk to CCR, as in normal reinsurance market, but CCR cannot decline to reinsurer an insurer that requests reinsurance. The common type of reinsurance agreement used is the Excess of Loss: CCR takes charge of payouts when the costs of a natural disaster exceed a certain level. However, the second transfer step moves from CCR to the state because CCR benefits from a “state guarantee” (“garantie de l’Etat”) meaning that the state becomes the insurer of last resort in case reinsurance cannot face with the level of payouts involved, in return, CCR pays the state premiums. This guarantee is not free but the amounts involved in the event of a major disaster are potentially higher than the level of premiums paid by CCR. In addition, this guarantee appears unlimited both financially and in duration resulting in the impossibility that CCR goes on bankrupt as normal reinsurers due to the protection given from the state.

The NatCat Regime can be considered as a “mediating membrane” between the state, capitalism and nature making the French state an “environment making” institution characterized by three main features:

1. The regime is a financial device based on a tax on insurance premiums meaning that the “production of nature” is mediated by finance, or more precisely by insurance, with behind the public guarantee;
2. This financial device is used to strength equality among its citizens and to manage the national territory with a political objective at its core based on a law-based legal framework that defines when the regime applies;
3. This regime is linked not with nature in general, but with natural disasters that are classified through specific criteria allowing insurers to cover nearly every home, office and vehicle.

There are also some debates between public and private actors regarding the function of the NatCat regime, in particularly between SCOR, one of the world’s largest reinsurers, and the French state. SCOR wants to terminate the state guarantee and replace the NatCat regime by a market-based system, where private reinsurance would play a much bigger role, and where the state would only reinsure costliest risks. Some arguments against the operating procedure of this regime have focus, in particular, on the second level of risk transfer:

- the state guarantee could constitute an illegal state aid to CCR;
- CCR has a quasi-monopoly on natural disaster reinsurance in France, around 90% of the reinsurance market;
- rates offered by CCR on the reinsurance market are influenced by the state guarantee, since around 30% of tis activities are market activities, penalizing the other private reinsurance companies;
- taxpayers will pay the bill for the damage resulting from the rise in natural disasters owing to climate change.

On the contrary, the French government's objections to SCOR are several and many of them are related to the state case where there is no ex-ante intervention by the state in the insurance sector: the cost of insurance will increase for policyholders, citizens and businesses are not willing to buy relevant insurance policies, insurers might be tempted to hold on more risk without a state guarantee and, since CCR's portfolio is less diversified than a normal reinsurance portfolio might be, the guarantee is a compensation for this penalization.

The position of SCOR and the French state are opposite: SCOR insists that climate change will put a growing danger on public finances, whereas the French state argues that the market alone will be unable to cope with the rising extent of natural disasters[76].

This is a specifically French system but public-private schemes for natural catastrophe insurance also exist in other countries, such as the *U.S. National Flood Insurance Program* or the "*Concorcio de Compensacion de Seguros*" scheme in Spain, which have similarities and differences among them.

The *U.S. National Flood Insurance Program* (NFIP) has been established in 1968 by the U.S. Congress with the objective to limit the costs of ad hoc federal disaster assistance paid out of taxes. This program is administrated by the Federal Emergency Agency (FEMA), which is responsible for covering the risks. Insurers are only financial intermediaries in the NFIP through what is called the "Write Your Own" (WYO) program, which allows the participating P&C insurers to sell the stand-alone standard flood insurance for which they receive an allowance. Individuals or companies can choose to buy expensive commercial flood insurance or purchase flood insurance from the NFIP. The only obligatory purchase requirement stands for homeowners in the 1/100-year flood zone having a mortgage that is backed by a federal lending institution. The application of the NFIP requires an official disaster declaration made by the U.S. President after a catastrophic event as a precondition for disaster assistance. The NFIP provides optional insurance coverage with a certain maximum amount for damage to buildings and their contents caused by flooding or other related events, except for landslides, direct rain, snow, hail and storm. Differently from the French system, here policyholders can choose between different levels of deductibles: a higher deductible lowers the premium to be paid. The NatCat regime is not currently in massive debt or experiencing structural imbalances, like for instance the NFIP. Initially, it aimed to achieve self-financing through actuarially based premiums different per flood zone, but this was difficult in practice. For example, the NFIP

[76] Antipode*, The "Environment making state" and climate change: the French "Cat Nat" reinsurance scheme under strain",* by Razmig Keucheyan, 2022, www.onlinelibrary.wiley.com

provides high subsidies to the owners of older buildings established before the creation of flood insurance rate maps who have incentive to purchase flood insurance, but they count on average 35-50% of the actual risk. In the end, the main sources of funding for the NFIP are premiums and loans from the federal government. In case of a premium shortfall, FEMA can borrow from the U.S Treaty with a maximum limit of $20.75 billion, which must be repaid at the risk-free interest rate.

The determination of premiums depends on different factors, especially on the physical characteristics of the flood hazard depicted by the Special Flood Hazard Area (SFHAs), the location, age, type of occupancy and the design of buildings. The NFIP premiums for standalone flood insurance are about three times higher than French NatCat regime and more than ten times than the public insurance systems. This difference can be explained by the high fee of more than 30% of the total premiums that insurers receive for selling flood insurance through the WYO program, which is 95% of the policies sold. Finally, the NFIP has no mechanism to hedge risk in the private reinsurance market. The NFIP regulates five main mitigation programs that provide funding to local communities for investments in flood damage mitigation measures prior to flooding. To join the NFIP, communities must register themselves into the program in order to become membership and promoting a premium discount to policyholders in such communities. In general, the NFIP has been successful in reducing the vulnerability of new buildings to flooding but less effective for existing buildings: there is the need for improving building codes and flood zoning regulations that limit new construction in high-risk areas.

The current Spanish system for catastrophe disaster coverage was established to cover losses from the Civil War between 1936 to 1939. Only in 1990 it has become a legal national framework that covers extreme risks, which includes both natural and man-made disasters. This system is very similar to the French one because flood insurance is a part of the catastrophe coverage compulsory included in the P&C insurance policy sold by private insurers based on solidarity and collective risk sharing. The public sector is responsible for covering the risks and paying out claims with an unlimited state guarantee to the CCS. The Spanish scheme provides broader coverage with lower premiums and deductibles compared with the other systems. The premiums are collected by insurers on behalf of the insurance Consortium, for which the insurers retain a fee of 5% of the premium. Also, here the premiums are set by CCS and are not differentiated according to flood risk zones, but according to the types of insured property. Differently from other countries, the CCS creates an equalization reserve in addition to the technical provisions.

Although it is difficult to identify the most optimal natural disaster insurance system for countries that are considering establishing such a system or for countries that want to improve their existing system, it is vital to have in place an efficient and properly functioning natural disaster insurance, given the projected increase in natural disaster risk because of climate change. The several factors that should be taken into consideration for future developments are the following:

a) mandatory participation requirements are eligible if the objective of a system is to achieve a high market penetration rate, since voluntary purchases of insurance against low-probability high-impact risk appear to be low;
b) adequate monitoring and enforcement mechanisms need to be put in place to ensure compliance with mandatory purchase requirements;
c) the government needs to take responsibility for part of the extreme damage by providing a state guarantee or public reinsurance in order to keep an insurance system for uncertain catastrophic risks, financially viable and affordable;
d) private insurance companies should participate in PP insurance scheme by selling and administering policies, by covering medium-sized losses and spreading their knowledge to manage risks leads to the reduction of operational costs;
e) the integration of risk transferring mechanism, such as reinsurance, catastrophe bonds and risk pooling, is preferred to help insurers spreading risks and generating sufficient funds for claims reimbursements;
f) governments should stimulate the building-up of insurer's reserves by providing tax exemptions to be available in the event of a catastrophe;
g) integration of risk mitigation policies in a natural disaster insurance system is beneficial for society by limiting risk in the long run;
h) effective mitigation policy can be assessed with a detailed assessment and mapping of risk
i) incentives for policyholders to take risk mitigation measures can be provided through risk-based premiums, premium discounts, and deductibles[77].

[77] The Geneva Paper, *A comparative study of Public-private catastrophe Insurance Systems: lessons form current practices*, by Youbaraj Paudel, 2012, www.genevaassociation.org

CHAPTER 4

PARAMETRIC DISASTER INSURANCE

Introduction

This chapter represents the focus of this analysis: the parametric insurance applied as an innovative alternative risk transfer solution for the mitigation and diversification of natural catastrophe risk. Firstly, it is introduced by analyzing its technical definition, mechanism, advantages and application fields compared to the traditional indemnity products. After having presented the main issue of parametric insurance coverage, the basis risk, it has been given a display about the general development and design of a parametric insurance index, with the presentation of the most common parametric insurance structures used. Finally, two recent indexes, the Actuarial Climate Index (ACI) and the European Extreme Events Climate Index (E^3CI), are shown because they are an innovative and strategic tool to monitor climate change trends and to provide helpful data for the (re)insurance and public sector for the assessment of economic losses linked to natural disasters.

4.1 Parametric (re)insurance: a strategic tool for the mitigation of natural catastrophe and weather risk

Throughout the centuries, (re)insurance products have evolved to become increasingly sophisticated thanks to the rise of modelling capacity, product innovation and data availability that have led to the development of solutions with an augmented range of perils and exposures: the parametric insurance products. It appears that nowadays the scope of the (re)insurance industry is to provide cover for previously uninsurable risks, in any part of the world and with fast and transparent payouts. Parametric insurance products are an innovative solution in a world of increasing weather-related natural catastrophes and potentially driving a hardening market. This product will be deeply presented in the following sub-paragraphs.

4.1.1 Introduction to parametric insurance: definition and mechanism

The phrase "parametric insurance" has probably recently appeared in different discussions on most hot topics, from closing the protection gap to ensuring the environmental transition toward sustainability, becoming a ubiquitous term in the (re)insurance world.

A parametric cover is a contract that makes a payout to a beneficiary in the event of an index exceeding a threshold: it allows providers to create a risk transfer solution without relying on the actual assessment of the insured's incurred losses as in traditional insurance, but is rather linked to an external, observable variable. In other words, using the definition given by the World Bank, the "*index or parametric insurance pays out benefits based on a pre-determined index for the loss of assets and investments as a result of weather or other catastrophe events*".

A parametric solution is composed of:

1. collected data, usually from a provider
2. a calculated index
3. a payout function.

The first step is the collection of the **underlying data** usually made by a specific independent data provider, such as a meteorological agency, related to the specific hazard object of the parametric solution. To assess the goodness of data in order to build an initial model, several improvements should be made:

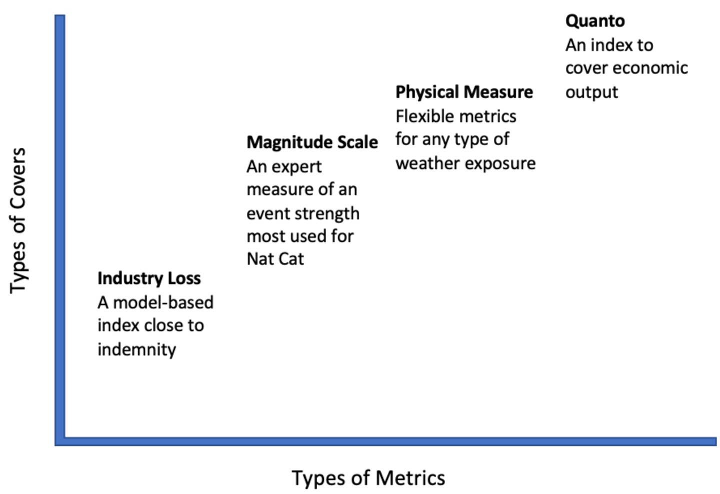
- *Cross-check with other sources to validate observation;*
- *Check if the available data is complete enough to provide accurate modelling* because it is important to consider the appropriate historical period and missing data points can be interpolated depending on the context;
- *Check the consistency of the data* related to the geographical context, urbanization influences and changing of measurement tools over time;
- *Measurement from the provider shall be reliable.*

By combining internal and public databases, significant improvements can be made to the underlying data used to model the transaction leading to basis risk reduction by itself.

Many parametric products, particularly the weather-related one, rely on historical data for their analysis and a process of **data cleaning** is needed to correct time series for potential breaks or shifts. On one hand breaks might be present in case of interrupted measurement and the reasons can be very different: ranging from failing instrumentation to an institute deciding to interrupt its own measurement. On the other hand, shifts can be introduced by a change in the environment, one potential cause being urban development. Another issue arises from trends present in time series on the observation period: ignoring them may lead to a misestimation of the risk to be covered, which would be translated into design bias and pricing adequacy. Then, curve fitting to historical loss data assumes stationarity (statistical properties such as the mean and the standard deviation do not change over time). Several linear and non-linear models can be used to estimate trends and longer time series extending at least a few decades into the past helps better to analyze past behavior. This point will be faced in the next paragraph.

The second step regards the central element of these products: the **definition of the index**, which is a metric mirroring the financial loss to which an asset is exposed while facing a given risks, from acts of God to acts of man. The following **Figure 13** illustrates the way in which coverages can use metrics ranging from those closest to the loss (lower-left) to more abstract or derivative indices (top-right):

Figure 13: Illustrative cover examples



Source: Parametric Insurance SCOR – part 1

The Industry Loss is mainly linked to natural catastrophe insurance loss covers and it typically uses catastrophe risk modelling and early claims information to provide an estimate of market loss: when the hazard occurs, the closest modelled event is searched for via a catalogue and its return frequency determines which percentage of a nominal value is paid. Then, the Magnitude Scale, like the Richter one, are best suited to the coverage of corporate assets in single or just a few sites and this approach has also been used for wide exposure areas: the payout is a higher percentage of a given nominal amount for increasing event magnitudes. The third group from the left is related to covers against adverse weather conditions, which are frequent in the energy and agriculture segments. These indices measure the aggregation of daily or hourly adverse weather conditions, such as temperature, rainfall, heat, windspeed, … This kind of cover pays a notional amount when the weather index exceeds a threshold over a period of typically three to six months. Two examples are particular derivative products traded in the energy sector over the counter, on exchanges like the Chicago Mercantile Exchange, or on platforms like weatherXchange::

- the **Heating Degree Daily** products that are derivatives covering against an accumulation of daily temperature deviations as a proxy for an increased demand for energy in winter (i.e., heating);
- the **Cooling Degree Day** products used to hedge against a higher energy demand during summer (i.e., cooling).

The last element on the right is Quanto, which summarizes financial products like temperature contingent options, also called *quantitative options or quantos*, add a degree of complexity, by introducing a secondary trigger that leads to a payment for anomalous weather days if commodity prices deviate beyond a dedicated threshold. These products are standard in Australia and other markets. Whereas the three other indices mentioned before reflect the weather dependency of electricity production, quantos mirror its economic value by adding a price tag.

Each case starts with the definition of the appropriate index, which will be the quantity triggering the observed or potential damage. An index is developed by analyzing the data available for that particular risk, then used for modelling and pricing, and forms the basis of loss settlement. A suitable metric should be considered and be specific for each hazard, for example rainfall for drought. The contractual parties usually want the index to adequately reproduce the historical data of the event considered. In addition, the regulators require basis risk to be controlled prior to agreeing on an insurance product. Various statistical methods can be used to assess the extent to which it is a good fit. A common choice is the so called R^2 value, which measure how much of yield variation can be explained by the index chosen: a R^2 value of 100% indicates a perfect linear model and 70% is considered more as a compromise to represent a moderately good relationship between parameters. The selection for the appropriate R^2 value depends on the application field and, hence, on the peril to be analyzed. For example, a R^2 value of 70% could seem to be good for crop yield in agriculture but it would not be enough for an earthquake coverage.

Setting the trigger is an important decision because it affects the frequency on recoveries and the price of the insurance product. There is a comparison between the cumulative function of empirical observations of the chosen index with its empirical return periods and the theoretical function. To define a trigger level, the attention will put on the right "tail" of this function, even if various levels can be selected depending on the risk appetite of the insured.

The last step is the choice of the **payout function** that translates the index into a nominal monetary amount with two features:

- **A triggering event**
  A triggering event is a condition to trigger the payout based on an index threshold, such as a storm exceeding Category 3 or the Saffir-Simpson Hurricane Wind Speed Scale, rainfall or snowfall exceedance or deficit, earthquake epicenter location and/or share intensity related to the Richter Scale. The parameter must be an objective measure that is transparent and consistent to avoid moral hazard both on the insured and reinsurer. It must be fortuitus, happening by chance rather than by design, and it can be modeled.
- **The type of payout**
  The policy will pay out a specified amount when a pre-agreed parameter or index threshold is reached or exceeded, regardless of what physical losses insured.

Even if parametric covers can seem to be the perfect product, they need to be used in situations where their advantages are used best because they entail the issue of basis risk. Basis risk is defined as the mismatch between the payout on a contract and the actual losses suffered by the policyholder and it is an integral part of a parametric product needed to be dealt with accordingly. It is an inherent part of these products because the payout is based on exogenous parameters and not on actual losses suffered by the insured. Since the magnitude of the basis risk can vary significantly depending on the accuracy of the modelled losses and the quality of the product design, it can be classified into two types:

- **type I** (false positive): the product provides more payout than occurred losses,
- **type II** (false negative): the product does not provide sufficient payout to cover occurred losses.

These two typologies can be visualized in the following **Table 13**:

Table 13: Basis risk configurations

	Occurred Losses	**No Loss**
Payout	Well designed	Type I (false positive)
No Payout	Type II (false negative)	Well designed

Source: SCOR, *Introduction to parametric solutions*

Fortunately, multiple techniques are available to mitigate such risks, and advances in technology and modelling are further helping to improve the accuracy of parametric covers. There are hence four elements that should be considered in order to assess basis risk and optimally reduce its impact:

- **Underlying Data**: can a relevant index be constructed with the available data? if not, can it be approximated with other data?
- **Index Construction**: is the index sufficiently correlated with the underlying risk? What is an acceptable trade-off between accuracy and simplicity, given the context of the inquiry? How quickly can the index be calculated and how trustworthy is the calculation?
- **Payout Design**: should the payout be a lump sum (binary payoff function) or should it be more complex?
- **Transaction Structure**: should the policy be a straightforward contract, or should it have additional components?[78]

4.1.2 Advantages of using parametric insurance in several application fields with respect the traditional indemnity products

Nowadays an established market uses parametric solutions as a hedge in the commodity sector, as cover against catastrophe risks for public assets, or as a volatility cap and cover against drought in agriculture. They have gained so much attention thanks to their combined differentiation efforts in multiple application levels, from microinsurance to corporates and from financial institutions to public authorities. The main advantages of this kind of products are:

- transparency of payout trigger;
- lower dispute risk;
- faster payout;
- no need for loss adjustment;
- resulting lower expenses.

The transparency advantage requires that payment in the event of a loss is only as certain as the solution design is accurate. The uncertainty mentioned is related to the "basis risk" issue that

[78] SCOR, *Parametric Insurance: a 360° View – Part One of Three*, by Expert Views, April 2023, www.scor.com
SCOR, *Introduction to parametric solutions*, Technical Newsletter #48, July 2019, www.scor.com
SCOR, *Parametric Insurance: a 360° View – Part Two of Three*, by Expert Views, www.scor.com

can be limited and ensured thanks to an effective payment that matches the actual loss as accurately as possible. This can be achieved through attention to contractual details, clarity in the wording, a robust data source, and a clear calculation process. It is important to remarked how the alignment of payment and actual loss is a key element of insurability, as after detailed in legal considerations.

The risk of dispute is significantly lowered, since payments rely on data collection and calculation, as opposed to loss adjustment. An agent should usually make an appointed calculation of the index based on the source data, within a pre-defined calculation timeline in order the risk taker can be informed of, and review, the payment amount. The risk taker is typically introduced to the payment from 10 to 20 business days after an event occurrence or the end of a coverage period. An adjustment can be always made at a later stage in case back-up data or re-analysis are required. Overall, the lead time to payment is significantly reduced compared to indemnity covers.

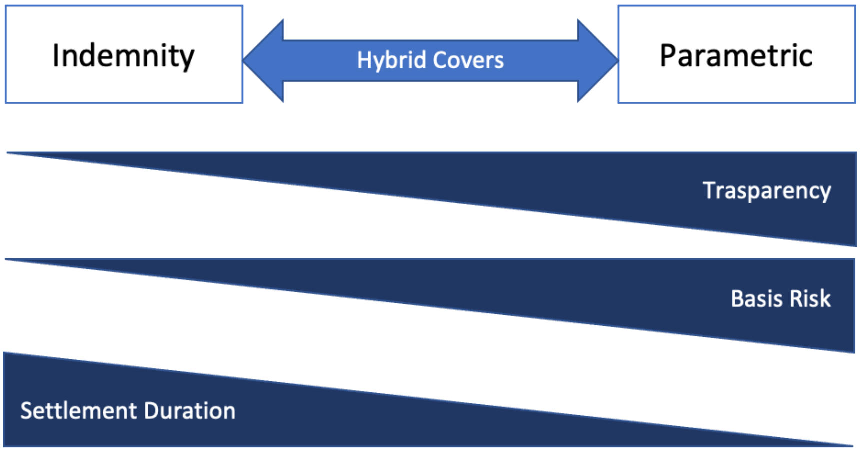
Within this kind of setup, lower expenses should be expected, even if it is important to underline that a perfect solution would lead to the same payout as the actual loss, notwithstanding loss-adjustment expenses. The expected loss and the cost of capital, the main cost drivers, should be the same as for a traditional solution. Parametric solutions should be a complementary to traditional covers thanks to their value proposition in the ability to cover uninsured risks.

