ECONOMIC & SOCIAL SCIENCES

DEPARTMENT OF INTERNATIONAL AND EUROPEAN STUDIES

MASTER'S PROGRAM IN EUROPEAN STUDIES ON INTERNATIONAL SERVICES AND TRANSACTIONS

Dissertation

ALTERNATIVE RISK TRANSFER TRANSACTIONS

Paspati Maria

mes16007

Supervisor

Dr. Kiohos Apostolos, assistant professor

Submitted as requirement for the postgraduate degree in European Studies on International Services and Transactions.

Thessaloniki, March 2019

HELLENIC REPUBLIC
UNIVERSITY OF MACEDONIA

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Two-member committee

Dr. Kiohos Apostolos

Assistant Professor, University of Macedonia

Dergiades Theologos

Lecturer, University of Macedonia

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(Signature)

Paspati Maria

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“To the rational mind, nothing is inexplicable; only unexplained”

Fourth Doctor, Doctor Who Series, BBC.

Abstract

The constantly increasing growth of insured losses due to nature related catastrophic events (i.e. sudden events that cause significant losses to an individual or a group of people) has pressured the reinsurance industry to consider and develop alternative risk transfer products and transactions. These products are designed to alleviate the risk, in whole or partly, by putting into effect securitisation mechanisms in order to access adequate liquidity funds. Among them, Catastrophe (CAT) risk bonds are designed to transfer the financial consequences of natural catastrophic events (e.g. floods, hurricanes, earthquakes etc.) from the issuers to investors. CAT bonds quickly became popular, as they have been shown to successfully cover the insurers' liabilities, while, on the same time, they protect traditional reinsurance providers and governmental budgets.

Key words: alternative risk transfer, natural catastrophe, natural hazard, insurance - reinsurance, liquidity, Catastrophe bonds.

Περίληψη

Η συνεχής αύξηση των ασφαλισμένων ζημιών, οφειλόμενων σε καταστροφικά γεγονότα που συνδέονται με τη φύση (αιφνίδια γεγονότα που προκαλούν σημαντικές απώλειες είτε σε μεμονωμένα άτομα είτε σε ομάδα ατόμων), δημιούργησε μια πιεστική αναγκαιότητα για την αναζήτηση και ανάπτυξη εναλλακτικών προϊόντων και συναλλαγών μεταφοράς κινδύνου. Ο κλάδος της αντασφάλισης ανταποκρίθηκε με τη δημιουργία προϊόντων που είτε μετριάζουν είτε απαλείφουν τους κινδύνους, μέσω της εφαρμογής μηχανισμών τιτλοποίησης για την απόκτηση πρόσβασης σε επαρκή κεφάλαια. Μεταξύ των εργαλείων αυτών συγκαταλέγονται και τα ομόλογα καταστροφής (Catastrophe -CAT- bonds), τα οποία έχουν σχεδιαστεί για τη μεταφορά των χρηματοοικονομικών συνεπειών των φυσικών καταστροφών (π.χ. πλημμύρες, τυφώνες, σεισμοί, κ.λπ.) από τους ασφαλιστές στους επενδυτές. Τα CAT bonds καθίστανται όλο και πιο δημοφιλή, καθώς αποδεικνύεται ότι καλύπτουν επιτυχώς τις υποχρεώσεις των ασφαλιστών, προστατεύοντας, ταυτόχρονα, τους παραδοσιακούς προμηθευτές αντασφαλίσεων και τους κρατικούς προϋπολογισμούς.

Λέξεις κλειδιά: alternative risk transfer, φυσική καταστροφή, φυσικός κίνδυνος, ασφάλιση - αντασφάλιση, ρευστότητα, ομόλογα καταστροφής (Catastrophe bonds).

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1. Introduction

The lack of an exact definition for Alternative Risk Transfer is a result of the wide range of products and carriers that can be defined as Alternative Risk Transfer. Furthermore, the innovation of these products continues to expand throughout the years contributing to a variety of literature approaches and descriptions of the ART market.

A concise overview of the ART market will be attempted in Section 2 of this dissertation, based on the typology provided by Banks, E. (2008) and Cummins, J. D., & Weiss, M. A. (2009). As ART was developed with the objective to resolve the capacity and coverage issues of the conventional (re)insurance market, a brief reference in the latter will precede. This will facilitate a better understanding of the ART transactions, namely the attempt to transfer risk exposure from one market to another and seek for alternative financing solutions. The convergence of financial and insurance markets ensues from these transactions.

Section 3 will provide the legal framework of the insurance market in the European Union, as set by the Directives commonly known as Solvency I and II. Given that the laws that regulate both (re)insurance and ART markets in the United States of America are instituted in state level, it is difficult to present the legislation of all 50 States within the limited extent of the present dissertation.

An earthquake is a natural disaster that causes damage worldwide. The consequences affect both economic and social life, and may result in many casualties, regardless of the magnitude, when an earthquake strikes unprepared regions. Unlike other natural disasters, it is difficult to estimate the exact time of an earthquake; scientists can only predict the timeline and magnitude based on the history of earthquakes in a region. Europe has a long history of destructive earthquakes. Italy, the Balkans, Greece, Bulgaria, Romania and Turkey are among the most exposed regions of the continent.

Within the above-mentioned context the probability of an earthquake Catastrophe Bond issuance in Romania will be explored in Section 4, as earthquakes pose serious risks for life, properties and infrastructure for Romania. The model is presented and used to point out the main financial characteristics of such securities. The dissertation closes with some concluding remarks.

2. Alternative Risk Transfer-ART

Alternative Risk Transfer (ART) is a concept that cannot be defined precisely, yet. This results from the wide range of products and carriers that can be characterised as Alternative Risk Transfer and their continuous innovation and expansion through the years. Additionally, ART is not just a product, rather than a way of doing business, or a line of transactions. Two segments are generally accepted as components of the ART market: risk transfer through alternative carriers and risk transfer through alternative products. The first segment (alternative carriers or riskbearers) consists of self-insurance, captives, risk retention groups, and pools, while the second (alternative risk products) includes finite risk reinsurance, runoff solutions, committed capital, multiline, multiyear products, multi-trigger programs, structured finance and new asset solutions, and capital market solutions for weather risk.

Despite the lack of an exact definition, almost all alternative risk transfer products have at least one of the following attributes, as noted by Hartwig and Wilkinson (2007):

- *custom-tailored to the unique needs of the client;*
- *coverage provided on a multiyear basis;*
- *coverage applicable to multiple lines; or*
- *payoff can be triggered by multiple factors, rather than a single event.*

The complexity of most alternative risk "solutions" requires a combination of skills, both of insurance and financial professionals. When structuring, for example, a unique catastrophe risk the expertise of catastrophe modellers, capital-market experts, accountants, tax and legal experts is needed. Captives, on the other hand, are easier and quicker to form, with the solicitation of an experienced captive manager.

One characteristic of alternative risk solutions, as coverage against large scale exposures, is their dependence on non-traditional sources of capital. In other words, while in traditional insurance the risk is transferred from the policyholder to the insurer (or insurer to reinsurer), ART often seeks to cede risk into the capital market, instead of solely depending on capital arising from the insurer's payment claims. It is widely accepted that the risk absorbance capacity of global capital markets is far greater than that of the insurance and reinsurance ones; hence ART poses as an attractive solution for large, one of a kind problems. (Hartwig & Wilkinson, 2007:925-926)

2.1 Risk transfer through conventional reinsurance

Traditionally, the main method of risk transfer for insurers was the purchase of reinsurance. As most of the hybrid and financial risk-transfer products that have been developed in the past few years aim to handle "mega" risks (for example the ones resulting from natural disasters), this section will focus on the use of reinsurance as coverage for such risks.

2.1.1 How reinsurance works

In essence, reinsurance provides the mechanisms to share and diversify risk. It enables primary insurers to reduce their risk exposure and capital requirements. Insurers transfer risks like natural catastrophe risk (for nonlife insurers), longevity, epidemics, terrorism or financial risk (for life insurers) etc. to the reinsurance market, as a means to making their balance sheets and risk trails less volatile. Additionally, the presence of a reinsurance market enables a better use of capital, which allows reinsurers to accept more contracts or undertake larger risks with the same amount of capital.

As a risk-sharing mechanism, reinsurance offers diversification for extreme risks across regions and across market participants. Catastrophes can cause simultaneous and dependent losses, or be independent, and thus insurable, when taking place in different parts of the world. In this context, reinsurance acts as protection against extraordinary and unforeseen losses. Considering that a reinsurer is, in general, more widely diversified than an insurer, the latter needs to hold more capital when covering the same risk. This represents an economic gain produced by the reinsurance market. There is also evidence that reinsurance can be used to reduce taxes or to avoid bankruptcy costs, but this exceeds the scope of the present dissertation.

One can conclude that different levels of the primary insurer's capitalization, risk exposure, as well as regulative restrictions and permissions provide various motives when it comes to purchasing reinsurance. To sum up, insurers buy reinsurance when they cannot or do not wish to retain a risk and they can do this through any of the several ways the market provides them. One of the most traditional methods is writing a reinsurance policy on the effective losses incurred by the insurer during a given period. The main issue with this form of reinsurance is moral hazard. (Bernard, 2013: 604-606)

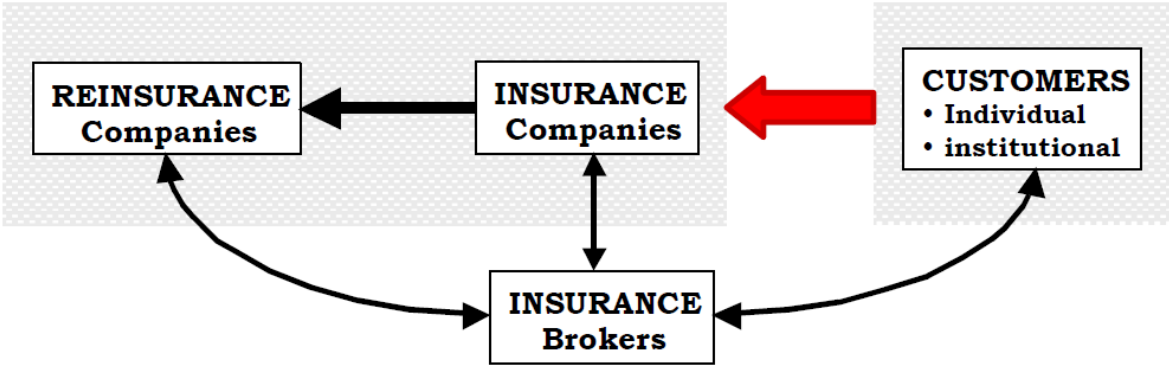

Figure 1: The Conventional Insurance Market
Source: Andersen, T. (2002). 16.

2.1.2 Moral hazard

International Risk Management Institute (2017) defines moral hazard as a "*term used to describe a subjective hazard that tends to increase the probable frequency or severity of loss due to an insured peril [...]*". It is estimated by the quality of the insured person and the particularities that surround the subject of the insurance, especially the extent of potential loss or gain to the insured in case of loss. Moral hazards should be taken into account when underwriting insurance, and are addressed by certain policy exclusions.

Like primary insurance, reinsurance contracts encounter moral hazard as well. Controlling the way the primary insurer underwrites activities or settles claims can prove costly and problematic for the reinsurer. Reinsurance allows a looser engagement in careful underwriting and loss mitigation for the primary insurer, a problem that can prove especially severe after a natural catastrophe, where the claims are overwhelming and the cost of settlements is transferred to the reinsurer.

Moral hazard can be averted through price controls, such as deductibles, co-payments, and "ex post settling up"[1]. Reinsurance is usually handled as a long-term relationship, where the cost of opportunistic behaviour increases as the contracting parties bond by means of experience. The primary insurer gets ongoing access to reinsurance, whereas the reinsurer can use the relationship's duration and the experience gained in increasing the effectiveness of its monitoring and setting future prices and terms. (Doherty & Smetters, 2005: 375-378)

[1] A retrospective adjustment of the premium based on losses incurred during the policy period that is also known as "retrospective rating".

2.1.3 Typical Reinsurance Arrangements

Ultimately, a reinsurance contract is an insurance contract bought by an insurance company from a reinsurer or from the financial market. The most commonly used structure of a reinsurance contract is non-proportional or *excess of loss* (XOL) reinsurance. It is used to transfer "mega" risks. Its payoffs have the same mathematical structure as on a call option spread[2] and are given by the following function (Cummins & Weiss, 2009:501-502):

$$L_R = a * \{Max\ [L_T - M, 0] - Max[L_T - (M + R), 0]\}$$

where

- L_R = the loss paid by the reinsurer,
- L_T = the total loss,
- M = the retention (lower strike price[3]),
- R = the reinsurer's maximum payment under the contract), and
- a = the proportion of loss paid by the reinsurer ($0 < a \leq 1$).

A loss-sharing proportion less than 1 (e.g., a = 0.9) is usually present to control moral hazard. Thereby, the ceding insurer (the one that transfers the risk) is more careful when settling underwriting and claims. Loss payoff triggers under non-proportional contracts can be defined in various ways, for example, per risk, per event, or per calendar period ("stop loss"). Catastrophe XOL contracts are usually per event.