Comparing, in general, traditional indemnity insurance to parametric coverage:

- parametric cover can fill the protection gap left by insurance products such as deductibles and uninsured business interruptions,
- it can provide revenue protection in addition to damage insurance for agriculture and electricity providers.

This **Figure 14** explains briefly the main three features and differences between indemnity and parametric solution:

Figure 14: Indemnity and Parametric solution component differences



Source: SCOR, *Introduction to parametric solutions*

Then, another detailed **Table 14** further summarizes the main differences between indemnity insurance and parametric insurance:

Table 14: Main differences between Indemnity and Parametric Insurance

	Indemnity Insurance	**Parametric Insurance**
Core legal requirements	Insurable interest proof of loss	Insurable interest
Nature of risk	Risk should be largely independent	Risk should be largely correlated
Payment determination	After the event loss assessment	Before the event pre-defined payments schedule
Actuarial determination	With independent risk, the risk of an insurance pool is less than the risk of thee individual	Historic time series of events is combined with the exposure to develop an expected loss for the parametric structure
Transparency	Can be challenged with complex exclusion, …	Can be fully transparent with good education for sophisticated clients
Moral hazard and adverse selection	The insured can influence the risk and will have more knowledge of their risk	The insured has no influence on payments but there can be adverse selection if sales closing is not properly set
Speed of payment	May take time to complete loss assessment	Can be made with a short time period

Core limitation	Higher cost for loss assessment and mechanisms to control adverse selection and moral hazard	Poorly designed products can fail to meet the needs when there is a loss or may even pay when there is no problem for the client (basis risk)
Flexibility	Sometimes constrained by requirements for **proof of loss****	Can cover a variety of financial risk that are difficult to prove use for business interruptions and good potential for the intangible economy

Source: Global Parametrics, Introducing Parametric Disaster Risk Financing

** The granularity level required for the proof of loss of a parametric product depends on the jurisdiction selected.

The main application fields go from protecting public infrastructure to supporting sovereign states exposed to climate disasters, adding also microinsurance and supporting microfinancing institutes to counter the exposure of small farms, and small enterprises in general. Large corporates are also parametric cover clients, to protect themselves against revenue volatility or property damage and the renewable industry must be considered in the context of the net-zero transition. Other industries like construction, transportation and leisure are also good candidate for, or buyers of, parametric cover. Retail businesses' supply chains are fine-tuned to consumption behavior making them exposed not only to business interruption and loss from natural catastrophes, but also to revenue volatility driven by weather patterns.
Business interruption is hence a significant value proposition of parametric covers, which fills a protection gap. To explain better this point, it is crucial to consider what is missing from traditional cover in terms of assisting with recovery from business interruption. Taking the example of some businesses that have suffered damage from Hurricane Katrina in 2005: they have been closed suffering from business interruption, whose losses has been covered directly. Even without damage, the flooded surroundings would have required the hotel to shut down, but the insured could not prove against the latter argument and the business interruption recovery was nil. Traditional products are based on a counterintuitive thought: the wider the impact of a natural disaster is, the less a business interruption policy will pay. But a parametric policy based on the extent of flooding in the surrounding area would have been triggered and paid.

Among the many emerging risks, parametric solutions have an ESG flavor addressing biodiversity protection. Investors have had an appetite for modelled peak perils with a broad consensus on the underlying risk, and hence very high transparency. At the planning phase, they can also consider the benefits of protection with their economic return expectations.

Parametric covers help to offset operational costs caused by the increased price of reinsurance capacity, the rising frequency of natural disasters with an increased retention on natural catastrophe insurance programs, and the uncertainty surrounding claims costs due to inflation. However, these alternative instruments are not always renewed when they do not meet the targeted recoveries. One solution to make parametric contracts more desirable is to create a combination with traditional solutions, focusing on complementary benefits rather than price competitiveness.

In both mature and developing economies, rapid payout is a key factor in recovering quickly after a shock. It helps people to rebuild their homes, to maintain their livings and jobs, and to avoid major post-disaster migration or displacement. Therefore, parametric solutions are a key component in development programs for vulnerable parts of economies providing coverage where no insurance framework is in place because they address risk which would otherwise be difficult to cover. They guarantee quasi real-time payment, where funding would otherwise take a long time to materialize.

There are numerous parametric covers against extreme events around the globe:

- the Pacific Alliance covering the Central and South American coast against earthquakes
- the CCRIF in the Gulf of Mexico covering against hurricanes, earthquakes, and excess rainfall
- the Solidarity Fund against Catastrophic Events (FSEC) in Morocco covered by parametric earthquake insurance
- the African Risk Capacity provides sovereign members with drought and cyclone parametric solutions
- the Southeast Asia Disaster Risk Insurance Facility (SEADRIF) insures countries in the region against flood
- the GSIS covers Philippine against earthquakes and cyclones, also in Fiji.

As massively anticipated in the Chapter 3, societies are becoming more vulnerable and the ability of public authorities to bear the cost of their debts is threatened by catastrophic events:

parametric solutions can help to restore the balance sheets of financial institutions under stress[79].

4.1.3 Assessment of a parametric product: legal consideration

The most important peculiar aspect of parametric products is that they can be shaped and sized in all forms, and consequently their product design can be very diverse. This product design poses its own challenges from a legal perspective, requiring a specific assessment of each product to ensure that it meets all the legal and regulatory requirements applicable to the relevant parametric risk transfer solution. The analysis needs to be done on a case-by-case basis because there is no "one-size-fits-all" solution, as the relevant regulatory requirements will depend on the jurisdiction where the parametric cover is to be offered.

There could be a misconception that make parametric solutions appears more complex than they really are. So, it is going to be a focus on the general legal concepts and re-occurring themes that form part of the legal assessment of a parametric product:

- **Classification**

  Generally, parametric products can be classified into either as (re)insurance products, or as financial market/derivative products. The product classification is important because it implies legal and regulatory implications to make the product meeting the classification standard in the applicable jurisdiction. The design of the product is a crucial phase, which includes the trigger applied, the payout mechanism and the correlation between payout and loss. The presence or absence of a direct interest in the risk itself from the protection buyers is crucial for the classification of a parametric product. Other soft indicators are local laws and regulations requiring the inclusion of the identity of the issuer (e.g., (re)insurer or bank), and the naming of the product as an insurance policy, reinsurance agreement or derivative. These indicators cannot replace the need for a detailed assessment of the product itself. Once the nature of the parametric product has been determined, this may influence its tax and accounting treatment, as well as the applicable regulatory regime. As a consequence, different regulatory and licensing requirements may apply, depending on whether the products are classified as insurance or reinsurance, or as a financial market product. This will also impact carrier

[79] SCOR, *Parametric Insurance: a 360° View – Part One of Three*, by Expert Views, April 2023, www.scor.com

management and regulatory restrictions. For example, an insurance or reinsurance company wants to offer a parametric product and the protection buyer is looking for a derivative product. Unless the (re)insurer includes a designated carrier, or the relevant jurisdiction allows (re)insurance companies to transfer risks via derivatives, the (re)insurance company would generally not be able to provide this cover directly to the protection buyer. It may be required to use an intermediary structure, which would incur extra costs and structure to ensure compliance with the relevant regulatory requirements.

- **Type of trigger**

  The type of trigger and trigger point together with the specific circumstances need to be considered and aligned with objective probabilities of occurrence. Different types of triggers may be used for parametric solutions: single trigger event (like cumulative rainfall that exceeds the pre-defined rainfall index over a set period of time, or an earthquake of a certain magnitude in exceeds of the pre-determined threshold) or a combination of triggers (for example, adding a requirement for the total loss amount in the industry or region concerned arising out of a single trigger event to exceed a pre-determined amount). Using double trigger mechanism would combine some of the purely parametric elements with aspects of subsequent loss adjustment.

  The design of single trigger products depends on the determination of the trigger itself, asl well as the amount of payout. The trigger should generally be set at a level very likely to incur a loss for the protection buyer. In addition, the payout amount should reflect the expected amount of loss for the protection buyer if that trigger threshold is reached. This would help to depict the protection buyer's insurable interest in the covered risk, which is a requirement in some jurisdictions to qualify cover as (re)insurance, i.e., its insurability. While a small payment amount may increase the probability of the protection buyer actually incurring a loss if the trigger is met, it raises another problem: whether the payout is sufficient to cover the loss incurred by the protection buyer or whether the protection buyer is left with a basis risk.

- **Payout mechanism**

  Payout mechanism may include a fixed sum, a staggered amount linked to the intensity of the trigger, or an initial payout with subsequent adjustment, depending on the actual loss sustained. The analysis will depend on the details of the product and the intended coverage afforded. A parametric product ca be easily classified as a (re)insurance product when the payout is closer to the actual loss incurred and greater is correlation between loss and payout. When the initial payout is subsequently adjusted in accordance with the outcome of the loss adjustment process, the final settlement amount should be equal to the loss incurred[80].

4.2 The general development and design of a parametric insurance index

The vast amount of parametric data sources available harbor big promises that the virtual world, the index, can holistically represent any risk situation and relieve society of some of its burdens. But a parametric journey has to face numerous challenges: hidden in the data, the underlying risk and the required expertise. Since parametric coverages are highly customizable to the individual insured request mainly linked to weather-related events, in the following paragraphs it will be presented a general overview on how an index is qualified and built.

4.2.1 What qualify a parametric insurance "index"

Since parametric insurance contracts cover the probability of a predefined event happening and pay out according to a predefined scheme instead of a lengthy claims adjustment process, it is crucial to identify to what events may refer: to an index-based trigger or to an event withing a defined area. First of all, the selected event / index must be:

- **Objective**: independent with verifiable data
- **Reliable**: from data source that provides consistent and timely measurement
- **Available**: access to historical statistical records to allow modelling
- **Correlated**: with the economic loss sustained paying attention to the basis risk issue

Secondly, the design of an index must be considered other factors, such as regulatory, legal, accounting aspects, reporting and trigger requirement, both for traditional solutions (for standard perils like earthquake and tropical cyclones) and for tailor-made concepts. It is evident how the current market is mainly influenced by public and industrial sectors, such as Energy and Agriculture, which are exposed to weather uncertainty risks and the relative indices are typically constructed around precipitation, temperature, wind speed, quake magnitude and

[80] SCOR, *Parametric Insurance: a 360° View – Part One of Three*, by Expert Views, April 2023, www.scor.com

hurricane category. Generally, an event / index design may consider the sector hit, the risk factors present and the relative consequences to be better tailored for different coverage needs. An example can be explained in the following **Table 15**:

Table 15: Sector, risk factor and consequences in the actual parametric insurance market

Sector	Risk Factor	Consequences
Public Authorities	Storm, flood, quake	Emergency and rescue expenses, infrastructure damage costs
Agriculture	Drought, temperature	Impact on yields
Energy	Rainfall, temperature, wind, sunshine	Production capacity
Construction	Temperature, wind	Interruption, extra costs and late penalties
Travel & Leisure	Rainfall, snowfall, temperature	Customer satisfaction
Transportation	Ice, snow	Access, cancellations
Sports & Events	Rainfall	Cancellations

Source: SCOR, *Introduction to parametric solutions*

In addition, vigilance is required throughout the design phase to stick to the purpose of the cover, where the first point is to start with a suitable choice of data.

Secondly, an index does not hide the underlying risk of a cover because the appetite of the risk carrier will always be measured by the underlying risk rather than by the data. Parametric and traditional solutions share the same targets and constraints in terms of pricing and capacity with the only difference that natural catastrophes models have a problem. They are not best calibrated for point-based exposure and some event tracks are not always available. Historical data might be tricky to interpret if close to the threshold but not close enough to verify if simulated events would trigger, which could lead to price arbitrage from the spread in the market view of the risk. The intensity might be expressed in a unit not available in existing modelling tools and the accumulation might be challenging to onboard for the risk carrier. For these reason, strong expertise is required[81].

[81] SCOR, *Introduction to parametric solutions*, Technical Newsletter #48, July 2019, www.scor.com

4.2.2 The most common parametric insurance structures

Cat-in-a-box, Cat-in-a-circle, Double Trigger, Single Trigger, and Intensity are just a few of the many different names and structures, that can be potentially an infinite number of thanks to the flexibility of the parametric insurance structure.

The most popular parametric insurance forms are the Cat-in-a-box or Cat-in-a-circle, which are similar: where a payout occurs if a catastrophe such as an extreme weather event, *the "Cat",* occurs in a given pre-agreed area, *the "Box*", which can take the form of a square, rectangle or circle. Essential is that the "Cat" must meet the minimum predefined intensity threshold and go through the "Box" to trigger the payout. This type of solution can be referred to also as a "double trigger" is it requires the catastrophe to occur in a predefined area (first trigger) and to be of a certain magnitude (second trigger). It means that the double trigger pays a claim when it is triggered by the occurrence of two events. Since the likelihood of both events occurring is less than the likelihood of only one of the events occurring, the dual trigger policy premiums are lower than traditional policies that insure only one of the risks. The double trigger solution is often purchased for providing coverage against a catastrophe since if both events occur, the combined impact would be devastating[82].

The cat-in-a-box concept is easy to understand because it pays out as a function of event triggering's intensity the circle, but its modelling is actually challenging because of basis risk. Recent developments in data analytics and data recording have developed the so called "2nd generation" parametric structures reducing this basis risk, such as intensity-based covers. They are solely based on the actual intensity (shaking intensity or windspeed) that occurs at specific locations defined by the insured resulting in a closer correlation with the potential economic impact. Since intensity-based solutions require a certain level of granularity of data available to be designed, they cannot be applicable for all perils and locations[83].

It is interesting to explain how an index construction works, with an example focusing on the "cat-in-a-box" index. The initial index is a "cat-in-a-box" index, that, in a designated geographical area, checks if a typhoon, for example, is within the area and outputs the maximal 2-minute observed average windspeed. Such index has the advantage so be simple, it may be enhanced as follows:

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[82] FASB, *FASB Embedded derivatives dual-trigger property and casualty insurance contracts*, by FASB Board, April 10, 2001, www.fasb.org

[83] Swiss Re – Corporate Solutions, *What is the most popular parametric solution*?, www.corporatesolutions.swissre.com

- **Make the index depend on insured values**

  The initial index is location independent as long as the measured typhoon is in the CAT circle. A first approach is to break down the coverage into N sub-regions (related to portfolio insured values) and use a locally weighted index:

$$\mathbf{I(t)} = \sum_{\mathbf{i=1}}^{\mathbf{N}} \mathbf{w_i} \, \mathbf{max}\{\mathbf{0}, \mathbf{v_i(t)} - \mathbf{t_i}\}^{\boldsymbol{\alpha}_\mathbf{i}}$$

  where:

- $\mathbf{v_i}$ is the observed windspeed at location $\mathbf{i} \in [\mathbf{1}, \mathbf{N}]$
- $\mathbf{w_i}$ is the weight of location **i** proportional to the sum of insured values of region **i**
- $\mathbf{t_i}$ is the corresponding threshold
- $\boldsymbol{\alpha}_\mathbf{i}$ is an exponent representing the relation between the windspeed and the damage to the insured values.

The index is tailored for the policyholder, even if the damage exponents $\boldsymbol{\alpha}_\mathbf{i}$ need to be calibrated by fitting a power function for each of the locations $\mathbf{i} \in [\mathbf{1}, \mathbf{N}]$. A power model has the advantage of being simple model, but it can be an unprecise approximation on tail events and can therefore still allow for significant basis risk. To reduce this issue, a more general approach to index modelling can be taken by performing a regression analysis, which in a formal way corresponds to a set of optimal $\mathbf{w_i}$ and $\mathbf{f_i}$ such that:

$$\mathbf{I(t)} \approx \sum_{\mathbf{i=1}}^{\mathbf{N}} \mathbf{w_i} \mathbf{f_i}(\mathbf{v_i})$$

where:

- $\mathbf{w_i}$ is a weighting coefficient
- $\mathbf{f_i} : \mathbb{R} \longrightarrow \mathbb{R}$ is a real-valued function.

On one hand a simpler model is more robust and better understood, but obviously it is less precise, on the other hand a more complex model might have better predictive power, but the model becomes increasingly opaque ("black-box" effect) and runs the risk of overfitting. This is a traditional data science problem: checking modelling assumptions, overfitting, data bias, and so on.

The advantage of creating a tailored index to a specific case with respect to an industry standard one is full transparency and precision in terms of the location and amount of insured assets.

- **Payout design**

  The payout function translates the index into a nominal monetary amount with two features: a condition to trigger the payout based on an index threshold, and the type of payout:

  - A well-chosen threshold is selected to meet a concrete need and is usually proposed directly by the company looking for the cover. The threshold can be calculated by transforming the index EP Curve into a loss EP Curve in case to have further optimization.
  - Additional trigger conditions are added to reduce basis risk and they could be an alternative index or an indemnity-related requirement, such as the observation of the actual losses. They can have two distinct effects:
    - an "and" additional trigger would provide the (re)insurer with additional protection against basis risk and it is against Type I basis risk;
    - an "or" additional trigger gives the cover a second possibility to produce a payout and potentially reduces basis risk for the insured corresponding to the protection against Type II basis risk[84].

A practical example of the payout structure is the following: a luxury hotel situated on an island wants to protect itself against losses arising from a potential Category 3 or stronger cyclone within a 50km radius from its property. Here the cat-in-box takes the shape of a circle. The policy is structured to pay out 25%, 50% or 100% of a predefined limit of USD %M for a category 3,4, or 5 Cyclone respectively, happening in a 50 km radius around the point of interest. The settlement will be determined by the highest wind speed of the track points within the circle, as explained in the following **Table 16**:

[84] SCOR, *Introduction to parametric solutions*, Technical Newsletter #48, July 2019, www.scor.com

Table 16: The payout structure of cat-in-a-circle

Intensity Category	Wind Speed	% of Event Limit	Payout (USD)
1 Tropical Cyclone	63-88 km/h	0%	USD 0
2 Tropical Cyclone	89-117 km/h	0%	USD 0
3 Tropical Cyclone	118-159 km/h	25%	USD 1.25M
4 Tropical Cyclone	160-199 km/h	50%	USD 2.5M
5 Tropical Cyclone	>200 km/h	100%	USD 5.0M

Source: Swiss Re, *What is the most popular parametric solution?*

4.3 Actuaries Climate Index and European Extreme Events Climate Index: "climate at a glance" indicator

The Actuaries Climate Index (ACI) and the European Extreme Events Climate Index (E^3CI) have been developed to allows an assessment of economic and insurance losses linked to the extreme climate events and their serious effects. The results provided are useful for the world of insurance to the public sector and scientific research for adjusting insurance premium rates, improving portfolio and risk management, developing new financial instruments and new (re)insurance products. Finally, the index is able to provide helpful data monitoring climate trends, increasing awareness among public opinion regarding this crucial topic and facilitating the decision-making process of public administrations, committed to building a sustainable development system.

4.3.1 Actuaries Climate Index – development and design

The Actuaries Climate Index (ACI) has been developed together among four North American actuarial organizations: the Canadian Institute of actuaries, the Society of Actuaries, the Casualty Actuarial Society, and the American Academy of Actuaries with climate expertise and research provided by Solterra Solutions.

The index follows changes in a variety of climate-related variables over time: it is retrospective without providing projections about future events because it is based on actual historical data. Then, it is updated quarterly, and has been designed to be statistically robust and easy to understand. The plan is to publish a seasonal Index, as well as monthly indices, each quarter by

reporting on the most available metrological season (three months ending February, May, August, and November) compared to the reference period.
The ACI is composed of six components representative of the key impacts of climate on people and economy, each of which is monthly time series beginning in 1961 based on a wide network of meteorological stations and coastal tide stations within the United States and Canada. They are:

- **Drought** $MaxCDD_{std}(j,k)$ is the maximum consecutive dry days (< 1 mm) in year
- **Sea Level** $S_{std}(j,k)$
- **Precipitation** ${Max^{(5-day)}}_{std}(j,k)$ is the maximum five-day precipitation in month
- **Warm Temperatures** $FT{:}\,warm_{std}(j,k)$ is the frequency of temperatures above the 90th percentile
- **Cool Temperatures** $FT{:}\,cool_{std}(j,k)$ is the frequency of temperature below the 10th percentile
- **Wind Power** $FWP_{std}(j,k)$ is the frequency of strongest wind power

where "j" indicates the month and "k" indicates the year.

Components measures as priority extremes rather than averages because extremes have the largest impact on people and property due an increasing tendency in frequency and intensity of climate events. It is thus interesting to see how the shape of the probability distribution function (PDF) of a certain component changes over time looking at the behavior of mean quantities. In addition, the standardization of data is crucial over the 30-year reference period of 1961 to 1990, which was the earliest available 30-year period with good data, to combine figures of widely disparate phenomena in terms of their units of measurement and variability among locations on a compatible basis. For each component, the standardized anomaly is calculated as the difference between the current period and the reference period, and then scaled by the division of its reference period standard deviation: $\frac{(X-\mu)}{\sigma}$. Standard deviations from a centralized mean are used to count variations and the index is defined by the average of the standardized components of the ACI, where the key metric is a five-year moving average, and it was carefully chosen as the most efficient time period to reduce the noise of time series data and allows users to see a punctual climate signal.