Other important parameters in understanding the role of hybrid and financial market contracts are time period and the perils covered by the contract. Conventional reinsurance contracts are generally negotiated and priced on annual basis and are single-peril contracts. Some of the disadvantages of these contracts, like pricing exposure to the underwriting cycle[4],

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[2] The same payoff structure is also used for most Cat bonds and options.

[3] The strike price is defined as the price at which the holder of an option can buy (in the case of a call option) or sell (in the case of a put option) the underlying security when the option is exercised. Hence, strike price is also known as exercise price.

See further: The Options Guide. (2017). *Strike Price.* Retrieved from http://www.theoptionsguide.com/strike-price.aspx, accessed on 01/04/2017.

[4] Reinsurance markets pass through recurrent intervals of soft markets, when prices are relatively low and coverage is imminently available, and hard markets, when prices are high and coverage is stringent.

A soft insurance market is characterised by 1) lower insurance premiums; 2) broader coverage; 3) reduced underwriting criteria (easier underwriting); 4) increased capacity (insurance carriers write more policies and higher limits); and 5) increased competition among insurance carriers.

On the other hand, while in a hard market cycle 1) insurance premiums are higher; 2) underwriting criteria become more stringent (underwriting is more difficult); 3) market capacity is reduced (insurance carriers write less insurance policies); 4) competition among insurance carriers is restrained.

lead to innovations both in insurance and capital market. In addition, such inefficiencies constitute main drivers in the development of the ART market. (Cummins & Weiss, 2009:501-505)

How excess of loss reinsurance works

According to Kunreuther, Kleindorfer, and Grossi (2005), a typical excess-of-loss reinsurance contract requires the primary insurer to retain a specified level of risk with the reinsurer covering all losses between an attachment point, L_A, and exhaustion point, L_E, on the exceedance probability (EP) curve. For the purposes of their analysis, they assume that the exhaustion point, L_E, corresponds to the worst-case loss (WCL), and is defined by the target ruin probability (TRP) of 1%. The layer of reinsurance, L_E-L_A, is denoted as Δ. Schematically, this can be presented with the following diagram:

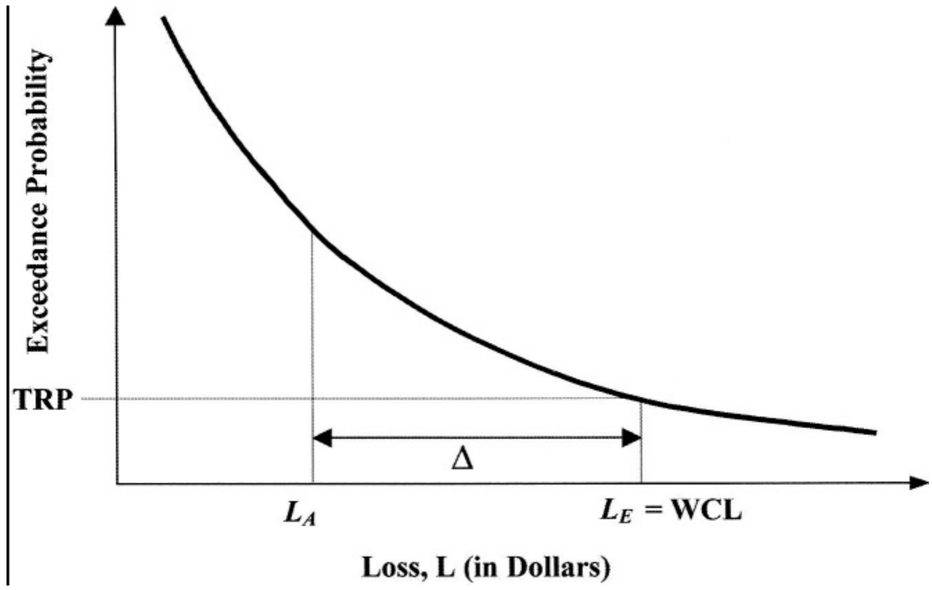


Figure 2: Excess-of-loss reinsurance contract
Source: Kunreuther, H., Kleindorfer, P., Grossi, P. (2005). 193.

Excess-of-loss reinsurance contracts have the following features: the reinsurer pays all losses in the interval L_A to L_E with a maximum payment to the insurer of Δ. The insurer pays the reinsurer a premium, which reflects the expected loss and poses as reimbursement for this protection, and a loading factor[5], λ_R If E(Δ) = the expected losses for Δ units of reinsurance, and λ_R is the loading factor, then the premium equals E(Δ) (1+ λ_R[6]).

See further: Craig, E. (2013). Hard Market vs. Soft Market: The Insurance Industry's Cycle and Why We're Currently in a Hard Market. PSA Financial Services Inc. Retrieved from https://goo.gl/eDEUK5, accessed on 01/04/2017.

[5] The loading factor is the fraction of premiums used to cover administrative costs and profits. It plays a crucial role in determining whether a market for a particular type of insurance will exist.

2.2 What is Alternative Risk Transfer (ART)

Alternative Risk Transfer (ART) basically uses alternative techniques toward achieving the same hedging and transfer of risk away from a risk bearing entity, like traditional insurance or reinsurance. ART enables companies to transfer risks to another party, or to capital markets' investors, and thus receive protection against certain risks the transactions aim to cover.

It grew popular during the 1990's, when insurance capacity issues drove insurers and reinsurers to seek new mechanisms (e.g. captives, risk retention groups, pools, etc.) to pass on their risks to a third party. Nowadays, alternative solutions emphasise on financing rather than transferring risks (e.g. finite solutions, committed capital, etc.), seeking multiline and multiyear coverage. Thereby, the term Alternative Risk Transfer is considered a misnomer and the more neutral term "non-traditional (re)insurance" or "structured (re)insurance" is sometimes used. Other authors refer to Alternative Risk Financing (ARF), though it is not solely restricted to the transfer of risks to the capital market but also comprises solutions to fund risk retention (e.g. via captives, contingent capital or financial reinsurance). (Frenz, 2012:5)

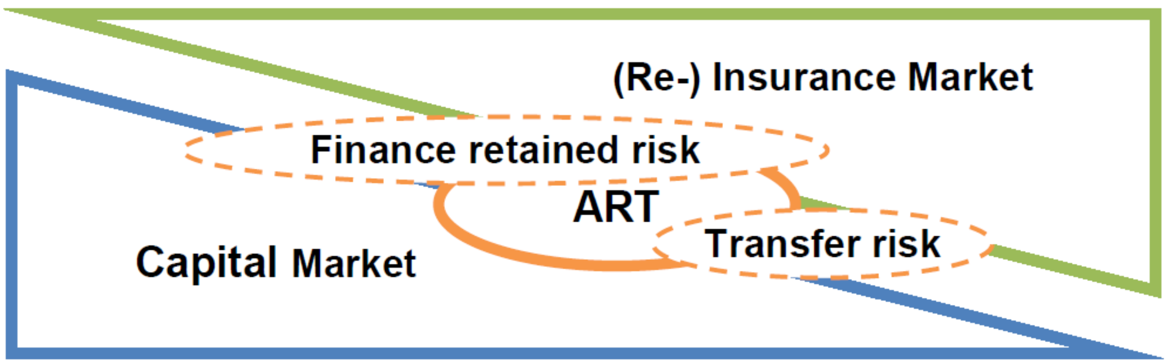


Figure 3: The ART market
Source: Frenz, T. (2012). 5.

2.2.1 Scope and coverage

ART market has a broad base so its scope and coverage vary significantly among practitioners, end users, and regulators. As indicated above, ART market offers combined risk management for innovative insurance and capital market solutions, while ART itself can be a product, channel, or solution for transferring risk exposures between the insurance and capital

One element of the loading factor is the insurer's required return on invested capital; the other is the administrative expense of the insurance company (the administrative component) and is affected by moral hazard. See further: Goodwin, B. K., Smith, V. H. (1995). *The Economics of Crop Insurance and Disaster Aid*. American Enterprise Institute, 77-83.

[6] For practical reasons the reinsurance loading factor λ_R is held constant in this particular example. In reality it varies, following the variations of the attachment points of the reinsurance contract.

markets. An optimal ART-based risk management plan often requires the combination of various multiple products, vehicles, and solutions. Banks (2008) uses these three categories to define ART market's scope, as they allow greater and more efficient dissemination of risk exposures throughout the financial system (Figure 4). The three segments are:

1) Product

Any instrument or structures used in achieving a defined risk management goal:

- Select insurance/reinsurance products, including finite risk policies. These minimal risk transfer insurance contracts are used to finance, rather than transfer, risk exposures.
- Multirisk products: insurance policies that combine multiple risks in a single structure, providing the client with a concentrated-integrated, and often cheaper and more efficient solution.
- Insurance-Linked Securities (ILS): capital markets issues referencing insurance risks, such as catastrophe, weather, and mortality, which are designed to transfer risk exposures and create additional risk capacity.
- Contingent capital structures: ex ante contractually agreed financing facilities that provide debt or equity financing for a corporation, in the wake of a loss event.
- Insurance derivatives: over-the-counter or listed derivatives that reference insurable risks, such as catastrophe or weather.

2) Vehicle

Any channel that is used to achieve risk management goals, like:

- Captives (risk retention groups): risk channels that are used to facilitate insurance/reinsurance the company itself, risk financing or risk transfer strategies (their usual form is that of a licensed insurance/reinsurance company that is controlled by one or more owners, often the sponsoring company).
- Special-purpose vehicles/reinsurers: subsidiaries that are used to issue insurance-linked securities and write offsetting reinsurance contracts.
- Bermuda transformers: insurance companies registered in the Bermudas, authorised to write and purchase insurance/reinsurance, and often used by banks to convert derivative instruments into insurance/reinsurance contracts.
- Capital markets subsidiaries: entities owned by insurance companies and are actively involved in the field of insurance derivatives and derivative products.

3) Solution

Any broad program that uses multiple products or vehicles to manage risk exposures on a consolidated basis. This category includes:

- Enterprise risk management programs: comprehensive risk management programs that combine diverse risks, time horizons, and instruments into a single, multi-year "plan of action". (Banks, 2008:50-51)

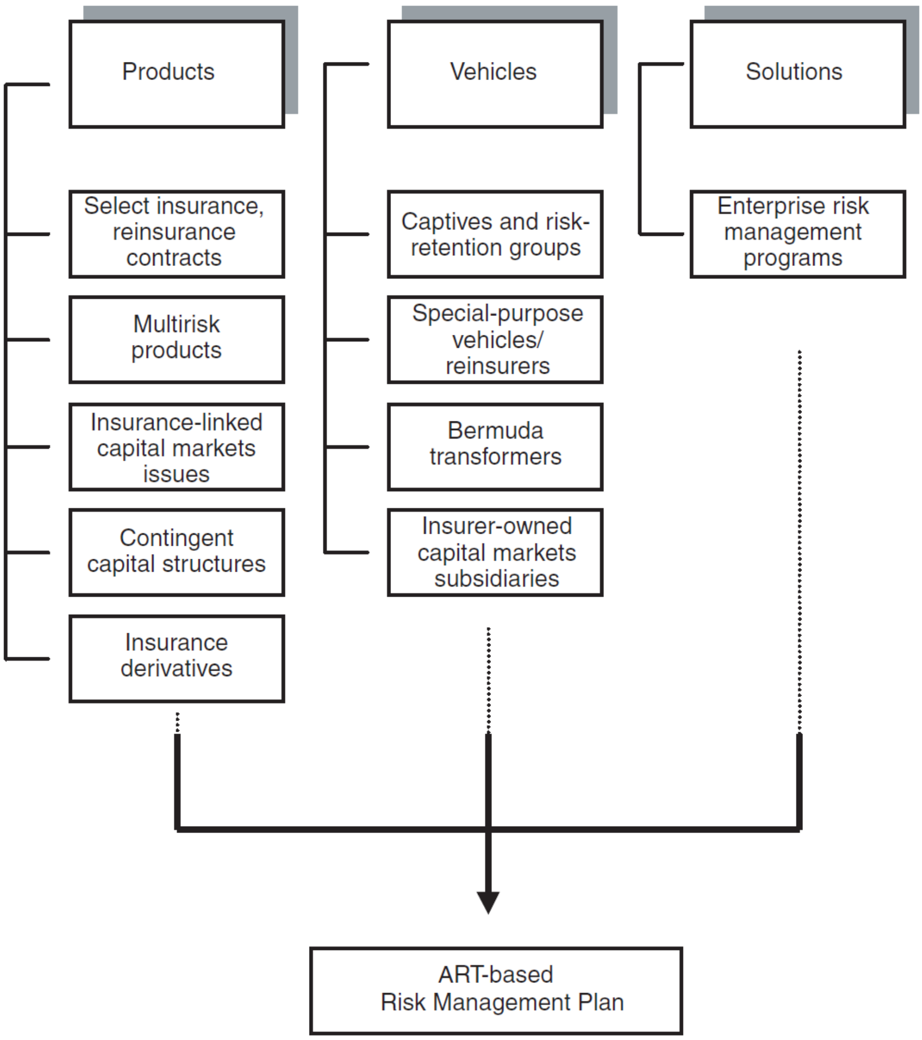


Figure 4: The three segments of ART market
Source: Banks, E. (2008). 51.