The standardized anomalies are averaged when combined into the Actuarial Climate Index with attention to the fact that the cool temperature component $FT\colon cool_{std}(j,k)$ is subtracted in the index as evidence of the shift of the temperature probability distribution curve to the right:

$$\boldsymbol{ACI(j,k)} = \frac{MaxCDD_{std}(j,k) + S_{std}(j,k) + {Max^{(5-day)}}_{std}(j,k) + FT\colon warm_{std}(j,k) - FT\colon cool_{std}(j,k) + FWP_{std}(j,k)}{6}$$

The first component is the **drought** centered ear Barstow, West San Bernardino County in south central California and it is measured by the maximum number of consecutive dry days in each year k, $\boldsymbol{MaxCDD(k)}$, where a dry day is counted when precipitation is less than 1 millimeter. Monthly values are obtained for each month j, year k, by linear interpolation, where $\boldsymbol{MaxCDD(12,k)} = \boldsymbol{MaxCDD(k)}$. For other values of j:

$$\boldsymbol{MaxCDD(j,k)} = \frac{\boldsymbol{(12-j)}}{\boldsymbol{12}} \cdot \boldsymbol{MaxCDD(12,k-1)} + \frac{\boldsymbol{j}}{\boldsymbol{12}} \cdot \boldsymbol{MaxCDD(12,k)}$$

Anomalies are measured by the departure in a month's maximum consecutive dry days form the average across the monthly reference period values from 1961 to 1990.

$\mathbf{MaxCDD(j,k)}$ is the maximum number of consecutive dry days in each month j, year k, while the average for the reference period 1961-1990 is $\boldsymbol{\mu}_{\mathbf{ref}}\mathbf{MaxCDD(j)}$. The variation of $\Delta\boldsymbol{MaxCDD(j,k)}$ is given by the difference between $\boldsymbol{MaxCDD(j,k)}$ and the average for the reference period resulting in an average reference period anomaly of zero, where the calculation is:

$$\Delta\boldsymbol{MaxCDD(j,k)} = \mathbf{MaxCDD(j,k)} - \boldsymbol{\mu}_{\mathbf{ref}}\mathbf{MaxCDD(j)}$$

Then, if this formula is divided by the standard deviation for the reference period, $\boldsymbol{\sigma}_{\mathbf{ref}}\mathbf{MaxCDD}$:

$$\mathbf{MaxCDD_{std}(j,k)} = \frac{\left[\boldsymbol{MaxCDD(j,k) - \mu_{ref}MaxCDD(j)}\right]}{\boldsymbol{\sigma}_{\mathbf{ref}}\mathbf{MaxCDD}}$$

The second component is the **Sea Level** (S) measurements are available on a monthly average basis via only reliable tide gauges located at over 100 permanent coastal stations in Canada and the United States. The monthly averages are based on hourly readings throughout the month.

For every twelve distinct sea level reference means, $\boldsymbol{\mu_{ref}S}(\mathbf{j})$, and 12 standard deviations, $\boldsymbol{\sigma_{ref}S}(\mathbf{j})$, are calculated from the reference period value of $\boldsymbol{S(j)}$. The measurements dove with tide gauges include also the impact of land movement affecting the sea level rise. Seasonal changes in sea level occur with changes in water temperature and salinity, and vary with land movements, ocean currents, precipitation, evaporation, and the water's slow absorption and release of heat. For each $\mathbf{S}(\mathbf{j}, \mathbf{k})$ the sea level in moth j and year k, the anomaly $\Delta\boldsymbol{S(j, k)}$ is given by:

$$\Delta\boldsymbol{S(j,k)} = \boldsymbol{S(j,k)} - \boldsymbol{\mu_{ref}S}(\mathbf{j}) \quad \text{for months j = Jan, Feb, Mar,…, Dec.}$$

Then, sea level anomalies $\Delta\boldsymbol{S(j,k)}$ are then standardized by the equation:

$$\mathbf{S}_{\boldsymbol{ref}}(\mathbf{j}, \mathbf{k}) = \frac{[\boldsymbol{S(j,k)} - \boldsymbol{\mu_{ref}S}(\mathbf{j})\ ]}{\boldsymbol{\sigma_{ref}S}(\mathbf{j})} = \frac{\Delta\boldsymbol{S(j,k)}}{\boldsymbol{\sigma_{ref}S}(\mathbf{j})}$$

The third component focuses on extreme **Precipitation** rather than average by using the maximum 5-day precipitation time series from GHCNDEX, which is the National Center for Atmospheric Research/University Corporation for Atmospheric Research providing gridded, station-based indices of temperature and precipitation-related climate extremes.

It is evident how the probability distribution function (PDF) of precipitation is not normal, but is instead right skewed, while the left tail must always be anchored at zero. On one hand, the high values of the right tail of the precipitation PDF are represented by the maximum five-day precipitation in a given month (in units of mm precipitation) noted as $\mathbf{MaxP}^{(\mathbf{5-day})}$, on the other hand the left side is addressed through a complementary ACI component focusing on meteorological drought. Because of precipitation is measured by maximum values, the distribution is more skewed than sea level: some months are extreme outliers, far above the average five-day maximum.

The data is translated by an average of the five-day maximum over the 30-year reference period, creating a set of 12 means, for each a related monthly standard deviation over the same reference period to scale and standardize the distribution. Thus, for each month over the observation period, the anomalies are determined by comparing the current monthly value with the values for the reference period. The anomaly of $\mathbf{MaxP}^{(\mathbf{5-day})}$ relative to the reference period value for a given month is given by:

$$\mathbf{\Delta MaxP^{(5-day)}(j,k) = MaxP^{(5-day)}(j,k) - \boldsymbol{\mu}_{ref}MaxP^{(5-day)}(j)}$$

The deviations have been converted to ratios to standard deviations using the following formula to obtain the final ACI:

$$\mathbf{MaxP^{(5-day)}{}_{std}(j,k) = \frac{\left[MaxP^{(5-day)}(j,k) - \boldsymbol{\mu}_{ref}MaxP^{(5-day)}(j)\right]}{\boldsymbol{\sigma}_{ref}MaxP^{(5-day)}(j)} = \frac{\Delta MaxP^{(5-day)}(j,k)}{\boldsymbol{\sigma}_{ref}MaxP^{(5-day)}(j)}}$$

The fourth component is **warm temperatures** that is a fundamental indicator of climate risk. Its definition is not absolute but comparative because it is throughout the year: war temperature in summer can lead to extreme heat causing excess morbidity and mortality, or can point to a changing climate in spring, fall, and winter affecting agriculture, weather patterns and storms. Since the highest temperatures and minimums are not always during daytime and minimums during nighttime due to changes in cloud cover and frontal movements, the measurements are referred to by the daily "maximum" and "minimum" rather than by "daytime" and "nighttime". "Warm temperatures" are established by calendar day thresholds, which are set during the reference period by the top 10 percent of temperatures for the surrounding five calendar days. The thresholds are smoothed by moving five calendar days centered at each calendar day calculation, taken over 30 years, for a bias of 150 values, due to the fact that temperatures fluctuate seasonally and daily during the entire year. A Monte Carlo simulation underlines how the threshold temperatures calculated during the base period is affected by sampling error, which can be restored by applying the bootstrap resampling procedure to avoid possible inhomogeneity.
The standardized anomalies are then calculated as:

$$\mathbf{FT\!:warm(j,k) = \frac{[FT\!:warm_{max}(j,k) + FT\!:warm_{min}(j,k)]}{2}}$$

$$\mathbf{\boldsymbol{\sigma}_{ref}FT\!:warm(j) = \frac{\boldsymbol{\sigma}_{ref}[FT\!:warm_{max}(j)\ +\ \boldsymbol{\sigma}_{ref}FT\!:warm(j)]}{2}}$$

$$\mathbf{FT\!:warm_{std}(j,k) = \frac{[FT\!:warm(j,k) - \boldsymbol{\mu}_{ref}FT\!:warm(j)]}{\boldsymbol{\sigma}_{ref}FT\!:warm(j)}}$$

where

- $\mathbf{FT\!:warm_{max}(j)}$ represents the monthly frequency of warm daily maximum temperatures

- $\mathbf{FT:warm_{min}(j,k)}$ represents the monthly frequency of warm daily minimum temperatures
- $\boldsymbol{\mu}_{\mathbf{ref}}\mathbf{FT:warm(j)}$ is the average of the monthly frequencies for all months during the reference period that is 10 percent, for $\mathbf{j = Jan, Feb, \ldots Dec.}$

Subsequently, the fifth component is the frequency of **cooler temperatures**, as a decrease in the occurrence of cooler temperatures is indicative that the temperature distribution has shifted to the right and also of a warming climate, that's why $\mathbf{FT:cool(j,k)}$ is subtracted from the ACI.

The calculation methodology is the same as for warm temperatures with the difference that "cool temperatures" are defined as daily temperatures in the lowest 10 percent as measured for the particular calendar day across the reference period. Also this measurement is comparative because a cool temperature can happen not only in the winter months but also during the remaining part of the year.

The last component refers to Wind Power with a right skewed daily mean speed PDF, and the changes of most interest occur in the high-value tail of the distribution. Daily mean wind speed measurements are converted to wind power **WP**, using the relationship:

$$\mathbf{WP = \left(\frac{1}{2}\right) pw^3}$$

where **w** is the daily mean wind speed and **p** is the air density (taken constant at $\mathbf{1.23\ km/m^3}$). The wind power thresholds are determined for each day and month in the reference period, $\mathbf{WP_{ref}(i,j)}$, for each day **i** and month ***j*** (j = Jan, Feb, …, Dec), at each grid point separately.

The $\mathbf{WP_{ref}(i,j)}$ value is calculated as the mean plus 1.28 standard deviation of $\mathbf{WP(i,j,k)}$ for all 30 values of year ***k*** in the reference period. It is important to state that 1.28 standard deviations above the mean was chosen to isolate the top 10 percent wind speeds and related wind power. The count of days exceeding the mean winds $\boldsymbol{WP_{ref}(i,j)}$ is than stated as a percentage of the number of days in the month, providing an exceedance frequency measure for every month of every year for the full period. Because of sampling error, the frequency of the extreme wind during the reference period is 13 percent, which is not in line with the frequency of exceedance of the threshold during the reference period of the other ACI components, which is 10 percent.

The exceedance frequencies during the current period are compared with the reference period ones, and then standardized by dividing the standard deviation of the exceedance frequencies during the same reference period:

$$\mathbf{F\ WP_{std}(j,k)} = \frac{[\mathbf{F\ WP(j,k)} - \boldsymbol{\mu}_{\mathbf{ref}}(\mathbf{j})]}{\boldsymbol{\sigma}_{\mathbf{ref}}(\mathbf{j})}$$

Note that the frequencies are identical for wind speed and wind power. They are standardized by subtracting the mean and dividing by the standard deviation of the reference period. The initial frequency calculation is given by the mean:

$$\mathbf{F\ WP(j,k)} = \frac{\left[\sum_{\mathbf{i=1}}^{\mathbf{n(j)}}\left((\mathbf{WP(i,j,k)} - \mathbf{WP_{ref}(j)} > \mathbf{0}) * \mathbf{1}\right)\right]}{\mathbf{n(j)}}$$

where $\boldsymbol{i}$ represents the day, $\boldsymbol{j}$ the month, $\boldsymbol{k}$ the year, and $\boldsymbol{n(j)}$ the number of days in month $\boldsymbol{j}$.

$$\mathbf{F}\ \boldsymbol{WP}_{\mathbf{std}}(\boldsymbol{j},\mathbf{k}) = \frac{[\mathbf{F\ WP(j,k)} - \boldsymbol{\mu}_{\mathbf{ref}}(\mathbf{j})]}{\boldsymbol{\sigma}_{\boldsymbol{ref}}(\boldsymbol{j})}$$

Finally, the main aim for the creation of an Index for the United States and Canada should not be taken as an indication that changes in this region are representative of changes globally because movements of climates statistics vary significantly from place to place. The developers of the ACI are hopeful that the geographical scope of the Index can be replicated and used in other countries or regions for the same scope to obtain a global index on climate extremes[85].

4.3.2 European Extreme Events Climate Index – development and design

The European Extreme Events Climate Index (E^3CI) is a synthetic objective index that provides information on areas affected by different types of hazards induced by extreme weather events and their severity. It is the first project of the International Foundation Big Data and Artificial Intelligence for Human Development (iFAB) and it is also the result of a collaborative effort

[85] Actuaries Climate Index, *Sample calculations*, by the American Academy of Actuaries, the Canadian Institute of Actuaries, the Casualty Actuarial Society, the Society of Actuaries, 2018, www.actuariesclimateindex.org

between the Euro-Mediterranean Center on Climate Change ("Regional Models and geo-Hydrological Impacts" division) and Leithà, which is a Unipol Group company that develops technological solutions based on Big Data. "E^3CI is an excellent example of effective technology transfer and a great demonstration of intersectoral collaboration, a hallmark of iFAB's mission", stated Dr. Avesani, Chief Innovation Officer of Unipol and CEO of Leithà.

The E^3CI is similar to the North American Actuaries Climate Index (ACI), just described above, and addresses five main impacts:

- cold and heat stress
- drought
- heavy precipitation
- intense winds

These indicators are identified and calculated on a month basis to generate information on the onset and severity of climate-related risks. For each variable, the current period is compared to the reference period 1981-2010. A difference compared to the AIC is that the E^3CI working group has the will to include sea level rise among variables, as well as an indicator related to the risk of forest fires.

In addition, the index is able to provide relevant data for monitoring climate trends, increasing awareness among public opinion regarding this crucial topic and facilitating the decision-making process of Public Administrations, committed to building a sustainable development system. Precisely for this purpose, the data will be made available free of charge in two different formats:

- first through an online visual dashboard hosted on the iFAB website containing synthetic maps and graphs
- second to download raw data by areas or month for expert users.

Finally, as for the other ACI index, the applications fields are wide from the (re)insurance world to the public sector, and research field. It has been developed to allow an assessment of economic and insurance losses linked to the occurrence of extreme climate events and their serious effects. The data provides will be useful for adjusting premium rates, improving portfolio and risk management, developing new financial instruments and new (re)insurance products[86].

[86] iFAB, *E^3CI Climate Index - Approfondimenti*, by Centro Euro-Mediterraneo sui Cambiamenti Climatici, UnipolSai Assicurazioni, Leithà, Associazione BigData, www.ifabfoundation.org/e3ci

CHAPTER 5

WEATHER BASED CROP INSURANCE: A PRACTICAL CASE STUDY IN INDIA

Introduction

This chapter is the practical application of the previous theoretical section about parametric disaster coverage, and it contains a case study based on how a particular insurance index-based product, the weather-based crop insurance, works on a developing country, such as India, in protecting farmers against adverse weather conditions that can jeopardize agricultural production, specifically the winter wheat crop, and more in general the overall economy of a state. After having presented a general overview about agricultural risks and their related risk management, it has been given a particular focus on the general steps needed for structuring a Weather-Index Insurance product (WII). Then, it has been shown a brief introduction about the main Indian features related to climate, agricultural production, and its historical weather-based crop insurance market, since India is considered to have been a pioneer in this niche alternative insurance sector. The core part of this chapter will be the results obtained by applying three rainfall indexes (Total Annual Rainfall Index, Total Seasonal Rainfall Index, and the Weighted Annual Seasonal Rainfall Index) on the rainfall data and winter wheat crop production of India and of four single Indian States.

5.1 Introduction to Weather Index Insurance: overview on agricultural risks and risk management

Hundreds of millions of farmers in developed and developing countries around the world have to face risks and uncertainties within agriculture and agricultural supply chains: a range of factors including weather variability, the unpredictable nature of biological processes, the pronounced seasonality of production and market cycles, the geographical separation of production and end uses, and the unique and uncertain pollical economy of food and agriculture sectors, both domestic and international. However, the impacts of realized agricultural risks are not peculiar to farmers alone but to the wider supply chain, ultimately the consumer passing throughout industries that move the produce from farm to the markets. The following sub-paragraphs are going to present how agricultural and weather risks are managed nowadays by insurance markets and governments, in particular by developing countries that have agriculture as leading productive activity.

5.1.1 Weather risk management in agriculture

Managing risks in agriculture is particularly challenging, as many risks are highly correlated, resulting in whole communities being affected at the same time. Given this feature, financial recovery is difficult for different actors: fiscal implication of social safety net payments or the rebuilding of damaged infrastructure by governments can be serious; possible financial instability and insolvency for a sudden loss suffered by a large number of policyholders within an insurance company; selling assets at distressed prices for farming communities.

There are numerous and varied risks faced by farmers, and they are specific to the country, climate, and local agricultural production systems. In addition, farmers face several constraints that do not enable them to either improve or increase their production and revenues: limited access to finance, dislocation from markets, poor access to inputs, lack of advisory services and information, and poor infrastructure (irrigation or rural roads).

The impacts of a given weather event can cause different effects depending on the specific agricultural system, variable water balances, type of soil and crop, and availability of other risk management tool (such as irrigation). From a weather risk management point of view, there are two main types of risk to consider in order to evaluate the negative impacts of weather events according to crop type, variety and timing of occurrence:

1. sudden, unforeseen events (e.g., windstorms or heavy rain)
2. cumulative events that occur over an extended period (e.g., drought).

The main weather-related risks affecting agriculture are:

- Drought (rainfall deficit): crop varieties suffer from annual or multiannual deficiency that is a key risk to livestock;
- Excess rainfall and flood: they cause direct damage and indirect impacts linked to watershed management (such as drainage and irrigation on flood);
- High temperatures: they have impacts on evapotranspiration and related to drought making crop stage vulnerable to seasonality

- Low temperatures: frost (short-term low temperatures causing early and late season damages), freeze and growing degree days (lack of warmth during season);
- Wind: cyclonic severe events (such as hurricane or typhoon)
- Hail: it is localized but it may be severe[87].

5.1.2 Crop Insurance Products: a background

At the top of all, agriculture needs to reinvest itself to face more frequent and severe droughts, floods and soil erosion, while meeting carbon sustainability targets. The aim of the insurance industry is expected to provide ex-ante financial solutions to help the public and private sectors to rise to these challenges. Particularly, where available and affordable, agricultural insurance (crop or livestock) can provide great benefits to farm households:

- Insurance can be used to complement other risk management approaches, such as crop and labor diversification for small-moderate risks at informal household- and community level strategies.
- In case of a major weather stock, insurance can be designed to protect against revenue or consumption losses.
- Insurance enables farmers in accessing new opportunities by experiencing safer and possibly higher returns.

The aim of this analysis is to analyze crop insurance products that can broadly be classified into two main groups:

A. **Indemnity-based Insurance** can be divided into:

- Damage-based indemnity insurance (or peril crop insurance)

  The insurance claim is calculated by measuring soon after the damage occurs the percentage damage in the field, which is measured less a deductible expressed as a percentage and applied to a pre-agreed sum insured. The sum insured is based on production costs or on the expected revenue. When damage cannot be immediately measured after the loss, the assessment can be delayed later in the crop season. This coverage is best known for hail and other perils, such as frost and excessive rainfall.
- Yield-based Crop Insurance (or Multiple Peril Crop Insurance, MPCI)

[87] The World Bank, "Weather Index Insurance For Agriculture: Guidance for Development Practitioners", by Agriculture and rural development discussion paper 50, November 2011

An insured yield (tons/ha) is established as a percentage (between 50% and 70% on the farm) of the farmer's historical average yield. If the realized yield is less than the insured yield, an indemnity is paid equal to the difference between the actual yield and the insured yield, multiplied by a pre-agreed value. This coverage is typically used to protect against multiple perils when it is generally difficult to determine the exact cause of loss.

B. **Index-based Crop Insurance** can be of two types:

- Area Yield Index Insurance

  The indemnity is based on the realized average yield of an area such a country or district, not the actual yield of the insured party. The insured yield is established as a percentage of the average yield for the area. The indemnity is paid if the realized yield for the area is less than the insured yield regardless of the actual yield on a policyholder's farm. Historical area yield data are required.

- Weather Index Insurance (WII)

  The indemnity is based on realizations of a specific weather parameters measured over a prespecified period of time at a particular weather station. The index can be built to protect against either so high or so low realizations expected to cause crop losses. An indemnity is paid whenever the realized value of the index exceeds or / and is less a prespecified threshold (too much rainfall/too little rainfall). The indemnity is calculated based on a pre-agreed sum insured per unit of the index.

The analysis wants to focus on this last index-based crop insurance product, which will be analyzed in the following paragraphs[88].

5.1.3 General steps for structuring a Weather-Index Insurance product (WII)

The practical main steps required to structure and delivered WII product in a developing country are:

1. **Prefeasibility assessment**: assessing the risk and its suitability as product with eventual preconditions;
2. **Technical feasibility**: the collection and manipulation of data, construction of index, and design of the product;

[88] The World Bank, "Weather Index Insurance For Agriculture: Guidance for Development Practitioners", by Agriculture and rural development discussion paper 50, November 2011

3. **Field implementation**: the distribution and sale of the product to policyholders, management of the index, data flows, and establishment of sustainability.

Before presenting these steps, it is important to underline how it is unlikely to promote WII as a single solution, since there will not be a single vulnerability (crop variety and area) with a single problem (single weather risk).

Starting from the prefeasibility assessment, a crucial preliminary step would be to conduct a "simple" weather risk mapping exercise that can be done for the agricultural sector as a whole, at the regional level, or simply at specific locations. The key objective is to identify:

- weather risks (wind, temperature, rainfall, hail, and so on) that are indexable
- type of crops subject to those risks (oil seed crops, vegetables, trees,…)
- number and type of producers that grow those crops
- location of weather stations
- agro-climatic zones with irrigated zone indication
- altitude
- crop yield levels

The next step is to assess whether several necessary and sufficient preconditions to create a conducive environment for WII are available: for example, 30 years of weather data are preferred. These conditions are a mixed of qualitative and quantitative factors and their degrees of acceptability moves from highly insufficient, insufficient, substantial up to ideal. One of the main crucial conditions are **weather data** that should be sound, long, "cleaned" and internally consistent historical records needed for a proper actuarial yield. They usually come from a dense, secure, and high-quality weather station network that report daily records. In addition, also **agronomic data** are essential to assess crop vulnerability in order to design an index that will truly be representative of loss. **Crop data** should be available in relation to the specific variety being planted in the given area, in opposite to general data that is not representative of the crop development features of the actual farmers' crops. Detailed information linked to variety's crop cycle is required as an important input to the crop model that will be used for estimating the index. In this situation, it may be more practical to design a catastrophic product that provides for compensation without seeking to compensate for actual loss. Finally, **financial data** are essential to calculate the level of loss per farmer across the whole area to be covered by the index. There are three main types of potential loss that a WII product could cover: first, input costs are based on input usage and unit cost for those inputs; second, credit amount as input costs plus any additional financing required by any farmer; third, loss linked to lost production and a set value per unit of production.

The second step regards checking technical feasibility that means to create the index – the "black box" and the prototype insurance contract. It is highly recommended to have opinions from professional experts in agrometeorology and agricultural insurance so adjust the contract parameters to best reflect the desired protection. This stage requires the application of "art" and science to build a mathematical model used as a proxy for losses based on information obtained from farmers and experts. By collecting exposure, hazard and vulnerability assessment, the output of these analyses will be:

- the mathematical probability of an occurrence of a given weather risk
- the potential intensity of that weather risk
- the potential level of damages caused given the intensities assessed

Since there is no one single way to design an index, these pieces can be explicit or implicit into the process makes the index significantly variable. An appropriate index for a client will predict loss events and their magnitude with a sufficient level of accuracy: simple indexes such as the amount of total cumulative rainfall in a season can be appropriate or in other cases much more complicated indexes such as dynamic crop models are preferred. During the exposure assessment, in agriculture there is an additional need to understand how a crop behaves in response to changes in weather variables at different stages of plant development and in order to identify the critical periods for any given level of weather hazards. This kind of information helps experts to differentiate between timing of rainfall opposed to merely being based on accumulated rainfall leading a better differentiation in the model through weighting of rainfall. Other number of variables are crucial for the crop model: soil type, evapotranspiration rates, and temperature. Hazard assessment aims to construct the whole range of probabilities, based on historical weather data sets, for various intensities or magnitudes of weather events known also as return period. Then, the vulnerability phase is focus on the quantification of the immediate fiscal impact of the weather risk on farmers by defining the main contract parameters: insured amount, risk retention levels, and the triggers per phase for the insurance contract. Finally, according to the qualitative and quantitative outputs collected in each of the three assessments, the contract can be structured by defining:

- **Trigger payout levels**: differently from traditional contracts, it is necessary to agree an ex-ante payout scale to determine how much the contract will pay for each unit of weather variable;
- **Pricing of the contract premium:**

$$Premium = Expected\ Loss + Risk\ Margin + Administrative\ Costs$$

The expected loss is the average payout of the contract in any given season, while the risk margin is charged by the providers to compensate the payouts in excess in the event of extreme events. Both values are established according to historical weather data.

- **Ensuring that the payout level is sufficient**: the level of protection of the insured required must be carefully reviewed.

The third and final step is the launch of a new financial product into the market towards a specific targeted clients with limited financial knowledge[89].

5.2 CASE STUDY: WEATHER BASED CROP INSURANCE IN INDIA

5.2.1 Introduction to India: climate and agricultural features

India, located in South Asia, is the second largest country in the world in terms of agricultural output with about 180-million-hectare land, 60.5% of total land area, used for agriculture. Despite the steady decline in agriculture's contribution to the total GDP, farming remains the biggest industry in India playing a key role in the socio-economic development of the country contributing for about 14% of total GDP and giving work to more than 50% of the total workforce.

India covers a range of climatic regions starting from the tropical south that can be wet, dry or humid to the Himalayan north defined by temperature alpine mountain ranges. Since India is a federation, it counts 28 states that can be divided into four major meteorological subdivisions:

- East & Northeast India
- Northwest India
- Central India
- South Peninsula

[89] The World Bank, "Weather Index Insurance For Agriculture: Guidance for Development Practitioners", by Agriculture and rural development discussion paper 50, November 2011

Figure 15: India – States and Union Territories

Source: Wikipedia, *Federated States and Territories of India*

India experiences four different seasons, two of which are shaped by the effects of the monsoon:

- JF or Winter Season: January – February
- MAM or Pre-Monsoon Season: March – April – May
- JJAS or SW-Monsoon Season: June – July – August – September
- OND or Post-Monsoon Season: October – November – December

In addition, there are about 15 different agro-ecological zones, each differing in climate, soil type, fertility condition, cropping patterns and hydrology. Then, the Indian cropping season is classified into two main seasons based on the Monsoon:

(i) Kharif (July-October)

(ii) Rabi (October-March)

Rice, wheat, sugarcane, cotton, soybean and pulses are the major crops in India in terms of economic value of total production.

Only about 35% of total agricultural land in India is irrigated and two thirds of cultivate land is entirely dependent on rainfall. Therefore, the Indian agricultural production system is more vulnerable to damage from extreme climatic events, which causes increased water stress leading to inadequate water supplies for irrigation. Rises in average temperatures, changes in rainfall patterns, increasing frequency of extreme weather events, such as droughts and floods, and the shifting of agricultural seasons have been observed in different agro-ecological zone of India causing serious distress to the farming communities in different states in recent years[90].

5.2.2 The historical weather-based crop insurance market in India

India have been the birthplace of the idea of weather indexed insurance thanks to Chakravarti's proposal in 1920: selling across India the first rainfall indexed insurance. This detailed proposal has been never implemented by this developing country because of the increasing role of weather indexed insurance programs across the world. In 1999 the Government of India launched the National Agricultural Insurance Scheme (NAIS), the successor of the Comprehensive Crop Insurance Scheme (CCIS), which was mandatory for all farmers that borrow from financial institutions and was voluntary for non-borrowing farmers without loans. Because of issues in design of the product due to long delays in claims settlement and basis risk, a significant majority of India's farmers have remained uninsured. The combination of high vulnerability of farmer households and low penetration of NAIS has proved fertile ground for innovations in the provision of agricultural insurance resulting in the introduction of weather index insurance with a simple logic: claim payment to farmers is an explicit function of weather parameters such as rainfall, temperature and humidity as recorded at a local weather station. The first weather insurance product in India, and indeed in the developing world, was a rainfall insurance contract underwritten in 2003 by ICICI-Lombard General Insurance Company for groundnut and caster farmers of BASIX's water user associations in the Mahabubnagar district of Andhra Pradesh, supported by the World Bank. This kind of product was then sold also by other insurers, such as IFFCO-Tokyo and the public insurer Agriculture Insurance Company of India (AICI) leading on one hand to a high rate of growth in the number of farmers insured between 2003 and 2007, and on the other hand a very low renewal rate (only 28% of farmers in Andhra Pradesh purchased insurance for more than one year). One big change happened in 2007 with the launch of the Weather Based Crop Insurance Scheme (WBCIS), which was the pilot scheme weather indexed insurance of the Indian government: farmers had an additional option of choosing WBCIS as an alternative to NAIS. One key difference between WBCIS and NAIS is that under WBCIS private sector insurance companies can compete at district level where the state governments choose a single provider for each district. Private insurance

[90] CGIAR, "INDIA – South ASIA", www.ccafs.cgiar.org

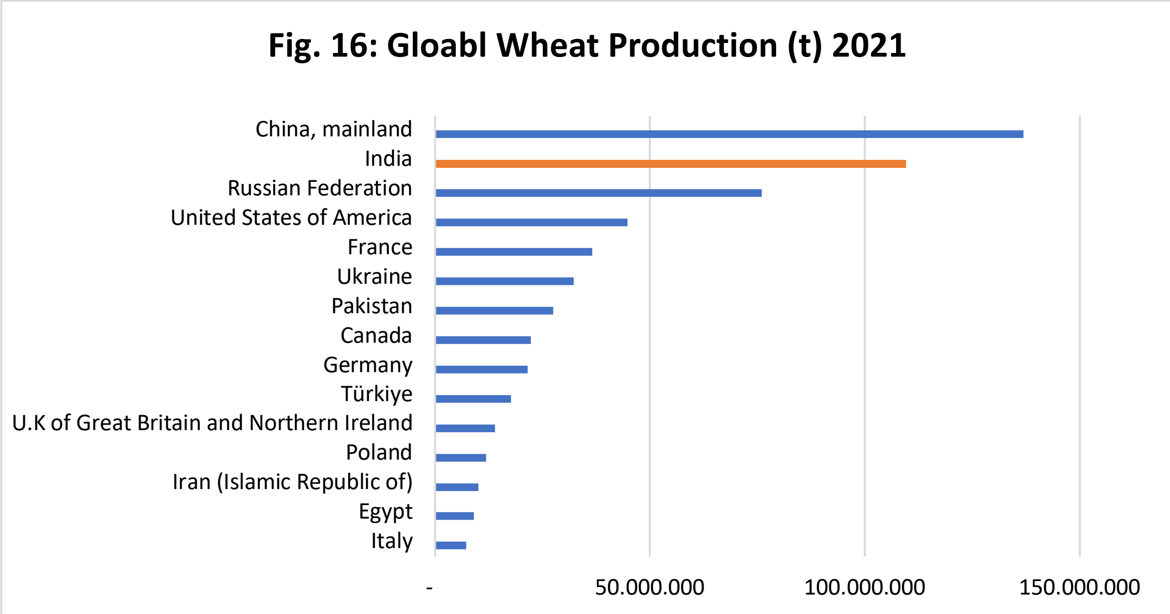
companies were allowed to offer voluntary coverages since 2007 and to borrowing farmers, for whom insurance products were compulsory. And by 2012, up to 12 million farmers growing 40 different crops over 15 million hectares were insured against weather-related losses. To achieve its full potential, the use of weather index-based insurance needs to reach a much higher proportion of insured farmers. Long-term benefits for farmers to become more resilient to climate change can be achieved by merging together insurance, climate-smart tolls and technologies for water management and soil conservation[91].

5.2.3 Introduction to the analysis - data and methodology

Today, rainfall variations account for more than 50% of the fluctuations in the Indian country's crop yields merged to the fact that the annual monsoon rainfall has become increasingly uncertain in onset, duration and intensity. Under these conditions, the purpose of the analysis is to replicate the functioning of a weather index insurance product (WII) based on a rainfall index aiming to protect Indian farmers' crop production against severe droughts or/and excess rainfall and the combination of the two events. The research has been conducted at macro level due to the impossibility of having reliable, robust, and detailed information about historical losses, sum insured, premiums on the insurer side and more high-level agricultural conditions at daily and geographical level for humidity, soil type, irrigation structure, and so on. Therefore, the main idea is to present on the insurer side how a WII works together with the importance of selecting proper parameters to minimize the basis risk, and on the farmer side how the WII protects the insured farmers against the adverse financial effects of crop failure.

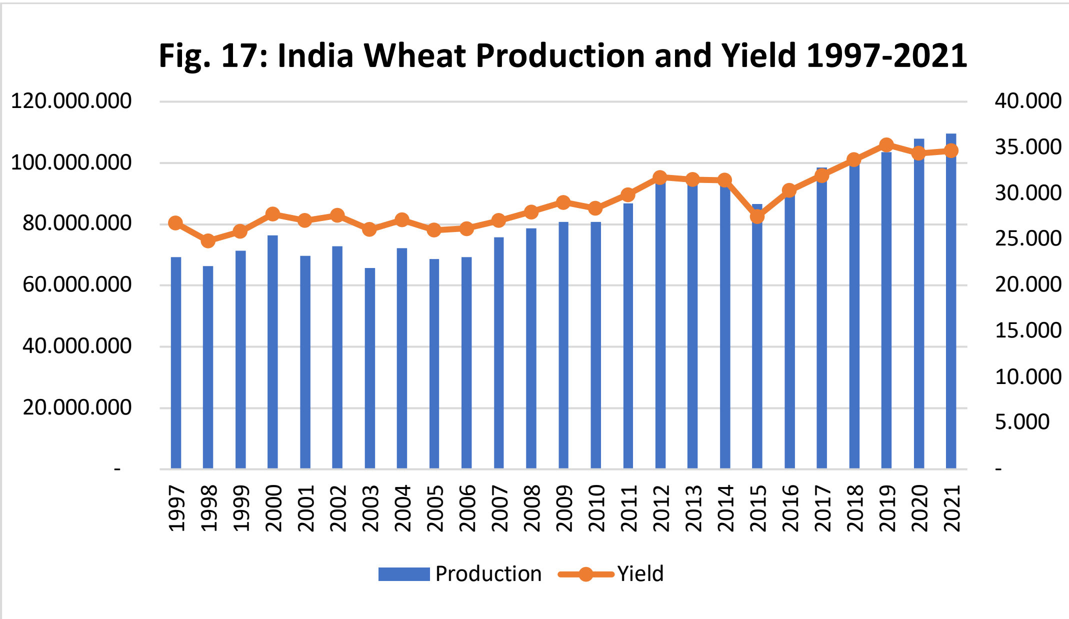
According to the Food and Agriculture Organization of the United Nations (FAO), India takes the second place with 109 millions of tons of wheat production in 2021 at worldwide level (see **Figure 16**) and it ranks ninth with 34.7 of wheat yield production measured in 100g/ha.

[91] The World Bank, *"Weather Index Insurance For Agriculture: Guidance for Development Practitioners"*, by Agriculture and rural development discussion paper 50, November 2011, www.worldbank.com



Source: www.fao.org

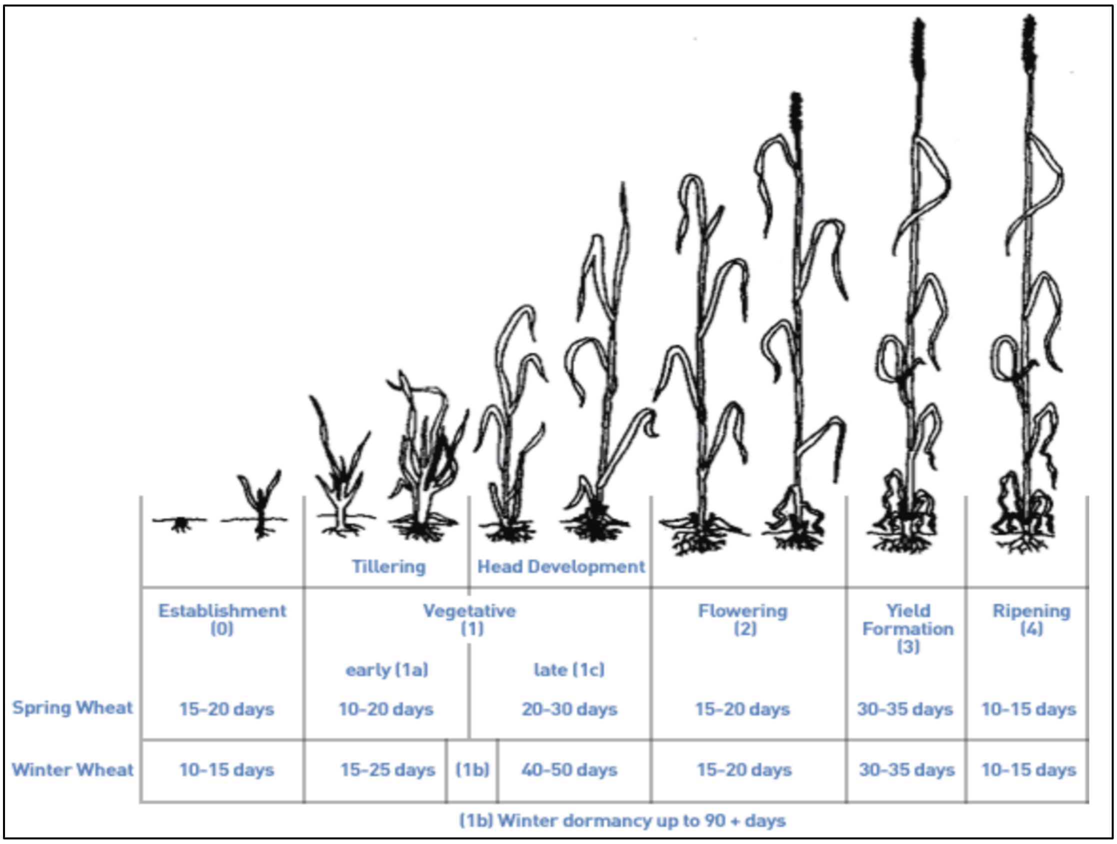
Then, the following **Figure 17** shows a combined representation of India wheat production in tons and yield focusing on the period 1997-2021:



Source: www.fao.org

To properly build a WII is crucial to understand the main features that characterize the wheat crop, for example the duration and period of wheat growth phases, the adequate level of rainfall needed, or the optimal temperature required. The crop is grown as a rainfed crop in the temperature climates with a length of the total growing period of winter wheat from about 180 to 250 days to mature. Daylength and temperature requirements are key factors, in particular, the winter wheat type requires a cold period or chilling (vernalization) during early growth for normal heading under long days. Winter wheat in its early stages of development exhibits a strong resistance to frost, down to -20°C, but then it loses its advantage in the active growth period during spring and head-flowering development periods due to spring frost. The minimum daily temperature for measurable growth is about 5°C, while the mean daily temperature for optimum growth and tillering is between 15°C and 20°C, even if a dry and warm ripening period of 18°C is preferred to select the delicate sowing date. The following **Figure 18** shows the growth periods of winter and spring wheat (Large, 1954), even if the focus will be done only on winter wheat:

Figure 18: Winter and spring wheat growth periods



Source: www.fao.org

The Rabi Season for winter wheat is generally divided into the sowing period 15th November - 15th December and harvesting period 15th March - 15th May. Given the fact that for obtaining high yields water requirements (ETm) is required to have 450 to 650 mm depending on climate and length of growing period, this condition indicates that the sensitivity to water deficit is differentiated according to the different growth stages. Little effect on crop development or hasten maturation can be in the vegetative period (1), while the most sensitive phase to water deficit is the flowering period (2): pollen formation and fertilization can be seriously affected under heavy water stress. During the time of head development and flowering, water shortage will reduce the number of heads per plant, head length and number of grains per head. Also, the flowering root growth may be very much reduced. In addition, the loss in the yield due to water deficits during the flowering period (2) cannot be recovered by providing adequate water supply during the later growth periods. During the yield formation period (3), water deficit will result in reduced grain weight, also combined with hot, dry and strong wind. A drying-off phase in the ripening period (4) is often induced by discontinuing irrigations that cause a slight effect on yield. The next **Table 17** presents an example of timeline period to determine the several wheat growth periods assuming to start from 15th November and to take the maximum number of days at each stage, underling the flowering period (2) in red to emphasize the fact that is the most sensitive period to water deficit/excess[92]:

Table 17: Example of timeline for winter wheat growth

Establishment (0)	**Vegetative (1) 1**	**Vegetative (1) 2**	**Flowering (2)**	**Yield Formation (3)**	**Ripening (4)**
30th November	25th December	13rd February	28th February	4th April	19th April

One of the main datasets used in the analysis is the "APY – Crop Production Statistics – India"[93] that contains comprehensive information on agricultural production statistics in India for crop production, yield and area cultivated, categorized by state and district for the major crop seasons on annual basis. The source comes from the Indian government's Area Production Statistics

[92] FAO, "Land & Water – Crop Information - Wheat", www.fao.org
[93] from www.kaggle.com - link: https://www.kaggle.com/datasets/nikhilmahajan29/crop-production-statistics-india

(APS) database maintained by the Ministry of Agriculture and Farmers Welfare. According to the accumulated volume production in tons of wheat, four main states for each macro geographical divisions are selected:

1. **Uttar Pradesh** in North West India
2. **Madhya Pradesh** in Central India
3. **Karnataka** in South Peninsola
4. **Bihar** in East & North east

Then, production and area values for each state are considered as the sum of the corresponding districts present in each state in order to obtain the relative yield production as:

$$Yield = \frac{Production}{Area}$$

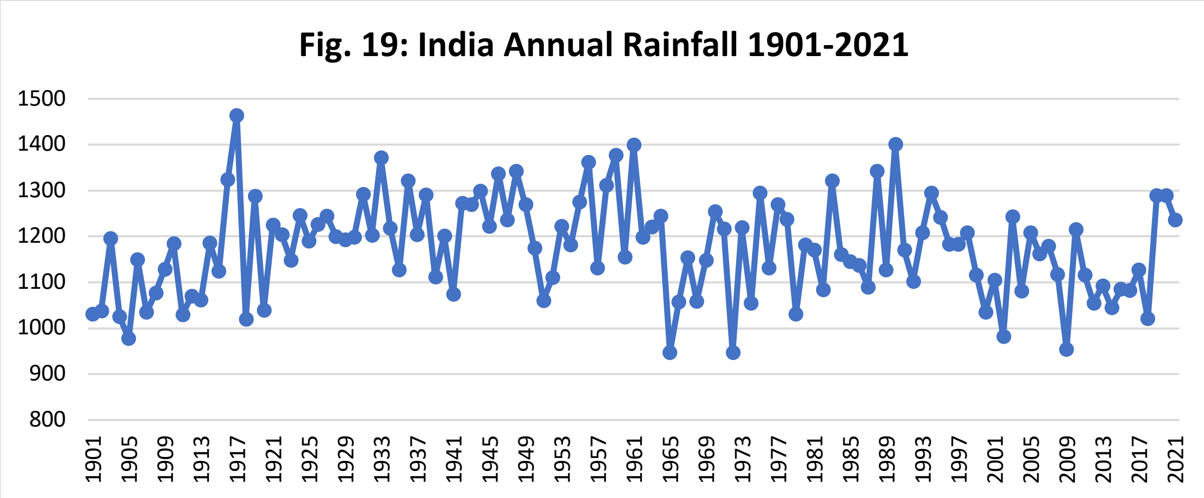
The total period considered for the research goes from 1997 to 2019, even if these years are split into two sub-periods:

1. from 1997 to 2010 are used to calculate the **Average Yield** and the **Average Production**;
2. from 2011 to 2019 contribute to evaluate the payout.