2.2.2 Participants

The participants in ART market are:

- Risk takers and investors such as reinsurers, life assurers, bank traders, capital market investors.
- Protection seekers like insurers, reinsurers and bank traders.
- Intermediaries like insurance brokers and investment bankers.

2.3 ART carriers and products

In order to explore how the various instruments fit in the ART marketplace, the typology of Cummins & Weiss (2009) was chosen among the wide literature studied for the purposes of the dissertation. The two authors categorise these instruments as shown in the following figure:

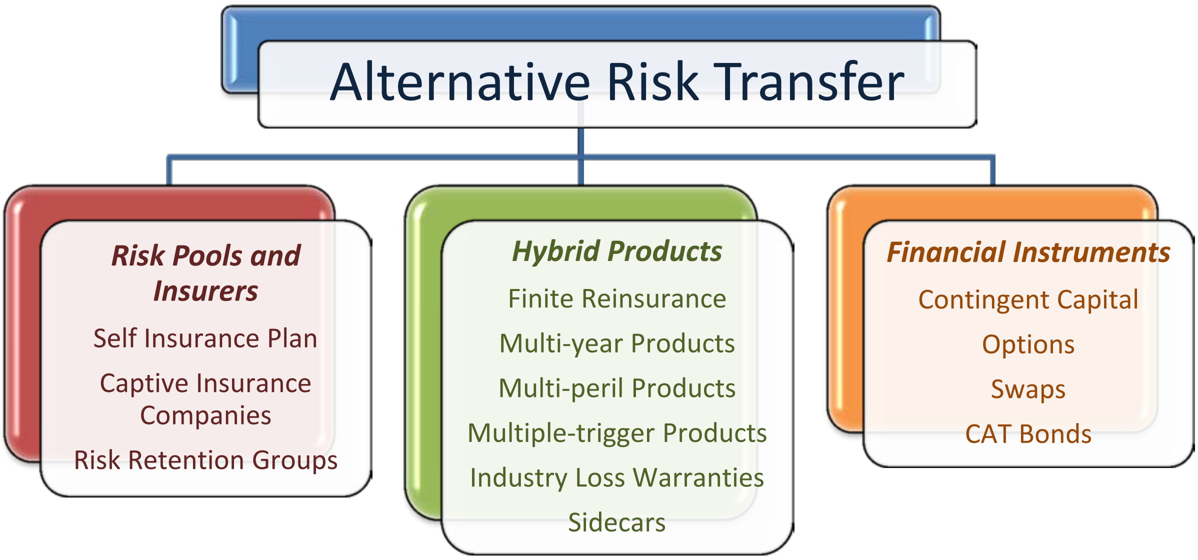


Figure 5: ART instruments
Source: Cummins, J. D., & Weiss, M. A. (2009). 506.

2.3.1 Risk Pools and Insurers

Arrangements between corporations or insurers to mobilise sufficient capacity for very large risks:

Self-Insurance Plans

Mostly a US phenomenon and strongly regulated in state level. It covers workers' compensation, general liability, product liability, auto liability and property. Workers' compensation, which accounts for the greatest area of self-insurance, and auto liability can only be self-insured as regulated programs.

Captive Insurance companies

Insurance or reinsurance companies created or owned by a corporation or an industrial, commercial or financial group of companies which are not active in the insurance business themselves (parent). The primary business purpose of a captive is to insure the risks of its parent(s). In essence a captive acts as an insurer that writes risks whose origins or access are restricted.

The simplest form of captive is pure or single parent captive, where a company sets up and capitalises a captive to cover its own risks (while not accepting risks from third parties). The captive acts like an insurer to the sponsor/owner, receiving insurance premium and paying claims. Part of the risk transferred to the captive is often ceded to a professional reinsurer. However this is not a main characteristic of a captive. Lastly, dividends or interest are paid to the sponsors of the captive, depending on the business performance. The workflow for a "pure" captive is presented in the following diagram:

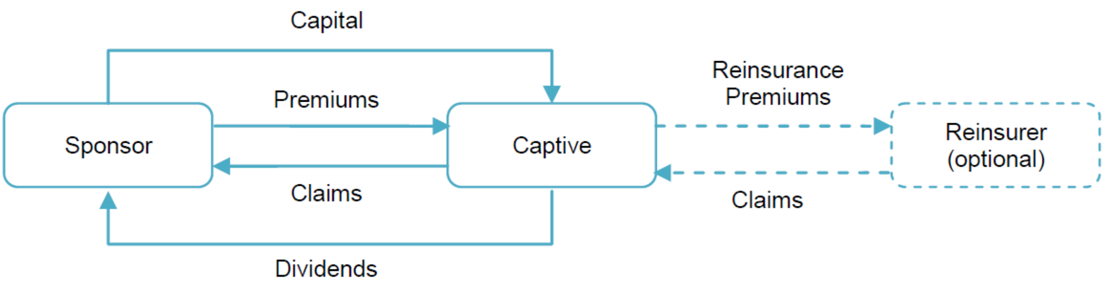


Figure 6: Single parent captive
Source: Frenz, T. (2012). 7.

The evolution of captives resulted in many variations that serve the different needs of their owners, like single owner and single user (related); single owner and multiple users (related); multiple owners and multiple users (related); single/multiple owner(s) and multiple users (unrelated). (Frenz, 2012: 7-8)