The subsequent **Table 18** summarizes the results for average yield, the relative sigma and Coefficient of Variation (CV) and the average production in tons:

Table 18: Reference Period: 1997-2010				
	Bihar	**Karnataka**	**Madhya Pradesh**	**Uttar Pradesh**
Avg. Yield	2.00	0.82	1.73	2.73
Sigma	0.26	0.20	0.16	0.18
CV	0.13	0.24	0.09	0.07
Avg. Production	4,202,208	259,503	7,180,155	25,521,959

Bihar and Uttar Pradesh have the highest average yield, even though they have very different average production dimension. Karnataka is the state with the tallest value in variability. The analysis presented in the following paragraph will give an insight on how WII works in these four states with different variability, average yield and production and geographical location. The diverse geographical positions heavily affect the wheat production, and it is important to analyze the historical rainfall behavior. The most relevant source for this kind of information is the India Meteorological Department (IMD) with its dataset named "All India Are Weighted Monthly, Seasonal and Rainfall (in mm)" from 1901 onwards for the whole country[94].



Source: www.data.gov.in

The average rainfall in mm is about 1.175 with a minimum of 947 in 1965 and with a maximum of 1.463 in 1917. However, the analysis will focus on the period 2011-2019 in order to match with the average wheat production values. The rainfall performance will be tabulated in terms of its departures from its normal or Long Period Average (LPA), which is the rainfall recorded over a particular region for a given internal (annual or season or month) average over a long period like 30-50 years. The normal rainfall used in this research is based on the rainfall records for the period 1961-2010. Considering the mean "m" and the standard deviation "d" of a long time series of the climate variable rainfall, it is assumed that the time series is normally distributed with 68% of the observations falling within +/- standard deviation from the mean. The LPA is calculated for the whole country of India on annual and seasonal basis and the other statistical values are summarized in the following **Table 19**:

[94] from www.data.gov.in - link: https://data.gov.in/catalog/all-india-area-weighted-monthly-seasonal-and-annual-rainfall-mm updated on 13/02/2014

Table 19: INDIA ANNUAL RAINFALL - Reference Period: 1997-2010					
	India	**JF**	**MAM**	**JJAS**	**OND**
Max	1,401 in 1990	69 in 2005	210 in 1990	1,052 in 1961	167 in 1977
Min	947 in 1972	16 in 2001	95 in 2009	674 in 1972	66 in 2000
Average (LPA)	1,164	39	129	873	121
Sigma	103	11	20	87	26
CV	0.089	0.293	0.161	0.100	0.220
m-d	1,060	28	108	785	94
m+d	1,268	51	150	961	148
Skewness	-0.04	0.30	1.37	-0.24	-0.05

This figure gives an indication on the concentration of rainfall in a specific season with respect the annual accumulated rainfall value and also regarding the normal distribution assumptions used in the analysis and confirmed but the negative / positive asymmetries present.

The WII will be built tailored to the historical crop production value and rainfall related to each of the four states presented above, hence another more detailed rainfall information at single state is needed and it is named "Sub Divisional Monthly Rainfall from 1901 to 2017"[95]. Some adjustments have been required to add missing values for the years 2918, 2019, 2020 and 2021 from the document "Rainfall Statistics of India" annually produced by the Indian Meteorological Department[96]. Both dataset use rainfall data received from a network of more than 5.100 rain-gauge stations which are under District wise rainfall Monitoring Scheme (DRMS) on near real time basis giving values on annual and seasonal basis. The following simplifications have been introduced to reconcile the rainfall dataset and the rainfall statistics terminology:

- N.I. Karnataka corresponds to Karnataka
- S.I. Karnataka corresponds to S. Interior Karnataka
- Marathwada corresponds to Matathwada
- Odisha corresponds to Odissa
- NMMT corresponds to Naga Mani Mizo Tripura
- SHWB & SKIKKIM corresponds to Sub Himalayan West Bengal & Sikkim
- HAR. CHD & DELHI corresponds to Haryana Delhi & Chandigarh
- J & K LADAKH corresponds to Jammu & Hashmir
- A & N ISLAND corresponds to Andaman & Nicobar Islands

[95] from www.data.gov.in – link: https://data.gov.in/resource/sub-divisional-monthly-rainfall-1901-2017 updated on 12/12/2021

[96]from www.hydro.imd.gov.in – link: https://hydro.imd.gov.in/hydrometweb/(S(cjsu5xz0222f5siejk3ejc45))/landing.aspx

- TAMIL., PUDU & KARAIKAL corresponds to Tamil Nadu
- EAST U.P. corresponds to East Uttar Pradesh
- WEST U.P. corresponds to West Uttar Pradesh
- COASTAL A. P. & YANAM corresponds to Coastal Andhra Pradesh
- KERALA & MAHE corresponds to Kerala
- some NAs present have been replaced with 0

The main steps of the analysis are:

a. calculating the LPA for each of the four selected states on annual and seasonal basis according to their specific rainfall history;
b. assuming the normal distribution of rainfall time series;
c. calculating the different categories of rainfall according to the ratio $\frac{Observed\ Rainfall\ Value}{LPA} - 1$ that creates the following classification presented in the **Table 20**:

Table 20: Rainfall categories depending on departure from Normal

Category	**Departure from Normal**	**Color Code**
Large Excess (LE)	60% or more	
Excess (E)	20 % to 59%	
Normal (N)	-19% to +19%	
Deficient (D)	-20% to -59%	
Large Deficient (LD)	-60% to -99%	
No Rain	-100%	

Source: www.hydro.imd.gov.in

This table will play a crucial role in determining the index and the consecutive payout. Until now, the data related to the wheat production are in amount (t) but the payout of the contract may be on monetary basis. It has been thought to calculate the average annual value from 2011 to 2019 based on a new dataset that returns the wheat monthly price based on Euro per metric tons[97]. Then, another average (the Average Annual Price 2011-2019) has to be calculated as the average summary value of all the single 2011-2019 annual averages previously obtained (see **Table 21)**.

[97] from www.indexmundi. com - Link: https://www.indexmundi.com/commodities/?commodity=wheat&months=12&currency=inr

Table 21: Wheat Monthly Price – Euro per Metric Ton	
Year	**Avg. Annual Price based on monthly values**
2011	227
2012	244
2013	235
2014	214
2015	184
2016	150
2017	154
2018	178
2019	180
Avg. Annual Price 2011-2019	196

Subsequently, The Average Annual Price 2011-2019 is multiplied by the Average Production 1997-2010 related to the four selected states in order to evaluate the Average Production value in € 2011-2019, which will be used to count the unit of production (€) paid by the WII and to be more consistent in the evaluation (see **Table 22**):

Table 22: Avg. Production Value in € - Reference Period: 2011-2019				
	Bihar	**Karnataka**	**Madhya Pradesh**	**Uttar Pradesh**
Avg. Annual Price € 2011-2019	196	196	196	196
Avg. Prod. 1997-2010	4,202,208	259,503	7,180,155	25,521,959
Avg. Prod. Value in € 2011-2019	825,430,670	50,973,622	1,410,382,556	5,013,223,970

Since most of the practical experiences with the development of WII have been with deficit and excess rainfall and have relied on data collection with terrestrial-based monitoring systems (weather stations), the following analysis will present the results obtained using the datasets and the methodology presented above.

5.2.4 The application of Total rainfall index vs Weighted rainfall index both on annual and seasonal basis – main results

The case study will focus on the creation of a hypothetical weather-based crop insurance product focused on the protection of four major Indian states (Bihar, Karnataka, Madhya Pradesh, Uttar Pradesh as previously anticipated) against rainfall negative effects. These four states have been selected by taking the state with the highest wheat production in one of the four geographical Indian divisions during the period 2011-2019.

Firstly, it has been interesting to investigate the presence of some correlation between the wheat production level and the rainfall fallen. The following **Table 23** and **24** show the data for production (tons), area (hectares) and yield (tons/hectares) used in the research for each of the selected states:

Table 23: Production, area and yield for Bihar and Karnataka

Year	Bihar			Karnataka		
	Production	Area	Yield	Production	Area	Yield
2011	6,530,955	2,141,892	3.05	200,932	225,472	0.89
2012	6,174,260	2,207,704	2.80	178,871	225,274	0.79
2013	6,134,679	2,148,818	2.85	210,041	209,079	1.00
2014	3,570,211	2,154,423	1.66	260,093	197,615	1.32
2015	4,736,448	2,110,750	2.24	128,988	173,856	0.74
2016	5,985,841	2,105,811	2.84	171,429	168,242	1.02
2017	6,104,303	2,101,311	2.90	219,087	193,338	1.13
2018	6,465,905	2,156,652	3.00	163,113	157,525	1.04
2019	5,579,348	2,150,180	2.59	180,114	158,319	1.14

Table 24: Production, area and yield Madhya and Uttar Pradesh

Year	Madhya Pradesh			Uttar Pradesh		
	Production	Area	Yield	Production	Area	Yield
2011	14,537,038	5,248,479	2.77	31,892,480	9,731,150	3.28
2012	16,510,524	5,601,025	2.95	31,332,434	9,733,617	3.22
2013	15,722,722	6,123,044	2.57	31,492,656	9,839,197	3.20
2014	18,463,000	5,999,000	3.08	20,054,791	9,846,466	2.04
2015	18,408,000	5,914,000	3.11	26,874,361	9,644,838	2.79
2016	21,916,000	6,423,000	3.41	34,971,381	9,884,913	3.54
2017	20,019,950	5,802,980	3.45	35,645,666	9,752,941	3.65
2018	25,276,038	7,721,549	3.27	38,039,724	9,855,900	3.86
2019	37,507,219	10,216,517	3.67	36,209,665	9,852,504	3.68

Madhya Pradesh and Uttar Pradesh are confirmed to be the states with the highest production level both in terms of tons and using the yield. As anticipated in the previous paragraph, the yield of production is calculated as the ratio between production and area values. Since the interest is to investigate the relationship between production and climate variables, it may be necessary the normalization of the terms in order to obtain comparable values between yield production and rainfall on the same scale. The normalization is achieved by taking the value of the Average Yield 1997-2010 from the **Table 18** and using the following formula to obtain the Normalized Yield Index (NYI):

$$NYI = \frac{(Actual\ Yield - Avg.Yield) * 100}{Avg.Yield}$$

Then, the same concept is applied to rainfall data. The subsequent **Table 25** presents the confrontation between India values (already appeared in the **Table 19**) with respect the other four Indian states by comparing the maximum and minimum values, the Long Period Average (LPA), sigma, coefficient of variation, m+/-d and the skewness on annual basis:

Table 25: ANNUAL RAINFALL - Reference Period: 1997-2010

	India	Bihar	Karnataka	Madhya Pradesh	Uttar Pradesh
Max	1,401 in 1990	1,660 in 1987	1,095 in 1997	3,032 in 1961	2,473 in 1971
Min	947 in 1972	629 in 2010	473 in 2010	874 in 2000	938 in 1997
Average (LPA)	1,164	1,167	737	2,051	1,750
Sigma	103	207	133	388	363
CV	0.089	0.178	0.181	0.189	0.208
m-d	1,060	960	603	1,663	1,386
m+d	1,268	1,375	870	2,439	2,113
Skewness	-0.04	-0.29	0.47	-0.18	0.07

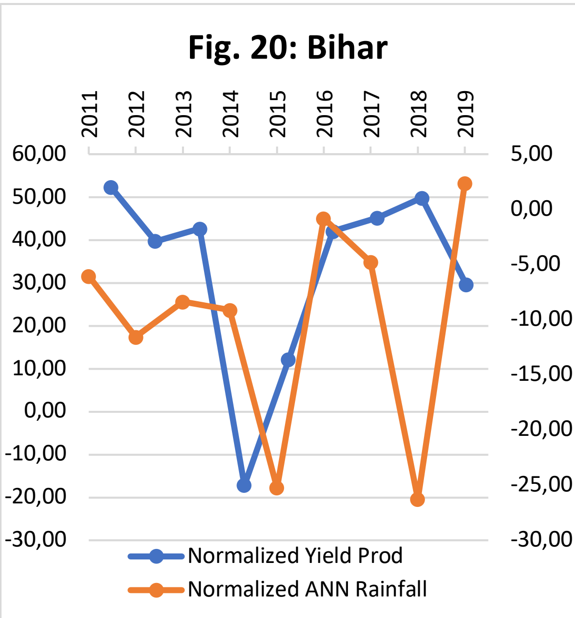
The same calculations were conducted also on annual basis but for the four different Indian seasons (JF, MAM, JJAS, OND) and they are visible in the **Appendix 1** (Table, 26, 27, 28, 29). It is evident how only Karnataka LPA is about half India LPA and together with Uttar Pradesh have a positive asymmetric distribution with respect India and the other two states. The other normalization term is the Normalized Rainfall Index (NRI) for each state is calculated by taking the corresponding LPA from **Table 25** and according to the following formula:

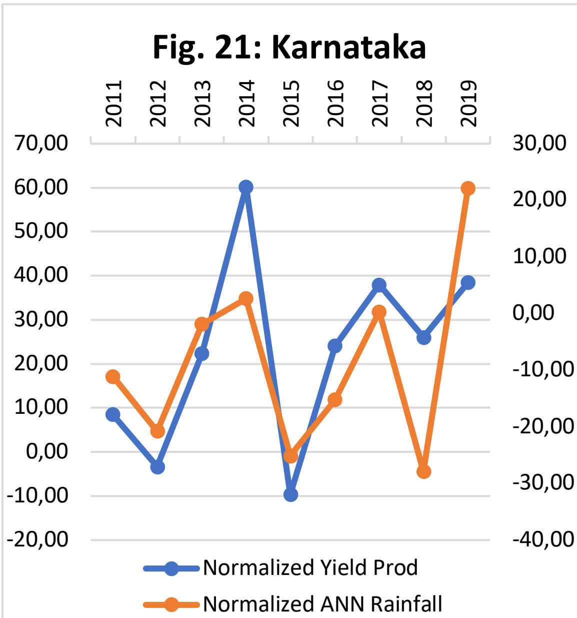
$$NRI = \frac{(Actual\ Rainfall - LPA) * 100}{LPA}$$

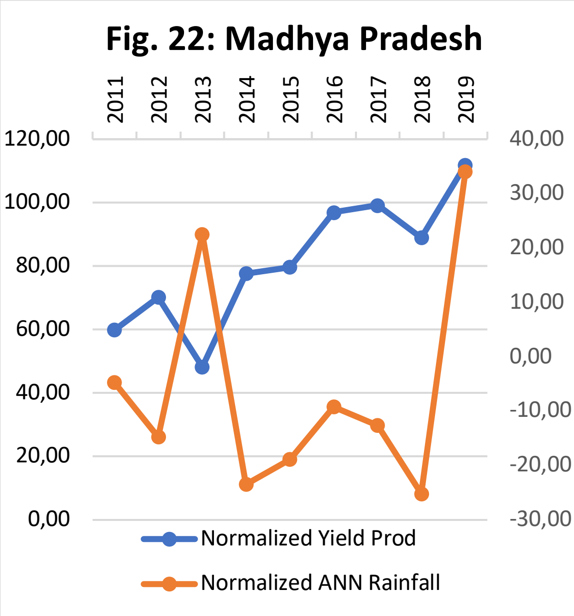
The actual rainfall values will be observable from the following Tables in this paragraph or in the Appendix. As soon as NYI and NRI are calculated, they are compared, and the results are visible from the **Table 30** and from **Figure 20, 21, 22 and 23**:

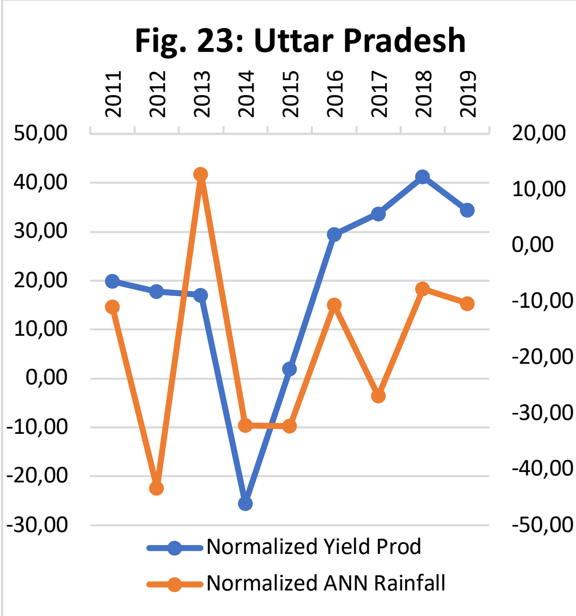
Table 30: Normalized Yield Index (NYI) and Normalized Rainfall Index (NRI)

	Bihar		Karnataka		Madhya Pradesh		Uttar Pradesh	
Year	**NYI**	**NRI**	**NYI**	**NRI**	**NYI**	**NRI**	**NYI**	**NRI**
2011	52	-6	8	-11	59	-4	19	-10
2012	39	-11	-3	-20	70	-14	17	-43
2013	42	-8	22	-1	48	22	17	12
2014	-17	-9	60	2	77	-23	-25	-32
2015	12	-25	-9	-25	79	-18	1	-32
2016	42	-0,83	24	-15	96	-9	29	-10
2017	45	-4	37	0,34	99	-12	33	-26
2018	49	-26	26	-27	88	-25	41	-7
2019	29	2	38	22	111	34	34	-10









Graphically, it can be said that there is a sort of immediate or delayed effects on crop due to excess or deficit rainfall: it seems that the best relation can be visible inside Karnataka state. This analysis is made at macro level to have a prompt and quick view. However, the correlation can be further investigated with statistical software in order to capture the statical significance of the regressor NRI variable onto the response variable NYI in a linear regression model. To gain a statical significant model, it is suggested to consider a wider time series period higher than nine years.

Now, it is time to think about the construction of the index that will characterize the weather index insurance product. This research will use a weather index linked to cumulative rainfall measured in mm fallen in each of the four specific Indian states presented above. For each of the selected states, three indexes will be proposed and each of them is characterized by three triggering events:

- 1° triggering event: Excess and Deficit cumulative rainfall includes the case in which the actual rainfall has a departure from the normal classified both under LE, E, D, LD, No rain as reported in **Table 21**;
- 2° triggering event: Only Excess cumulative rainfall includes the case in which the actual rainfall has a departure from the normal classified only under LE and E;
- 3° triggering event: Only Deficit cumulative rainfall includes the case in which the actual rainfall has a departure from the normal classified only under D, LD and No rain.

1. The **Total Annual Rainfall Index** considers rainfall values on annual basis without differentiation according to seasonal periods, which will indeed considered in the following index;
2. The **Total Seasonal Rainfall Index** considers rainfall values on annual basis and differentiated into the four Indian seasons of JF, MAM, JJAS and OND;
3. The **Weighted Annual Seasonal Rainfall Index** considers the Total Seasonal Rainfall Index but ratio $\frac{Observed\ Rainfall\ Value}{LPA} - 1$ is then weighted according to the different contribution that a specific season has to the wheat growth. Following the winter wheat timeline growth, the JF results to be the most important period for the flowering phase followed by MAM for the harvest and OND for the sowing. The chosen weights are the following:
   - 45% for JF
   - 25% for MAM
   - 5% for JJAS
   - 25% for OND

   These weights will change the rainfall classification and so the consequent payout structure.

Then, the payout function should be chosen to translate the index into a nominal monetary amount. Here, the payout will pay a pre-agreed percentage of the Average Production Value in € for each year from 2011 to 2019, supposed to be the sum insured of the policyholder. The percentages of the payout function are classified into two classes:

- **Case A** called "Soft" meaning that higher percentages (25%) on the average production value are applied in case that the $\frac{Observed\ Rainfall\ Value}{LPA} - 1$ falls into Deficit and Excess cases, which are the less extreme events with respect the normal scenario;
- **Case B** called "Hard" meaning that lower percentages (10%) on the average production value are applied in case that the $\frac{Observed\ Rainfall\ Value}{LPA} - 1$ falls into Deficit and Excess cases, which are the less extreme events with respect the normal scenario.