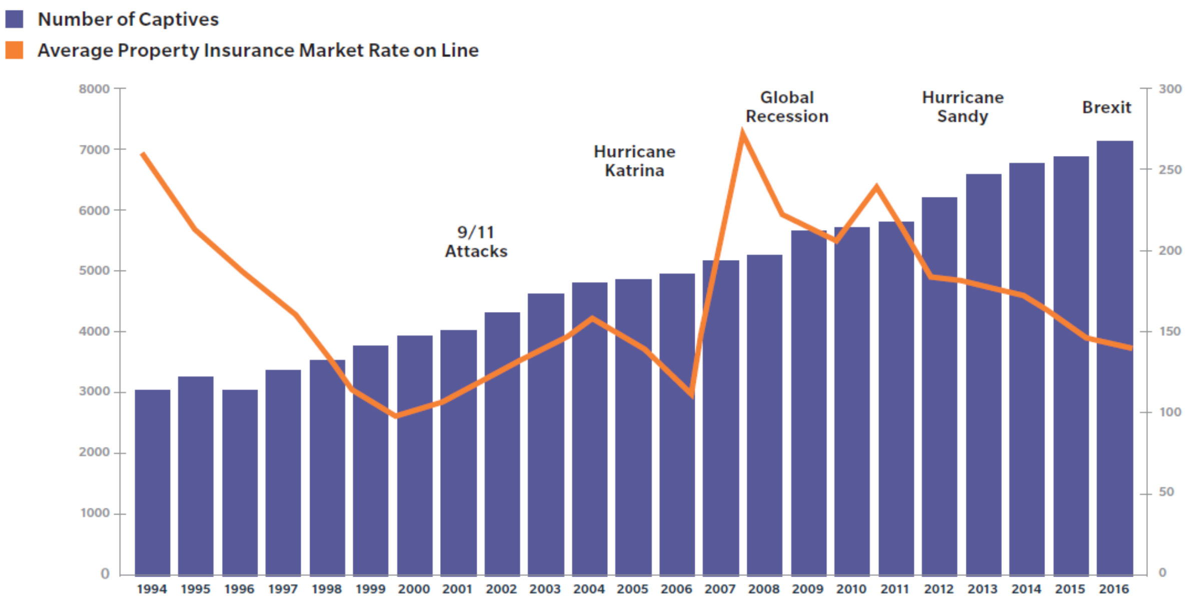


Figure 7: Total Captives Worldwide by Year with Corresponding World Events
Source: Marsh LLC and the Risk and Insurance Management Society, Inc. (2017). 2.

Table 1: Captive Utilisation by Parent Company Industry, 2016

Percentage by Number of 2016 Captives		Premium Volume of 2016 Captives
24%	Financial Institutions	US$24,590,900,884
12%	Health Care	US$2,058,491,682
7%	Manufacturing	US$1,325,169,540
6%	Retail/Wholesale	US$2,079,570,549
5%	Construction	US$291,735,058
4%	Communications, Media & Technology	US$4,872,307,853
4%	Transportation	US$938,123,258
4%	Power & Utility	US$839,130,666
3%	Other Services	US$524,282,103
3%	Energy	US$592,489,653
3%	Real Estate	US$82,123,740
3%	Chemical	US$287,423,741
3%	Automotive	US$244,732,345
2%	Mining, Metals & Minerals	US$623,252,794
2%	Food & Beverage	US$964,015,319
2%	Misc. Other	US$3,359,705,962
2%	Life Sciences	US$1,311,593,286
2%	Marine	US$700,942,832
1%	Education	US$57,453,610
1%	Agriculture & Fisheries	US$113,427,455
1%	Aviation, Aerospace & Space	US$389,259,718
1%	Professional Services	US$250,197,598
1%	Public Entity & Not-For-Profit	US$29,936,220
1%	Sports, Entertainment & Events	US$17,552,457
1%	Forestry & Integrated Wood Products	US$170,211,424
1%	Hospitality & Gaming	US$28,322,170

Source: Marsh LLC and the Risk and Insurance Management Society, Inc. (2017). 11.

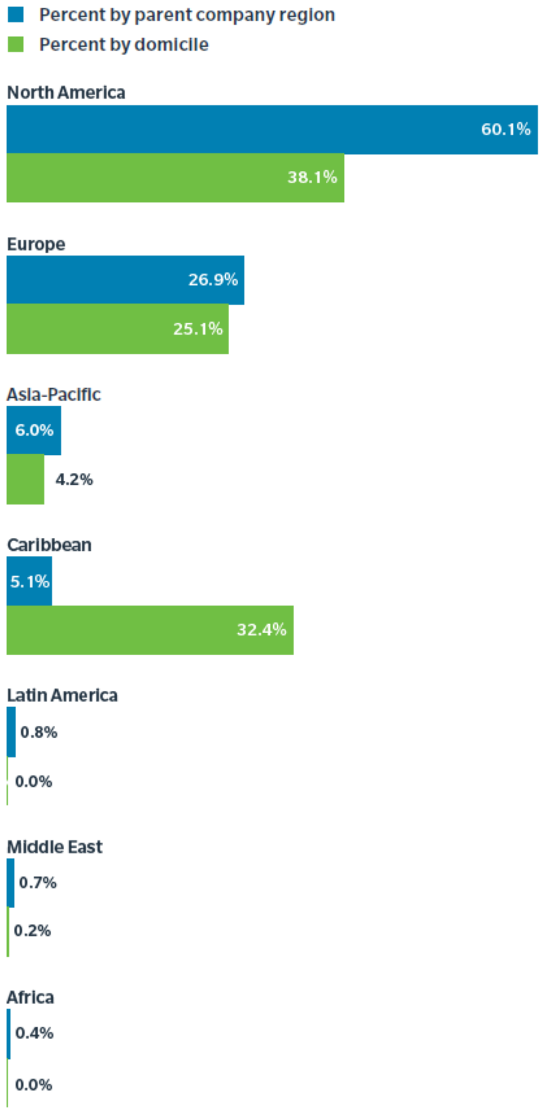


Figure 8: Parent Company Regions
Source: Marsh LLC and the Risk and Insurance Management Society, Inc. (2018). 15

1	Canada	4%
2	Greece	3%
3	Panama	3%
4	Hong Kong	2%
5	Taiwan	0%
6	China	-1%
7	Egypt	-4%
8	France	-12%
9	Denmark	-22%
10	Ireland	-24%

Figure 9: Least profitable countries for all captive business (Expressed as a percentage of all reinsured premiums per country)
Source: Commercial Risk Europe. (2017). 11.

Risk retention groups - RRGs

Kunkel (2003) describes a risk retention group as a policy issuing liability insurance company that is controlled by its owner. RRGs are met only in USA and can be formed either as captive or as a traditional insurance company, under the Federal Liability Risk Retention Act of 1986. Within a RRG, members who engage in similar or related business or activities are allowed to write liability insurance for all or any portion of the exposures of group members, excluding first party coverage (e.g. property, worker's compensation and personal lines).

Palumbo. Insurance Associates. (n.d.) add that RRG distribute the responsibility equally among the members and basically offer a different way of financing such liability. The primary requirements of an RRG include that:

- it can only write liability insurance;
- there must be more than one insured/owner;
- all insured's must be owners and likewise all owners must be insured's.

Table 2: RRGs premiums by business area 2014-2015, in million dollars

Business area	2014	2015 (1)
Healthcare	$1,594.3	$1,604.0
Professional services	477.8	466.3
Government and institutions	310.5	322.5
Transportation	194.6	223.7
Property development	140.0	149.4
All other sectors	118.8	151.2
Total	**$2,836.0**	**$2,917.1**

(1) Projected.

Source: Insurance Information Institute, Inc. (2018).

2.3.2 Hybrid Reinsurance-Financial Products

They incorporated characteristics of both financial instruments and reinsurance, while the financial instruments resemble products traded in capital markets.

Finite Risk Reinsurance

Finite is a type of reinsurance contract. Finite risk solutions constrain the reinsurance company's drawback, in contrast with conventional reinsurance, leaving a greater amount of that risk with the insured. The insured contractor also partakes in its own positive claims experience, sharing a portion of the gains that insurance companies typically retain. In this sense, finite risk is a hybrid of risk finance and risk transfer. There is risk finance because on one hand the insured can access capital to meet timing risk, but on the other carries the cost of his/her own risks. There is risk transfer because some risk is transferred to the reinsurer, even if less evidently than in traditional reinsurance programs. (Culp & Heaton, 2005:18)

Blended and Multi-Year, Multiline products

Blended covers combine elements of both conventional (significant underwriting) and finite risk reinsurance (non-traditional risk-management). Thus, blended covers may cover multiple years, insulating the cedent from the reinsurance cycle, and usually involve recognition of the time value of money. They tend to be more available during the "soft" phase of the reinsurance cycle.

Integrated or structured multi-year/multiline products (MMPs) modify conventional reinsurance by: (1) incorporating multiple lines of insurance in the same policy; (2) providing coverage at a predetermined premium for multiple years; (3) including hedges for financial and underwriting risks; and (4) covering risks not traditionally considered insurable (e.g. political risks and business risks). (Cummins & Weiss, 2009:510-511)

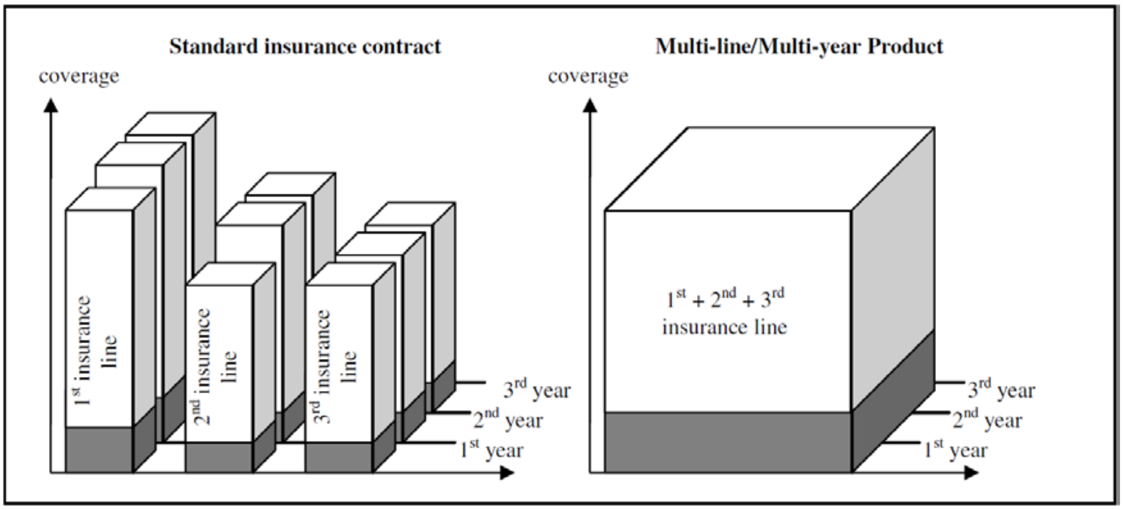


Figure 10: A model of Multi-line/Multi-year Product (MMP) compared to the model of a standard insurance contract
Source: Wieczorek-Kosmala, M. (2010). 456.

Multiple-Trigger products

Multi-trigger products (MTPs) are based on a holistic risk approach and their key feature is that the burden of loss, and consequently the claim, is paid only if two or more predefined triggers occur simultaneously. In a typical dual trigger structure the first trigger is always a defined insurance event and the second trigger a non-insurance one. However, a MTP can also be structured as a triple trigger structure. From the insurer stance the presence of a second (or third) trigger reduces the probability of loss and allows offering a lower premium. In general, the non-insurance trigger is linked to a financial indicator, namely the price of a commodity, an interest rate or a rate of return. (Wieczorek-Kosmala, 2010: 456-457)

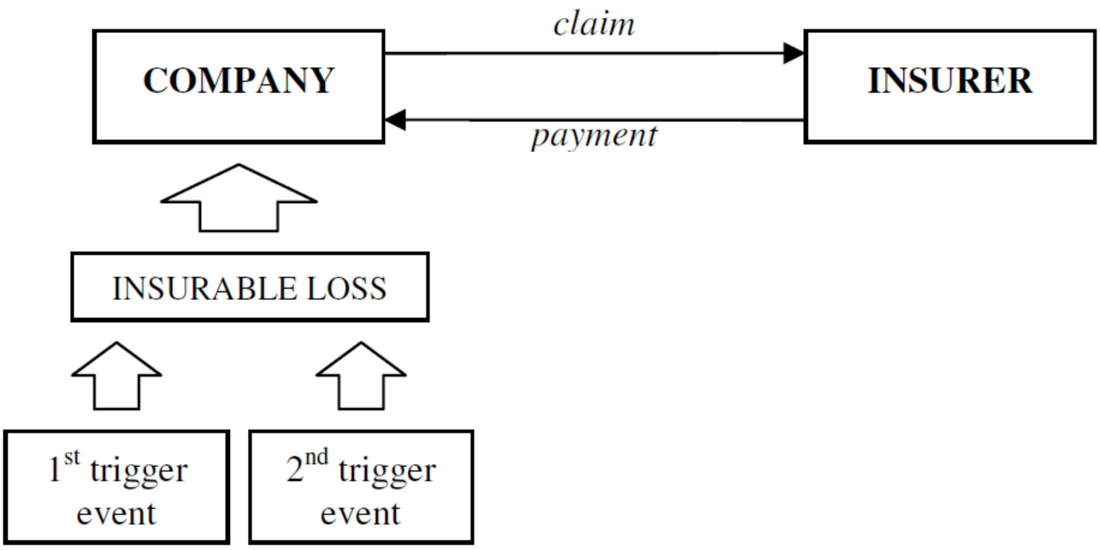


Figure 11: A model of Multi-trigger Product (MTP) with a dual trigger structure
Source: Wieczorek-Kosmala, M. (2010). 457.