The percentage values are summarized in the following **Table 31**:

Table 31: PAYOUT STRUCTURE		
	CASE A - SOFT	**CASE B - HARD**
LE	75%	75%
E	**25%**	**10%**
N	0%	0%
D	**25%**	**10%**
LD	75%	75%
NO RAIN	100%	100%

The following formulas allow to sum up the three indexes with the different triggering event:

$$\textbf{Total Annual Rainfall Index} =$$

$$Payout\ \%_i \sum_{t\epsilon\{year\}} \alpha < \left(\frac{Obs. Rainfall\ Value}{LPA} - 1\right) < \beta$$

$$\textbf{Total Seasonal Rainfall Index} =$$

$$Payout\ \%_i \sum_{\substack{t\epsilon\{year \\ for\ each \\ season\}}} \alpha < \left(\frac{Obs. Rainfall\ Value}{LPA} - 1\right) < \beta$$

$$\textbf{Weighted Annual Seasonal Rainfall Index} =$$

$$Payout\ \%_i \sum_{\substack{t\epsilon\{year \\ for\ each \\ season\}}} \alpha < \left(\frac{Obs. Rainfall\ Value}{LPA} - 1 * \omega_j\right) < \beta$$

with:

- i corresponds to Case A or Case B of the payout percentages;
- α *and* β are the extremes of the rainfall categories depending on departure from Normal described in the **Table 20;**
- ω_j represents the selected weight chosen for each season according to the importance that rainfall has during the different growth phases of winter wheat

Before applying the index function for each Indian States, a first analysis can be made by comparing the rainfall categories obtained by India and the other four states using the well-known ratio $\frac{Observed\ Rainfall\ Value}{LPA} - 1$ but the LPA used will be for the five cases the LPA calculated at India country level (see **Table 32**):

Table 32: Obs/LPA using India LPA on annual values for each states						
Year	**Rainfall Annual India**	**India Obs/LPA**	**Bihar Obs/LPA**	**Karnataka Obs/LPA**	**Madhya Pradesh Obs/LPA**	**Uttar Pradesh Obs/LPA**
2011	1,116	N	N	D	LE	E
2012	1,054	N	N	D	E	N
2013	1,092	N	N	D	LE	LE
2014	1,045	N	N	D	E	N
2015	1,085	N	D	D	E	N
2016	1,083	N	N	D	LE	E
2017	1,127	N	N	D	E	N
2018	1,020	N	D	D	E	E
2019	1,288	N	N	D	LE	E

These results are an example of the first application Total Annual Rainfall Index. It highlights how the choice of the appropriate parameters and its calibration for the index construction is crucial and vital for the well-functioning of a weather index insurance product. The usage of India LPA for each single states is a big mistake that can probably increases the basis risk by transforming some cumulative rainfall values from normal to above / below normal according to a wrong LPA estimation. This can generate a payment when it is not necessary or contrary no indemnity when it should be required. In addition, the different geographical position of a state, in general, or the crop production of the insured farmer meaningfully determine the activation or not of a parametric contract.

The focal point will be to compare the application study of the previous three weather indexes on the four selected Indian states. But from now on, a deeper comparison will be visible in this paragraph only between two of the states that are different for amount of wheat production and rainfall fallen. The two states mentioned so far are Bihar and Madhya Pradesh. The other states analysis will be presented in the Appendix.

The next **Table 33 and 34** exhibit the results after having applied the Total Annual Rainfall Index on Bihar and Madhya Pradesh:

Table 33: BIHAR - TOTAL ANNUAL RAINFALL INDEX								
Year	Rainfall	Obs/LPA	Excess-Deficit		Excess		Deficit	
			A	B	A	B	A	B
2011	1,097	N	-	-	-	-	-	-
2012	1,032	N	-	-	-	-	-	-
2013	1,070	N	-	-	-	-	-	-
2014	1,061	N	-	-	-	-	-	-
2015	873	D	193	77	-	-	193	77
2016	1,158	N	-	-	-	-	-	-
2017	1,112	N	-	-	-	-	-	-
2018	861	D	187	74	-	-	187	74
2019	1,195	N	-	-	-	-	-	-
TOTALE			380	152	-	-	380	152
Per 1 unit of production (in €)			0.46	0.18	-	-	0.46	0.18

Table 34: MADHYA PRADESH - TOTAL ANNUAL RAINFALL INDEX								
Year	Rainfall	Obs/LPA	Excess-Deficit		Excess		Deficit	
			A	B	A	B	A	B
2011	1,954	N	-	-	-	-	-	-
2012	1,749	N	-	-	-	-	-	-
2013	2,515	E	422	168	422	168	-	-
2014	1,571	D	384	153	-	-	384	153
2015	1,665	N	-	-	-	-	-	-
2016	1,863	N	-	-	-	-	-	-
2017	1,793	N	-	-	-	-	-	-
2018	1,535	D	319	127	-	-	319	127
2019	2,750	E	323	129	323	129	-	-
TOTALE			1,449	579	745	298	703	281
Per 1 unit of production (in €)			1.03	0.41	0.53	0.21	0.50	0.20

It makes manifest that the 1° triggering event comprehending both Excess and Deficit cases is frequently activated as in regions such as Madhya Pradesh producing also high level of repayment of the average production repaid in subsequent nine years. The activation of the Total Annual Rainfall Index for the three-triggering events quickly fells out due to two main limitations:

a. indices based on total rainfall in a given period, such as a year, ignore the significance of rainfall distribution related to the specific crop growth object of protection because a significant number of incidences of large-scale crop losses in India can be the result of long dry spells, which may not be reflected in total rainfall;
b. assuming that only average rainfall affects crop yields in this case, the approach disregards the phenological stages of crop growth and effective soil field capacity.

Using the Total Seasonal Rainfall Index returns the same two limitations just presented above but the Tables below (**Table 35 and 36**) show a better situation: the index has been calibrated taking the LPA specific to the state and to the season. This tailoring process has underlined situations, in which the policies that have not been activated in the total case are now operating, and vice-versa.

Table 35: BIHAR JF - TOTAL SEASONAL RAINFALL INDEX								
Year	**Rainfall JF**	**Obs/LPA**	**Excess-Deficit**		**Excess**		**Deficit**	
			A	**B**	**A**	**B**	**A**	**B**
2011	12	D	238	95	-	-	238	95
2012	21	N	-	-	-	-	-	-
2013	28	E	247	98	247	98	-	-
2014	51	LE	674	674	674	674	-	-
2015	15	D	193	77	-	-	193	77
2016	10	D	158	63	-	-	158	63
2017	1	LD	486	486	-	-	486	486
2018	0	No Rain	748	748	-	-	748	748
2019	31	E	189	75	189	75	-	-
TOTALE			2,935	2,319	1,110	849	1,824	1,470
Per 1 unit of production (in €)			3.56	2.81	1.35	1.03	2.21	1.78

On the contrary, weighted rainfall indices offer more flexibility trying to compensate a large volume of rainfall in a period of low significance (weight) with poor rainfall in phase of high significance. For example, 2018 year has been characterized by 0 mm of rain that is categorized as "No rain" in this table. But going to weight the JF season for 45%, the "No rain" category becomes a "Deficit". Passing towards the next Table 37, the payout will be less drastic both in terms of monetary amount and per unit of production. It will also be less burdensome considering the Case B.

Table 36: BIHAR JF - WEIGHTED ANNUAL SEASONAL RAINFALL INDEX								
Year	**Rainfall**	**Obs/LPA**	**Excess-Deficit**		**Excess**		**Deficit**	
			A	**B**	**A**	**B**	**A**	**B**
2011	12	D	238	95	-	-	238	95
2012	21	N	-	-	-	-	-	-
2013	28	N	-	-	-	-	-	-
2014	51	LE	674	674	674	674	-	-
2015	15	N	-	-	-	-	-	-
2016	10	D	158	63	-	-	158	63
2017	1	D	162	64	-	-	162	64
2018	0	D	187	74	-	-	187	74
2019	31	E	189	75	189	75	-	-
TOTALE			1,609	1,048	863	750	745	298
Per 1 unit of production (in €)			1.95	1.27	1.05	0.91	0.90	0.36

The same reasoning is applied to Madhya Pradesh with a more evident effect visible in **Table 37 and 38**, since it is one of the most productive states of wheat in India.

Table 37: MADHYA PRADESH JF - TOTAL SEASONAL RAINFALL INDEX								
Year	**Rainfall**	**Obs/LPA**	**Excess-Deficit**		**Excess**		**Deficit**	
			A	**B**	**A**	**B**	**A**	**B**
2011	4	LD	1,223	1,223	-	-	1,223	1,223
2012	46	N	-	-	-	-	-	-
2013	78	LE	1,266	1,266	1,266	1,266	-	-
2014	142	LE	1,152	1,152	1,152	1,152	-	-
2015	95	LE	993	993	993	993	-	-
2016	28	D	270	108	-	-	270	108
2017	18	D	276	110	-	-	276	110
2018	22	D	319	127	-	-	319	127
2019	27	D	323	129	-	-	323	129
TOTALE			5,826	5,112	3,412	3,412	2,413	1,699
Per 1 unit of production (in €)			4.13	3.62	2.42	2.42	1.71	1.20

Table 38: MADHYA PRADESH JF – WEIGHTED SEASONAL ANNUAL RAINFALL INDEX								
Year	**Rainfall**	**Obs/LPA**	**Excess-Deficit**		**Excess**		**Deficit**	
			A	**B**	**A**	**B**	**A**	**B**
2011	4	D	407	163	-	-	407	153
2012	46	N	-	-	-	-	-	-
2013	78	E	422	168	422	168	-	-
2014	142	LE	1,152	1,152	1,152	1,152	-	-
2015	95	E	331	132	331	132	-	-
2016	28	N	-	-	-	-	-	-
2017	18	D	276	110	-	-	276	110
2018	22	D	319	127	-	-	319	127
2019	27	N	-	-	-	-	-	-
TOTALE			2,910	1,855	1,906	1,454	1,004	401
Per 1 unit of production (in €)			2.06	1.32	1.35	1.03	0.71	0.28

In addition, the weighted rainfall index makes the extreme categories converging towards the normal, so the central values, taking for example 2011, 2013, 2015, 2016 and 2016 years. This process makes the payout cheaper for the insurance company and trying to be active only in extreme events, which is one of the founding reasons for choosing parametric products.

The same analysis can be done by taking another season, JJAS, that is supposed to weight only for 5% in the winter wheat growth. The results in **Table 39 and 40** show up an overall reduction in the payouts, given the different climatic features of the two states: Bihar appears to be in a deficit situation contrary to Madhya Pradesh, which is in an excess phase during these nine years.

Table 39: BIHAR JJAS - TOTAL SEASONAL RAINFALL INDEX								
Year	Rainfall JF	Obs/LPA	Excess-Deficit		Excess		Deficit	
			A	B	A	B	A	B
2011	965	N	-	-	-	-	-	-
2012	924	N	-	-	-	-	-	-
2013	722	D	247	98	-	-	247	98
2014	849	N	-	-	-	-	-	-
2015	742	D	193	77	-	-	193	77
2016	994	N	-	-	-	-	-	-
2017	937	N	-	-	-	-	-	-
2018	771	D	187	74	-	-	187	74
2019	1.049	N	-	-			-	-
TOTALE			627	251	-	-	627	251
Per 1 unit of production (in €)			0.76	0.30	-	-	0.76	0.30

Table 40: MADHYA PRADESH JJAS - TOTAL SEASONAL RAINFALL INDEX								
Year	Rainfall	Obs/LPA	Excess-Deficit		Excess		Deficit	
			A	B	A	B	A	B
2011	2.316	E	407	163	407	163	-	-
2012	2.014	N	-	-	-	-	-	-
2013	2.607	E	422	168	422	168	-	-
2014	1.518	N	-	-	-	-	-	-
2015	1.660	N	-	-	-	-	-	-
2016	2.293	E	270	108	270	108	-	-
2017	1.534	N	-	-	-	-	-	-
2018	1.757	N	-	-	-	-	-	-
2019	2.693	E	323	129	323	129	-	-
TOTALE			1,423	569	1,423	569	-	-
Per 1 unit of production (in €)			1.01	0.40	1.01	0.40	-	-

The most impressive evidence is that in all the four states using the Weighted Annual Seasonal Rainfall Index for JJAS period produces no payouts during 2011-2019 for the three triggering events.

To sum up the results obtained by applying the three indexes according to the three triggering events and considering the peculiarities of each state, the following **Figures** will give a prompt picture of the different total payout levels in €, with respect the average production in € considered to be the sum insured, accumulated in nine years and supposing a continuous renewal of the policies during this period.

FIG. 24: TOTAL ANNUAL RAINFALL FOR EACH STATES

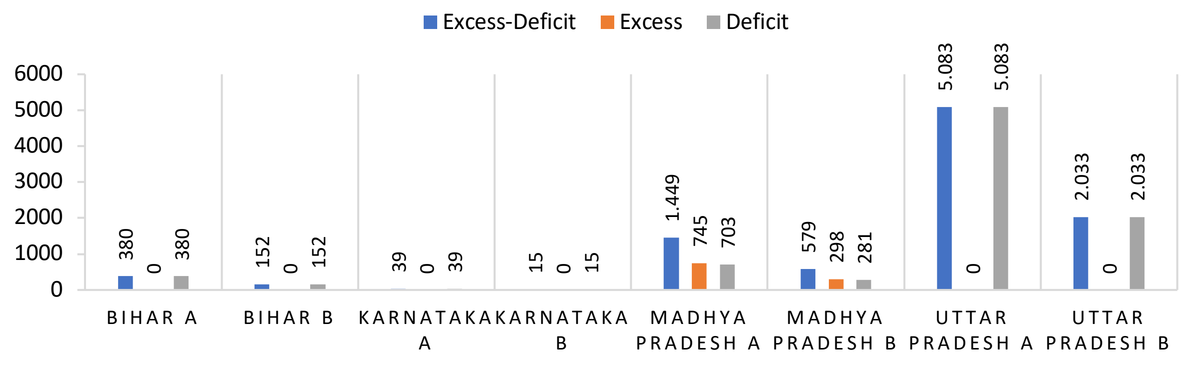


FIG. 25: TOTAL ANNUAL RAINFALL JF FOR EACH STATES

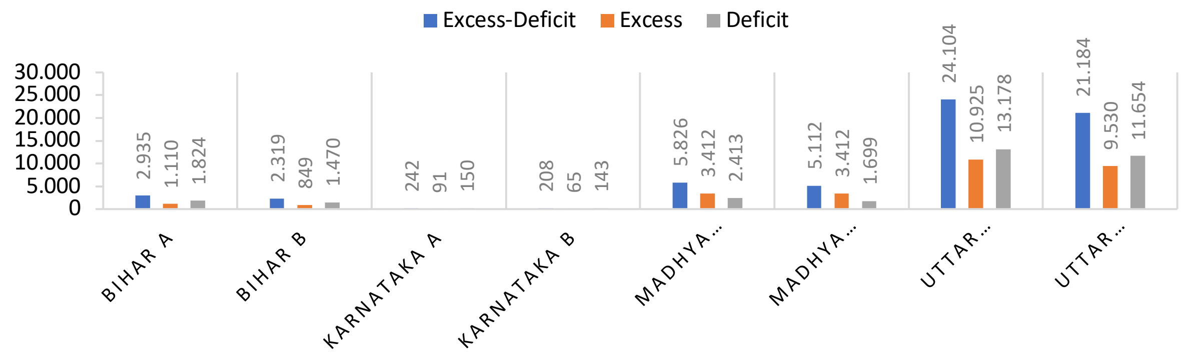
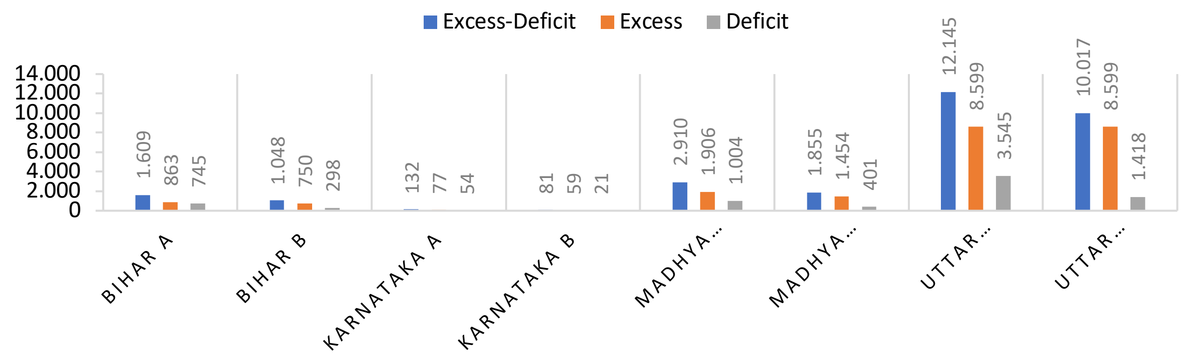


FIG. 26: WEIGHTED ANNUAL SEASONAL RAINFALL JF



Here, it is presented also the application case of Total Annual Rainfall for the MAM season that is supposed to count for 25%, the middle case of relevance to winter wheat growth.

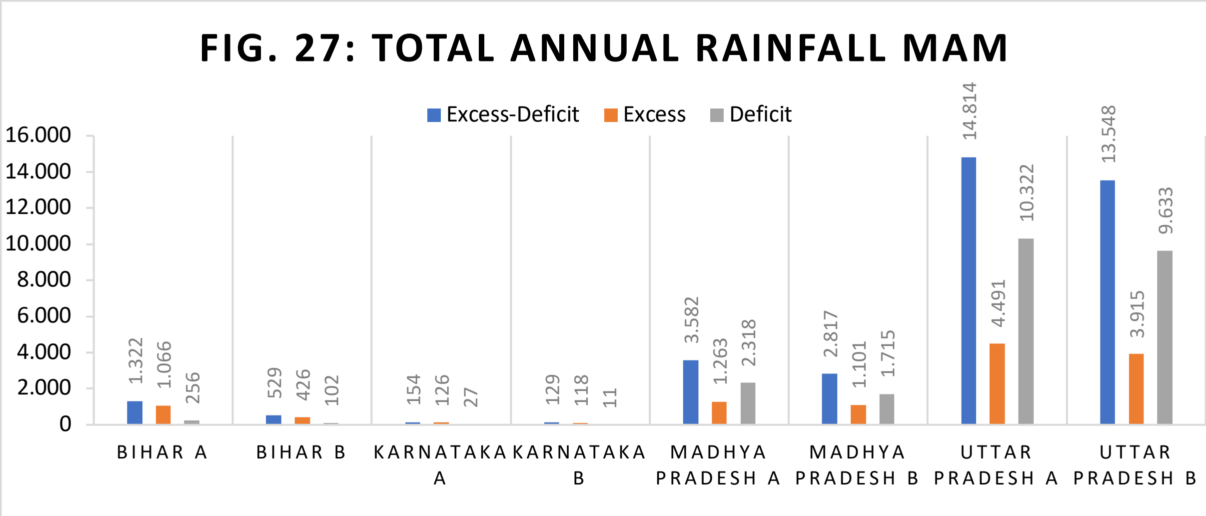


FIG. 27: TOTAL ANNUAL RAINFALL MAM
Excess-Deficit
Excess
Deficit
16.000
14.000
12.000
10.000
8.000
6.000
4.000
2.000
0
1.322
1.066
256
529
426
102
154
126
27
129
118
11
3.582
1.263
2.318
2.817
1.101
1.715
14.814
4.491
10.322
13.548
3.915
9.633
BIHAR A
BIHAR B
KARNATAKA A
KARNATAKA B
MADHYA PRADESH A
MADHYA PRADESH B
UTTAR PRADESH A
UTTAR PRADESH B

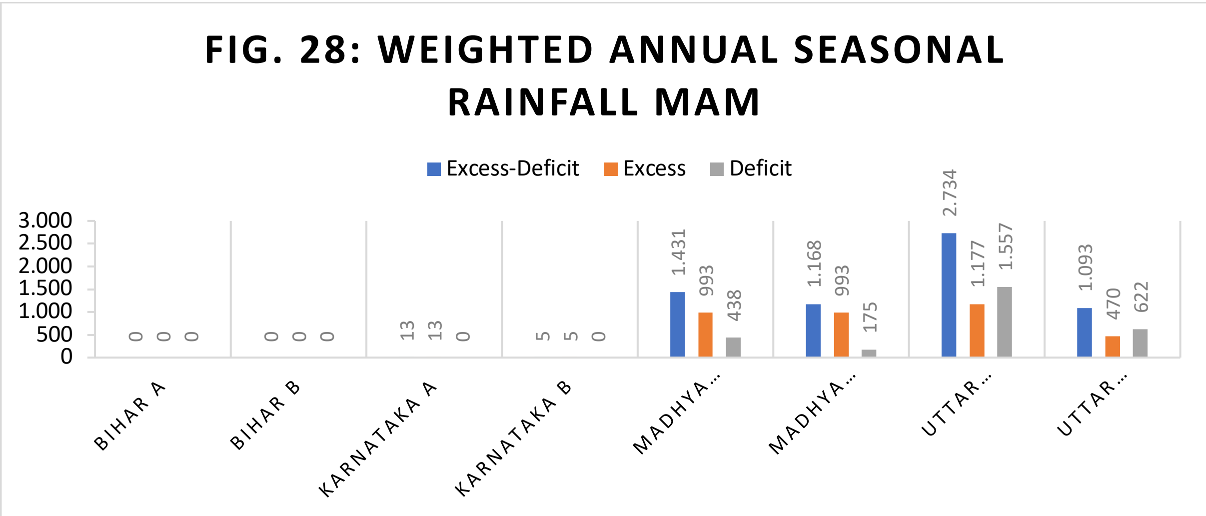


FIG. 28: WEIGHTED ANNUAL SEASONAL RAINFALL MAM
Excess-Deficit
Excess
Deficit
3.000
2.500
2.000
1.500
1.000
500
0
0 0 0
0 0 0
13 13 0
5 5 0
1.431
993
438
1.168
993
175
2.734
1.177
1.557
1.093
470
622
BIHAR A
BIHAR B
KARNATAKA A
KARNATAKA B
MADHYA...
MADHYA...
UTTAR...
UTTAR...

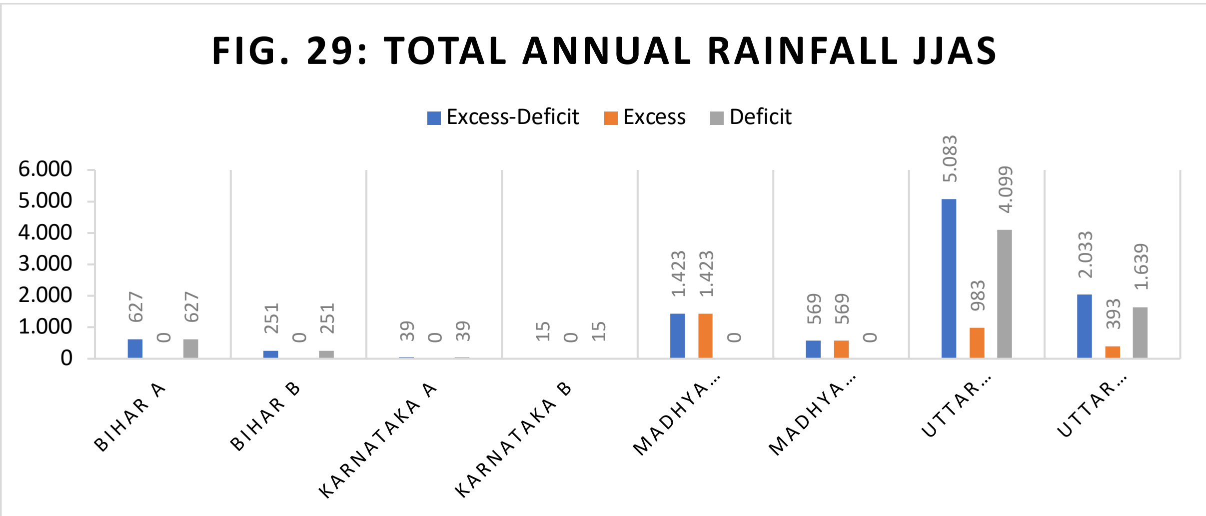


FIG. 29: TOTAL ANNUAL RAINFALL JJAS
Excess-Deficit
Excess
Deficit
6.000
5.000
4.000
3.000
2.000
1.000
0
627 0 627
251 0 251
39 0 39
15 0 15
1.423 1.423 0
569 569 0
5.083
983
4.099
2.033
393
1.639
BIHAR A
BIHAR B
KARNATAKA A
KARNATAKA B
MADHYA...
MADHYA...
UTTAR...
UTTAR...

5.2.5 Conclusions

The analysis has confirmed how weather-based crop insurance products can be an innovative and valid instrument against rainfall negative effects on crop production, especially in India as symbol of countries whose economy is based massively on agriculture and where the climate change plays a decisive role. Obviously, the research has given quite important results made at macro levels and it would be interesting to further investigate the potential of the parametric instruments having more detailed, advanced, and specific information about agricultural aspects but also related to historical losses and sum insureds in the (re)insurance market.

Starting from the approach used for the calculation of an average value for rainfall data (LPA), it was found to be appropriate for the estimation of the index. A longer time series with respect the 50-year historical data used can be considered, even though the results would have been the same in this study and, hence, a shorter time series resulted to be more in line with the climate change effects. Also, the normal distribution assumption adopted for the rainfall distribution turned out to be an efficient and practical simplification able to give an insight at macro level between data at country size (India) with respect the specificities owned by Bihar, Karnataka, Madhya Pradesh and Uttar Pradesh. The five different LPAs are almost the same but it is curious how the usage of India LPA or state specific LPA values can so much affect the ratio $\frac{Observed\ Rainfall\ Value}{LPA} - 1$, which is the core of the three indexes implied, and, consequently, also of the final payout. This evidence is visible from **Table 32**, in which some years are scheduled to be "Normal" for India, but they diverge a lot for the other four states: moving from "Deficit" years for Karnataka to "Excess" or "Large Excess" for Madhya and Uttar Pradesh. Indeed, passing to analyze the same single four states under the Total Annual Rainfall Index using now their specific LPA, the results appear almost completely different from the previous case, except for Bihar state. This result highlights how the geographical position and climatic variables are crucial elements to consider during the identification of benchmark or threshold for the index construction. Then, some policies can be thought to cover policyholders only on specific months with respect the entire year, especially to better embrace the phenological stages of crop growth, the soil field capacity, and the periods of high/low significance of rainfall for a specific crop production. To achieve this object, another index named Total Seasonal Rainfall Index has been introduced resulting in a much more activation of the policy during the nine years in all the states with respect the Total Annual Rainfall Index. The disbursement is more onerous when the coverage protects from the extremes both in the up and down scenario and, especially, in case A with higher percentage applied for the intermediate rainfall categories of “Excess” and “Deficit”. Considering the JF season as crucial in the winter wheat growth for the successful of the production, the re-payments in the triggering event Excess-Deficit under case A measured using the metric “per 1 unit of production” pass from 0.46 and 1.03 for Bihar and Madhya Pradesh to 3.56 and 1.95 counting for +674% and +89%. The same effects are experienced by the Karnataka and Uttar Pradesh. Obviously, considering only the 2° or 3° triggering event, the payout and the “per 1 unit of production metric” are reduced. From the insurer point of view, the Weighted Annual Seasonal Rainfall Index can be introduced to reduce the payout and to make more normal all the years: the weighting makes the extreme categories concentrating towards the normal ones and reducing the percentages applied to evaluate the final payout. It is an important pricing strategy because it enables to react only to truly extreme events against rainfall excess and/or deficit years. For example, considering the JF season, that counts for 45% in winter wheat growth cycle, the “per 1 unit of production metric” related to Bihar reduces from 3.56 to 1.96 for Excess-Deficit case A passing from a total to a weighted index and the worst year, 2018 “No rain”, has become less severe (“Deficit”). The same effect is experienced by Madhya Pradesh for the same period by halving the values, which were already high because Madhya Pradesh is one of the most productive winter wheat states and so one of the more sensible to negative climate consequences. In both two states, 2014 year remains the only severe period that has experience “Large Excess” of rain in JF and deserves a fair payout. There are even several cases in all the four states using the Weighted Seasonal Annual Rainfall Index that leads to the total non-activation of the triggering events with the consequence to have no payout in all the nine years.

In the end, as anticipated in the previous paragraph, the usage of a wrong LPA or more in general an unfair parameter identification, it can lead to an increase in basis risk, since the payout is based on exogenous parameter, here rainfall quantity affecting crop yield, and not on actual losses suffered. This issue may be properly minimized to gain benefits from a point of view of the policyholder but also from the insurer’s perspective. In addition, to better tailoring a weather index product, designers have experimented the introduction of the conditionability between crop growth phases. It is recommended that products usually include a maximum claim payment for the policy which is smaller than the sum of maximum claim payments for each phase, here thought to be related to the average production over a specific period reported in monetary amount coherently with the years considered. In the analysis there are no explicit cap in the payment, but a similar role is played by the weighting, even though a maximum claim payment may be triggered by exceptionally poor or excess weather in one or small number of phases. Subsequently, it is difficult to choose the appropriate payout structure to capture the true correlation between rainfall and crop yield loss: timing and amount of rainfall during the various growth phases of a plant are very important for satisfying the soil water balance and therefore the ultimate yield. Dry spells or deficits and excess of rain over the main phases of crop growth can cause yield loss, even if cumulative season rainfall is adequate. To sum up, index product designs may commonly use several phases of measurement during the crop season, each with their own thresholds and limits of the weather parameter to maximize their advantages and to use these coverages at their best.

Conclusion

In a world of increasing weather-related natural catastrophes, this analysis revealed how parametric insurance coverages are becoming an innovative tool and a valid alternative to traditional indemnity insurance, especially in case of hard insurance market. Notwithstanding the fact that (re)insurance products have evolved to become increasingly sophisticated thanks to the rise of modelling capacity, product innovation and data availability, other issues such as exposure data quality, risk mitigation and the growing frequency of secondary perils, have moved forward requiring the urgent attention of (re)insurers, policymakers, governments, and society. Since climate change combined with other loss drivers (exposure growth, inflationary pressure, claims litigation, higher construction/labor costs) can massively affect human and financial consequences produced by natural disasters, especially driven by secondary perils, which are driving up loss costs to new heights by becoming the future growing concern for the (re)insurance market. Higher losses come at a time when the volume of reinsurance aggregate cover placement continues to decline, and the increased uncertainty generated by climate change has been translated in additional risk bear both by insurance companies in terms of additional capital and by policyholders in terms of premium. In this environment, the phrase "parametric insurance" has probably recently become a ubiquitous term in the (re)insurance world because it appears that nowadays the scope of the (re)insurance industry is to provide cover for previously uninsurable or hardly insurable risks, in any part of the world and with fast and transparent payouts. It has been presented how parametric coverages are contracts that make a payout to a beneficiary only in the event of an index exceeding or not a threshold linked to an external observable variable. Also, the composition of this alternative solution is very simple because it includes three main steps: collection of data from a provider, calculation of an index used for modelling and pricing, and the choice of the related payout function. Apart from the transparency of payout trigger, other relevant advantages are the lower dispute risk, a faster payout, no need for loss adjustment resulting in lower expenses, even if it is important to underline that a perfect solution would lead to the same payout as actual loss. The expected loss and the cost of capital should remain the same cost drivers as for a traditional solution. It is even true that there is the high chance that an insured party may not be paid when they suffer loss and/or that they may receive a payment when they have suffered no loss. This phenomenon is called "basis risk" and it is a particular and unique issue for index products that must be minimized. That's why the implementation of index insurance schemes is technically very challenging. Setting the trigger is an important decision because it affects the frequency on recoveries, the price of the insurance product and the risk appetite of the insured, even though the attention will be put on the right "tail" of the selected function. Insurance can always exist only if risk can be transferred but vigilance is always required throughout the design phase to stick to the purpose of the cover and to control the level of basis risk present. Another issue to be improved is that parametric products are not best calibrated for point-based exposure because historical data might be tricky to interpret if close to the threshold but not close enough to verify if simulated events would trigger. In addition, the role and judgments of experts are highly recommended, especially when the intensity might be expressed in a unit not available in existing modelling tools and the accumulation might be challenging to onboard for the risk carrier.

In conclusion, parametric solutions should be implemented as a complementary instrument with respect to traditional covers thanks to their value proposition in the ability to cover uninsured risks and to overcome traditional insurance issues, such as the reduction of the protection gap. Furthermore, they are used as a hedge in the community sector as cover against catastrophe risks and they have gained so much attention thanks to their combined differentiation efforts in multiple application levels, from microinsurance to corporates and from financial institutions to public authorities. The current main application sector of this alternative risk transfer solution is the agriculture with a wide range of indexable weather risks, which are most applicable to highly correlated risks, such as drought and temperature, while localized (independently occurring) risks, such as hail or fire, do not easily lend themselves to index insurance, even though it could be a hot debate for the future. Additionally, there is growing research on the usage of alternative data sources and risk modeling also from the scientific community to overcome some of the limitations related to reliable access to data and to the lack of (weather) monitoring systems in many developing countries. Ultimately, it is recommended to recall how there is no single methodology in the construction or identification of a parametric coverage, since it can be used either on a stand-alone basis or as part of an established insurance strategy. Personally, I think that parametric solutions are playing an important role in helping to address direct and indirect impacts of loss events across a wide range of climatic risks. It is evident how these alternative products have gained attraction in the face of difficult underwriting conditions and protection gaps leading to a growing focus on the wider resilience benefits those parametric products can offer to society in response to a changing risk landscape.

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APPENDIX

The following **Tables (26,27,28,29)** present the confrontation between India values (already appeared in the **Table 19**) with respect the other four Indian states by comparing the maximum and minimum values, the Long Period Average (LPA), sigma, coefficient of variation, m+/-d and the skewness on annual basis for the four different Indian seasons:

Table 26: JF RAINFALL - Reference Period: 1997-2010					
	India	**Bihar**	**Karnataka**	**Madhya Pradesh**	**Uttar Pradesh**
Max	69 in 2005	62 in 1984	28 in 1994	160 in 1986	175 in 1996
Min	16 in 2001	0.1 in 2006	0 in many years	0 in 2006	0.5 in 2006
Average (LPA)	39	21	4	43	55
Sigma	11	16	6	41	42
CV	0.293	0.783	1.289	0.951	0.768
m-d	28	4	1.43	2	12
m+d	51	37	11	85	98
Skewness	0.30	0.67	1.62	1.34	0.92

Table 27: MAM RAINFALL - Reference Period: 1997-2010					
	India	**Bihar**	**Karnataka**	**Madhya Pradesh**	**Uttar Pradesh**
Max	210 in 1990	178 in 1971	161 in 2008	152 in 2006	222 in 1982
Min	95 in 2009	8.8 in 1995	24 in 1983	3 in 2010	11 in 1996
Average (LPA)	129	81	75	35	63
Sigma	20	35	32	28	41
CV	0.161	0.44	0.43	0.805	0.664
m-d	108	45	43	6	21
m+d	150	116	108	63	104
Skewness	1.37	0.11	0.68	1.73	1.52

Table 28: JJAS RAINFALL - Reference Period: 1997-2010					
	India	**Bihar**	**Karnataka**	**Madhya Pradesh**	**Uttar Pradesh**
Max	1.051 in 1961	1.515 in 1987	852 in 1997	2.717 in 1961	2.343 in 1980
Min	674 in 1972	536 in 2010	329 in 2003	1.212 in 1965	808 in 1997
Average (LPA)	873	989	521	1.882	1.550
Sigma	87	181	116	338	335
CV	0.100	0.18	0.22	0.180	0.217
m-d	785	807	4305	1.544	1.214
m+d	961	1.171	638	2.220	1.885
Skewness	-0.24	-0.05	0.54	0.31	-0.10

Table 29: OND RAINFALL - Reference Period: 1997-2010					
	India	**Bihar**	**Karnataka**	**Madhya Pradesh**	**Uttar Pradesh**
Max	167 in 1977	246 in 1961	344 in 1975	422 in 1997	369 in 1961
Min	66 in 2000	9 in 2000	33 in 1965	3 in 2000	8 in 1976
Average (LPA)	121	75	134	102	81
Sigma	26	55	61	82	72
CV	0.220	0.73	0.45	0.802	0.893
m-d	94	20	73	20	8
m+d	148	131	195	184	153
Skewness	-0.05	1.09	0.74	1.74	2.17

These other Tables represent the application of the Total Annual Rainfall Index for each state, the Total Seasonal Rainfall Index and the Weighted Annual Seasonal Rainfall Index for each state and with different weights according to the four seasons: JF 45%, MAM 25%, JJAS 5% and OND 25%. The states present here are the one absent in the analysis of the Chapter 5.

Table 41: KARNATAKA - TOTAL ANNUAL RAINFALL INDEX								
Year	**Rainfall**	**Obs/LPA**	**Excess-Deficit**		**Excess**		**Deficit**	
			A	**B**	**A**	**B**	**A**	**B**
2011	665	N	-	-	-	-	-	-
2012	584	D	15	6	-	-	15	6
2013	723	N	-	-	-	-	-	-
2014	757	N	-	-	-	-	-	-
2015	552	D	11	4	-	-	11	4
2016	625	N	-	-	-	-	-	-
2017	740	N	-	-	-	-	-	-
2018	532	D	11	4	-	-	11	4
2019	900	N	-	-	-	-	-	-
TOTALE			39	15	-	-	39	15
Per 1 unit of production (in €)			0.77	0.31	-	-	0.77	0.31

Table 42: UTTAR PRADESH - TOTAL ANNUAL RAINFALL INDEX								
Year	Rainfall	Obs/LPA	Excess-Deficit		Excess		Deficit	
			A	B	A	B	A	B
2011	1.559	N	-	-	-	-	-	-
2012	992	D	1,557	622	-	-	1,557	622
2013	1.974	N	-	-	-	-	-	-
2014	1.188	D	1,365	546	-	-	1,365	546
2015	1.186	D	1,177	470	-	-	1,177	470
2016	1.565	N	-	-	-	-	-	-
2017	1.280	D	983	393	-	-	983	393
2018	1.615	N	-	-	-	-	-	-
2019	1.570	N	-	-	-	-	-	-
TOTALE			5,083	2,033	-	-	5,083	2,033
Per 1 unit of production (in €)			1.01	0.41	-	-	1.01	0.41

Table 43: KARNATAKA JF - TOTAL SEASONAL RAINFALL INDEX								
Year	Rainfall	Obs/LPA	Excess-Deficit		Excess		Deficit	
			A	B	A	B	A	B
2011	8	E	14	5	14	5	-	-
2012	35	LE	47	47	47	47	-	-
2013	7	E	15	6	15	6	-	-
2014	6	E	13	5	13	5	-	-
2015	2	D	11	4	-	-	11	4
2016	1	LD	29	29	-	-	29	29
2017	0	No Rain	40	40	-	-	40	40
2018	2	LD	34	34	-	-	34	34
2019	1	LD	35	35	-	-	35	35
TOTALE			242	208	91	65	150	143
Per 1 unit of production (in €)			4.75	4.10	1.79	1.28	2.96	2.82

Table 44: KARNATAKA JF - WEIGHTED ANNUAL SEASONAL RAINFALL INDEX								
Year	Rainfall	Obs/LPA	Excess-Deficit		Excess		Deficit	
			A	B	A	B	A	B
2011	8	E	14	5	14	5	-	-
2012	35	LE	47	47	47	47	-	-
2013	7	E	15	6	15	6	-	-
2014	6	N	-	-	-	-	-	-
2015	2	D	11	4	-	-	11	4
2016	1	D	9	3	-	-	9	3
2017	0	D	10	4	-	-	10	4
2018	2	D	11	4	-	-	11	4
2019	1	D	11	4	-	-	11	4
TOTALE			132	81	77	59	54	21
Per 1 unit of production (in €)			2.60	1.60	1.52	1.17	1.08	0.43

Table 45: UTTAR PRADESH JF - TOTAL SEASONAL RAINFALL INDEX								
Year	**Rainfall**	**Obs/LPA**	**Excess-Deficit**		**Excess**		**Deficit**	
			A	**B**	**A**	**B**	**A**	**B**
2011	16	LD	4,348	4,348	-	-	4,348	4,348
2012	36	D	1,557	622	-	-	1,557	622
2013	156	LE	4,502	4,502	4,502	4,502	-	-
2014	151	LE	4,097	4,097	4,097	4,097	-	-
2015	73	E	1,117	470	1,117	1,117	-	-
2016	11	LD	2,881	2,881	-	-	2,881	2,881
2017	33	D	983	393	-	-	983	393
2018	12	LD	3,408	3,408	-	-	3,408	3,408
2019	77	E	1,149	459	1,149	459	-	-
TOTALE			24,104	21,184	10,925	9,530	13,178	11,654
Per 1 unit of production (in €)			4,81	4,23	2.18	1.90	2,63	2,32

Table 46: UTTAR PRADESH JF – WEIGHTED SEASONAL ANNUAL RAINFALL INDEX								
Year	**Rainfall**	**Obs/LPA**	**Excess-Deficit**		**Excess**		**Deficit**	
			A	**B**	**A**	**B**	**A**	**B**
2011	16	D	1,449	579	-	-	1,449	579
2012	36	N	-	-	-	-	-	-
2013	156	LE	4,502	4,502	4,502	4,502	-	-
2014	151	LE	4,097	4,907	4,097	4,097	-	-
2015	73	N	-	-	-	-	-	-
2016	11	D	960	384	-	-	960	384
2017	33	N	-	-	-	-	-	-
2018	12	D	1,136	454	-	-	1,136	454
2019	77	N	-	-	-	-	-	-
TOTALE			12,145	10,017	8,599	8,599	3,545	1,418
Per 1 unit of production (in €)			2.42	2.00	1.72	1.72	0.71	0.28

Table 47: BIHAR MAM - TOTAL SEASONAL RAINFALL INDEX								
Year	**Rainfall JF**	**Obs/LPA**	**Excess-Deficit**		**Excess**		**Deficit**	
			A	**B**	**A**	**B**	**A**	**B**
2011	108	E	238	95	238	95	-	-
2012	47	D	256	102	-	-	256	102
2013	122	E	247	98	247	98	-	-
2014	113	E	224	89	224	89	-	-
2015	106	E	193	77	193	77	-	-
2016	94	N	-	-	-	-	-	-
2017	124	E	162	64	162	64	-	-
2018	67	N	-	-	-	-	-	-
2019	69	N	-	-			-	-
TOTALE			1,322	529	1,066	426	256	102
Per 1 unit of production (in €)			1.60	0.64	1.29	0.52	0.31	0.12

Table 48: KARNATAKA MAM - TOTAL SEASONAL RAINFALL INDEX								
Year	Rainfall	Obs/LPA	Excess-Deficit		Excess		Deficit	
			A	B	A	B	A	B
2011	95	E	14	5	14	5	-	-
2012	55	D	15	6	-	-	15	6
2013	76	N	-	-	-	-	-	-
2014	149	LE	41	41	41	41	-	-
2015	124	LE	35	35	35	35	-	-
2016	67	N	-	-	-	-	-	-
2017	66	N	-	-	-	-	-	-
2018	123	LE	34	34	34	34	-	-
2019	43	D	11	4	-	-	11	4
TOTALE			154	129	126	118	27	11
Per 1 unit of production (in €)			3.03	2.53	2.49	2.32	0.54	0.22

Table 49: KARNATAKA MAM - WEIGHTED ANNUAL SEASONAL RAINFALL INDEX								
Year	Rainfall	Obs/LPA	Excess-Deficit		Excess		Deficit	
			A	B	A	B	A	B
2011	95	N	-	-	-	-	-	-
2012	55	N	-	-	-	-	-	-
2013	76	N	-	-	-	-	-	-
2014	149	E	13	5	13	5	-	-
2015	124	N	-	-	-	-	-	-
2016	67	N	-	-	-	-	-	-
2017	66	N	-	-	-	-	-	-
2018	123	N	-	-	-	-	-	-
2019	43	N	-	-	-	-	-	-
TOTALE			13	5	13	5	-	-
Per 1 unit of production (in €)			0.27	0.11	0.27	0.11	-	-

Table 50: MADHYA PRADESH MAM - TOTAL SEASONAL RAINFALL INDEX								
Year	Rainfall	Obs/LPA	Excess-Deficit		Excess		Deficit	
			A	B	A	B	A	B
2011	18	D	407	163	-	-	407	163
2012	7	LD	1,314	1,314	-	-	1,314	1,314
2013	36	N	-	-	-	-	-	-
2014	33	N	-	-	-	-	-	-
2015	174	LE	993	993	993	993	-	-
2016	48	E	270	108	270	108	-	-
2017	22	D	276	110	-	-	276	110
2018	19	D	319	127	-	-	319	127
2019	38	N	-	-	-	-	-	-
TOTALE			3,582	2,817	1,263	1,101	2,318	1,715
Per 1 unit of production (in €)			2.54	2.00	0.90	0.78	1.64	1.22

Table 51: MADHYA PRADESH MAM - WEIGHTED ANNUAL SEASONAL RAINFALL INDEX								
Year	**Rainfall**	**Obs/LPA**	**Excess-Deficit**		**Excess**		**Deficit**	
			A	**B**	**A**	**B**	**A**	**B**
2011	18	N	-	-	-	-	-	-
2012	7	D	438	175	-	-	438	175
2013	36	N	-	-	-	-	-	-
2014	33	N	-	-	-	-	-	-
2015	174	LE	993	993	993	993	-	-
2016	48	N	-	-	-	-	-	-
2017	22	N	-	-	-	-	-	-
2018	19	N	-	-	-	-	-	-
2019	38	N	-	-	-	-	-	-
TOTALE			1,431	1,168	993	993	438	175
Per 1 unit of production (in €)			1.01	0.83	0.70	0.70	0.31	0.12

Table 52: UTTAR PRADESH MAM - TOTAL SEASONAL RAINFALL INDEX								
Year	**Rainfall**	**Obs/LPA**	**Excess-Deficit**		**Excess**		**Deficit**	
			A	**B**	**A**	**B**	**A**	**B**
2011	73	N	-	-	-	-	-	-
2012	12,8	LD	4,671	4,671	-	-	4,671	4,671
2013	20	LD	4,502	4,502	-	-	4,502	4,502
2014	67	N	-	-	-	-	-	-
2015	176	LE	3,531	3,531	3,531	3,531	-	-
2016	88	E	960	384	960	384	-	-
2017	56	N	-	-	-	-	-	-
2018	61	N	-	-	-	-	-	-
2019	28	D	1,149	459	-	-	1,149	459
TOTALE			14,814	13,548	4,491	3,915	10,322	9,633
Per 1 unit of production (in €)			2.96	2.70	0.90	0.78	2.06	1.92

Table 53: UTTAR PRADESH MAM - WEIGHTED ANNUAL SEASONAL RAINFALL INDEX								
Year	**Rainfall**	**Obs/LPA**	**Excess-Deficit**		**Excess**		**Deficit**	
			A	**B**	**A**	**B**	**A**	**B**
2011	73	N	-	-	-	-	-	-
2012	12,8	D	1,557	622	-	-	1,557	622
2013	20	N	-	-	-	-	-	-
2014	67	N	-	-	-	-	-	-
2015	176	E	1,177	470	1,177	470	-	-
2016	88	N	-	-	-	-	-	-
2017	56	N	-	-	-	-	-	-
2018	61	N	-	-	-	-	-	-
2019	28	N	-	-	-	-	-	-
TOTALE			2,734	1,093	1,177	470	1,557	622
Per 1 unit of production (in €)			0.55	0.22	0.23	0.09	0.31	0.12

Table 54: KARNATAKA JJAS - TOTAL SEASONAL RAINFALL INDEX								
Year	Rainfall	Obs/LPA	Excess-Deficit		Excess		Deficit	
			A	B	A	B	A	B
2011	473	N	-	-	-	-	-	-
2012	359	D	15	6	-	-	15	6
2013	535	N	-	-	-	-	-	-
2014	483	N	-	-	-	-	-	-
2015	357	D	11	4	-	-	11	4
2016	524	N	-	-	-	-	-	-
2017	521	N	-	-	-	-	-	-
2018	357	D	11	4	-	-	11	4
2019	612	N	-	-	-	-	-	-
TOTALE			39	15	-	-	39	15
Per 1 unit of production (in €)			0.77	0.31	-	-	0.77	0.31

Table 55: UTTAR PRADESH JJAS - TOTAL ANNUAL RAINFALL INDEX								
Year	Rainfall	Obs/LPA	Excess-Deficit		Excess		Deficit	
			A	B	A	B	A	B
2011	1.466	N	-	-	-	-	-	-
2012	939	D	1,557	622	-	-	1,557	622
2013	1.628	N	-	-	-	-	-	-
2014	857	D	1,365	546	-	-	1,365	546
2015	908	D	1,177	470	-	-	1,177	470
2016	1.430	N	-	-	-	-	-	-
2017	1.187	E	983	393	983	393	-	-
2018	1.535	N	-	-	-	-	-	-
2019	1.376	N	-	-	-	-	-	-
TOTALE			5,083	2,033	983	393	4,099	1,639
Per 1 unit of production (in €)			1.01	0.41	0.20	0.08	0.82	0.33

Table 56: BIHAR OND - TOTAL SEASONAL RAINFALL INDEX								
Year	Rainfall JF	Obs/LPA	Excess-Deficit		Excess		Deficit	
			A	B	A	B	A	B
2011	108	E	238	95	238	95	-	-
2012	47	D	256	102	-	-	256	102
2013	122	LE	741	741	741	741	-	-
2014	113	E	224	89	224	89	-	-
2015	106	E	193	77	193	77	-	-
2016	94	E	158	63	158	63	-	-
2017	124	LE	486	486	486	486	-	-
2018	67	N	-	-	-	-	-	-
2019	69	N	-	-	-	-	-	-
TOTALE			2,299	2,656	2,042	1,553	256	102
Per 1 unit of production (in €)			2.79	2.01	2.47	1.88	0.31	0.12

Table 57: KARNATAKA OND - TOTAL SEASONAL RAINFALL INDEX								
Year	Rainfall	Obs/LPA	Excess-Deficit		Excess		Deficit	
			A	B	A	B	A	B
2011	79	D	14	5	-	-	14	5
2012	135	N	-	-	-	-	-	-
2013	105	D	15	6	-	-	15	6
2014	120	N	-	-	-	-	-	-
2015	69	D	11	4	-	-	11	4
2016	33	LD	29	29	-	-	29	29
2017	154	N	-	-	-	-	-	-
2018	50	LD	34	34	-	-	34	34
2019	245	LE	35	35	35	35	-	-
TOTALE			140	115	35	35	105	80
Per 1 unit of production (in €)			2.77	2.27	0.69	0.69	2.08	1.58

Table 58: KARNATAKA OND - WEIGHTED ANNUAL SEASONAL RAINFALL INDEX								
Year	Rainfall	Obs/LPA	Excess-Deficit		Excess		Deficit	
			A	B	A	B	A	B
2011	79	N	-	-	-	-	-	-
2012	135	N	-	-	-	-	-	-
2013	105	N	-	-	-	-	-	-
2014	120	N	-	-	-	-	-	-
2015	69	N	-	-	-	-	-	-
2016	33	N	-	-	-	-	-	-
2017	154	N	-	-	-	-	-	-
2018	50	N	-	-	-	-	-	-
2019	245	E	11	4	11	4	-	-
TOTALE			11	4	11	4	-	-
Per 1 unit of production (in €)			0.23	0.09	0.23	0.09	-	-

Table 59: MADHYA PRADESH OND- TOTAL SEASONAL RAINFALL INDEX								
Year	Rainfall	Obs/LPA	Excess-Deficit		Excess		Deficit	
			A	B	A	B	A	B
2011	1	LD	1,223	1,223	-	-	1,223	1,223
2012	21	LD	1,314	1,314	-	-	1,314	1,314
2013	197	E	1,266	1,266	1,266	1,266	-	-
2014	97	N	-	-	-	-	-	-
2015	53	D	331	132	-	-	331	132
2016	70	D	270	108	-	-	270	108
2017	36	LD	830	830	-	-	830	830
2018	10	LD	958	958	-	-	958	958
2019	128	E	323	129	323	129	-	-
TOTALE			6,518	5,963	1,589	1,395	4,928	4,567
Per 1 unit of production (in €)			4.62	4.23	1.13	0.99	3.49	3.24

Table 60: MADHYA PRADESH OND - WEIGHTED ANNUAL SEASONAL RAINFALL INDEX								
Year	Rainfall	Obs/LPA	Excess-Deficit		Excess		Deficit	
			A	B	A	B	A	B
2011	1	D	407	163	-	-	407	163
2012	21	D	438	175	-	-	438	175
2013	197	E	422	168	422	168	-	-
2014	97	N	-	-	-	-	-	-
2015	53	N	-	-	-	-	-	-
2016	70	N	-	-	-	-	-	-
2017	36	N	-	-	-	-	-	-
2018	10	D	319	127	-	-	319	127
2019	128	N	-	-	-	-	-	-
TOTALE			1,587	635	422	168	1,165	466
Per 1 unit of production (in €)			1.13	0.45	0.30	0.12	0.83	0.33

Table 61: UTTAR PRADESH OND - TOTAL SEASONAL RAINFALL INDEX								
Year	Rainfall	Obs/LPA	Excess-Deficit		Excess		Deficit	
			A	B	A	B	A	B
2011	3	LD	4,348	4,348	-	-	4,348	4,348
2012	5	LD	4,671	4,671	-	-	4,671	4,671
2013	171	LE	4,502	4,502	4,502	4,502	-	-
2014	114	E	1,365	546	1,365	546	-	-
2015	29	LD	3,531	3,531	-	-	3,531	3,531
2016	36	D	960	384	-	-	960	384
2017	5	LD	2,951	2,951	-	-	2,951	2,951
2018	8	LD	3,408	3,408	-	-	3,408	3,408
2019	100	E	1,149	459	1,149	459	-	-
TOTALE			26,888	24,803	7,017	5,508	19,871	19,295
Per 1 unit of production (in €)			5.36	4.95	1.40	1.10	3.96	3.85

Table 62: UTTAR PRADESH OND - WEIGHTED ANNUAL SEASONAL RAINFALL INDEX								
Year	Rainfall	Obs/LPA	Excess-Deficit		Excess		Deficit	
			A	B	A	B	A	B
2011	3	D	1,449	579	-	-	1,449	579
2012	5	D	1,557	622	-	-	1,557	662
2013	171	E	1,500	600	1,500	600	-	-
2014	114	N	-	-	-	-	-	-
2015	29	N	-	-	-	-	-	-
2016	36	N	-	-	-	-	-	-
2017	5	D	983	393	-	-	983	393
2018	8	D	1,136	454	-	-	1,136	454
2019	100	N	-	-	-	-	-	-
TOTALE			6,627	2,650	1,500	600	5,126	2,050
Per 1 unit of production (in €)			1.32	0.53	0.30	0.12	1.02	0.41

ACKNOWLEDGEMENTS

First of all, I want to thank Prof. Gian Paolo Clemente for accepting without hesitation to follow me in the successful completion of this work and for accompanying me to the end of this course of study. Again thanks to his passion both as a teacher and as a professional, I was able to discover myself curious about the insurance world and more aware that it would be my path.

I want, in addition, to thank the whole team of P&C Underwriting Intern at SCOR in Milan who despite the fact that I have only recently embarked on the path with you, you have been welcoming, patient, eager to make me grow and to help me in the writing of the thesis by putting me in contact with Dr. Stève Udriot, whom I thank for his precious time and trust.

Inevitably, I have to thank my parents to whom I owe everything: you took me by the hand from a very young age until you made sure I could make it on my own. You have always been my safe haven, the hug after a cry, the pizza on a Saturday night and the strength to always get back up. You have always sought my smile even before yours and for that I will always be grateful because you are my only certainty and example of what it means to love unconditionally.
Thanks to you, Mom, who always listened to me and with your sweetness made me understand that small gestures matter, make us human and make more noise than many words. To you, Dad, on the other hand, I thank you because you have always lovingly tried to make me more aware of my abilities and qualities to always believe in and strive for even more.

A huge thank you also goes to my Aunt who has always been by my side at every milestone, every dance recital and every important moment for me. You always took care of the little girl inside me who, although grown up, should not be forgotten.

I must thank my beloved Grandparents, both those who are here with me and those who are but not physically, because you have always cuddled me during the endless afternoons of study, dance and more study. You have always rejoiced in my achievements and supported me in defeats, though always giving me a smile from which to start again.

Another particular thank goes to Giulia, Chiara and Arianna who have always understood me, sometimes more than I could do on my own, without judging me but simply listening to me.
Thank you, Giulia, who have always been a sure reference by my side accompanying me in my growth with thoughtfulness and showing me what it meant to be there for each other.
Thank you, Chiara, who always spurred me on to give the best of myself while also making me understand how to be well all it takes is a few people but sincere ones like you.

Thank you, Arianna, for always giving me your sweet point of view in every affair, for opening my eyes to the important things and for always being ready to give me the best possible advice.
Then I cannot fail to mention my university "colleagues" Chiara, Sofia, Alessandra and Sofia who have made these years better by making every class, every exam, every session in Necchi more possible. Thanks to you who have always supported and put up with me in my every doubt, indecision, joys (20%) and sorrows (80%) with your empathy, understanding and even a pinch of irony.

Thanks also go to you, Angelica, Marika, Alessandra,Ilaria, Alessandra and Silvia who always made me feel your affection, supported me through the ups and downs, and made me a better person with more lightheartedness in my heart.

Thank you to Francesca and Lisa who although you saw me grow up, you still decided to stay by my side, making your presence and affection felt, always.

I also thank Gaia, Arianna, Federica and Giorgia who besides the immense passion for dance that we share, you have always supported me and believed in me.

A huge thank you also goes to the "Baglioni" group who have always given me a smile, help, support and made this college journey surprisingly better.

I also thank all the people who always wanted to be near me with sincerity and affection, who cared about how I was doing, who helped me to make me see beyond the visible and understand beyond the unintelligible. Thank you to all of you who, even if temporarily or by accident, have left a positive wake in my life.

Finally, I thank myself for never giving up despite my being fragile in the face of all the disappointments, all the setbacks, all the "you can't do it," all the "you're not up to it." Thank you because even though giving up is not for the weak anyway, you decided to always get back up, to always believe, to always see a chance in the impossible as a testimony to all that you were able to overcome.

I wish everyone the strength to always believe in themselves without ever giving up because "to dare is to momentarily lose your balance, not to dare would be to lose yourself."

RINGRAZIAMENTI

Voglio ringraziare innanzitutto il Prof. Gian Paolo Clemente per aver accettato senza esitazione di seguirmi nella buona riuscita di questo lavoro e per avermi accompagnata alla fine di questo percorso di studi. Sempre grazie alla sua passione sia come insegnante e sia come professionista, ho avuto modo di scoprirmi curiosa per il mondo assicurativo e più consapevole che sarebbe stata la mia strada.

Voglio, inoltre, ringraziare tutto il team di P&C Underwriting Intern di SCOR a Milano che nonostante abbia intrapreso da poco il percorso con voi, vi siete dimostrati sin da subito accoglienti, pazienti, desiderosi di farmi crescere e di aiutarmi nella stesura della tesi mettendomi in contato con il Dott. Stève UDriot, il quale ringrazio per il suo tempo prezioso e la sua fiducia.

Inevitabilmente devo ringraziare i miei genitori a cui devo tutto: mi avete preso per mano sin da piccolina finché vi siete accertati che potessi farcela da sola sulle mie gambe. Siete sempre stati il mio porto sicuro, l'abbraccio dopo un pianto, la pizza al sabato sera e la forza per rialzarmi sempre. Avete sempre cercato il mio sorriso ancora prima del vostro e per questo ve ne sarò sempre grata perché siete l'unica mia certezza ed esempio di cosa voglia dire amare incondizionatamente.
Grazie a te, Mamma, che mi hai sempre ascoltata e con la tua dolcezza mi hai fatto capire che i piccoli gesti contano, ci rendono umani e fanno rumore più di molte parole. A te, Papà, invece ti ringrazio perché hai sempre cercato affettuosamente di rendermi più consapevole delle mie capacità e qualità in cui credere sempre e per cui lottare ancora di più.

Un immenso grazie va anche a mia Zia che è sempre stata al mio fianco in ogni traguardo, ad ogni saggio di danza e ad ogni momento importante per me. Ti sei sempre presa cura della bambina dentro di me che, seppur cresciuta, non va dimenticata.

Devo ringraziare i miei adorati Nonni, sia chi è qui con me e chi lo è ma non fisicamente, perché mi avete sempre coccolata durante gli infiniti pomeriggi di studio, danza e ancora studio. Avete sempre gioito delle mie conquiste e supportata nelle sconfitte, seppur donandomi sempre un sorriso da cui ripartire.

Un altro grazie particolare va a Giulia, Chiara e Arianna che mi hanno sempre compresa, talvolta più di quanto riuscissi a fare da sola, senza giudicarmi ma semplicemente ascoltandomi.
Grazie, Giulia, che sei sempre stata un riferimento certo al mio fianco accompagnandomi nella mia crescita con premura e mostrandomi cosa significasse esserci per l'altro.
Grazie, Chiara, che mi hai sempre spronata a dare il meglio di me stessa facendomi anche comprendere come per stare bene bastino poche persone ma sincere come te.

Grazie, Arianna, per avermi sempre dato il tuo dolce punto di vista in ogni vicenda, per avermi aperto gli occhi sulle cose importanti e per essere sempre pronta a darmi il miglior consiglio possibile.
Non posso poi non nominare le mie "colleghe" universitarie Chiara, Sofia, Alessandra e Sofia che avete reso questi anni migliori riuscendo a rendere più possibile ogni lezione, ogni esame, ogni sessione in Necchi. Grazie a voi che mi avete sempre supportata e sopportata in ogni mio dubbio, indecisione, gioie (20%) e dolori (80%) con la vostra empatia, comprensione e anche un pizzico di ironia.

Un grazie va anche a voi, Angelica, Marika, Alessandra, Ilaria, Alessandra e Silvia che mi avete fatto sempre sentire il vostro affetto, mi avete supportato negli alti e bassi, e mi avete resa una persona migliore con più spensieratezza nel cuore.

Grazie a Francesca e Lisa che nonostante mi abbiate vista crescere, avete deciso di rimanere comunque al mio fianco, facendo sentire la vostra presenza e il vostro affetto, sempre.

Ringrazio anche Gaia, Arianna, Federica e Giorgia che oltre l'immensa passione per la danza che ci accomuna, mi avete sempre sostenuta e avete sempre creduto in me.

Un immenso grazie va anche al gruppo "Baglioni" che mi avete sempre regalato un sorriso, un aiuto, un supporto e avete reso questo percorso universitario sorprendentemente migliore.

Ringrazio, inoltre, tutte le persone che hanno sempre voluto starmi vicino con sincerità e affetto, che si sono preoccupate di come stessi, che mi hanno aiutata a vedere oltre il visibile e comprendere oltre l'incomprensibile. Grazie a tutti voi che, anche se temporaneamente o per caso, avete lasciato una scia positiva nella mia vita.

Infine, ringrazio me stessa per non essersi mai arresa nonostante il mio esser fragile di fronte a tutte le delusioni, a tutti gli imprevisti, a tutti i "non ce la fai", a tutti i "non sei all'altezza". Grazie perché, anche se arrendersi non è comunque da deboli, hai deciso di rialzarti sempre, di crederci sempre, di vedere sempre una possibilità nell'impossibile come testimonianza di tutto quello che sei stata in grado di superare.

Auguro a tutti la forza di credere sempre in se stessi senza arrendersi mai perché "osare è perdere momentaneamente l'equilibrio, non osare sarebbe perdere se stessi".