Industry loss warranties

The various instruments that can be identified as Industry Loss Warranties (ILW) are also known as Original Loss Warranties (OLW). They basically cover losses from events where the industry-wide insured loss (and not a single company's loss) exceeds some pre-agreed threshold. As the operative trigger is an industry loss, there is an implication of a possible loss to the reinsured portfolio without triggering the ILW, on the condition that the corresponding industry loss is smaller than the industry trigger amount. This is the "basis risk" for the reinsured and is higher for companies whose aggregated risk exposures are far from the industry norm. Hence, ILW covers are usually preferred by companies whose portfolios closely follow the market. Such detach can be relented with the selection of a proper trigger. Factors like geography, level, and other events contribute to the formation of the trigger amount and the selection of industry loss in each case, offering a variety of ILWs. (Ishaq, 2005:76)

Sidecars

The main purpose of sidecars is to allow investors to take the risk and return of a small and limited category of insurance policies, like short-tailed property catastrophe policies written by a (re)insurer. They are funded by capital market investors (sponsors) through equity or debt financing. In the first case, a holding company is usually set-up in order to allocate the equity stake to equity investors. In the second case, debt financing is provided either directly to the sidecar or through its holding company.

In essence sidecars are special purpose entities (or special-purpose vehicles, or "disposable reinsurers"), with limited life span (usually 3 years), that serve as quota-share reinsurance against property catastrophe for their sponsors. The latter aren't obliged to undertake the long-term investment risk associated with a (re)insurer's entire book of business or legacy loss reserves. (Willis Property Resource Group, 2007:1)

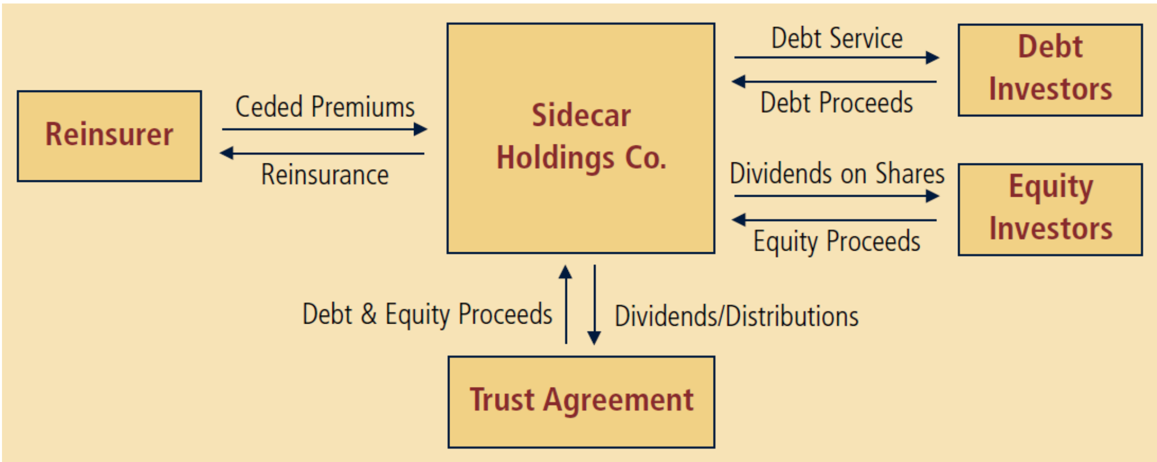


Figure 12: Simplified sidecar structure
Source: Willis Property Resource Group. (2007). 1.

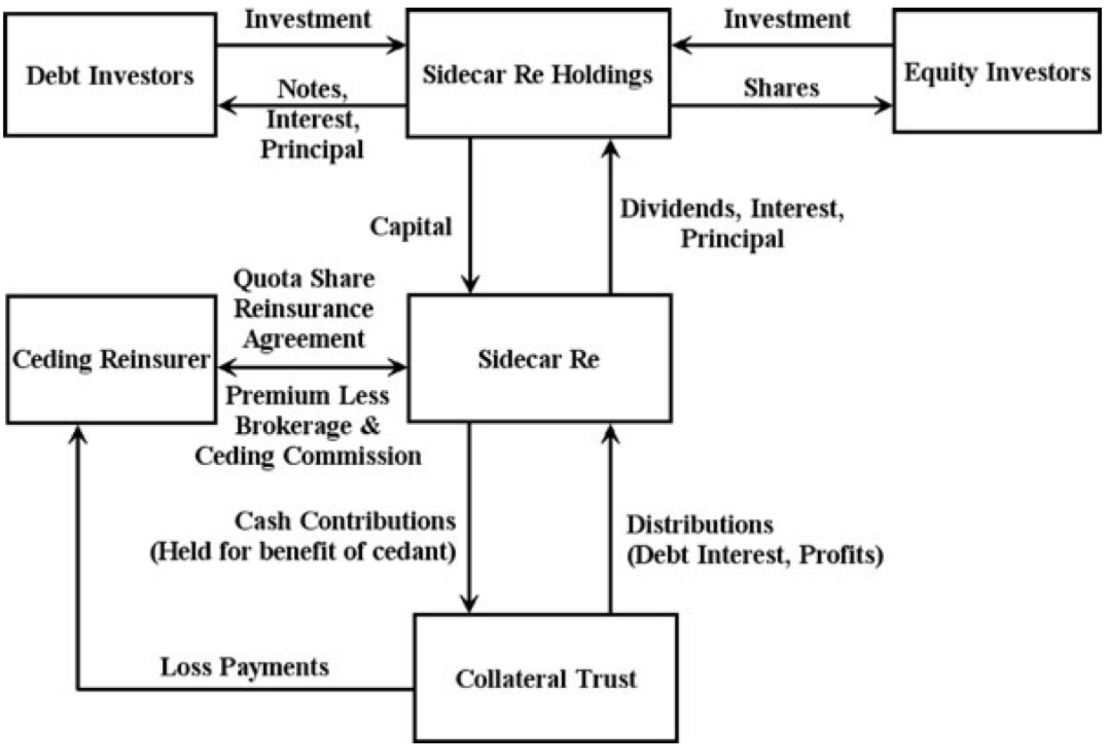


Figure 13: Structure of a typical sidecar
Source: Cummins, J. D., & Weiss, M. A. (2009). 514.

2.3.3 Financial Instruments

Financial instruments are of great importance because of their ability to absorb the risk of large catastrophes and their potential to add transparency and liquidity to the risk transfer market.

Contingent Capital

Contingent capital instruments, also known as contingent convertible bonds (CoCo bonds), contingent surplus notes, or enhanced capital notes, provide a mechanism that automatically converts the instruments to equity upon the occurrence of some specified trigger event.

Two of the most common types are catastrophe equity puts and contingent surplus notes. The first entitles the insurer to sell stocks at a fixed price if a specified trigger event occurs. The second entitles the insurer to issue surplus notes in exchange for liquid assets, in case a predefined trigger event takes place. However, the trigger events (i.e. the risks from which the companies have been protected), are normally related to catastrophe risk. The term of the protection is also relatively short.

The main reason why contingent capital was introduced into the capital structure was that, from the regulators' perspective, it could solve the "too-big-to-fail" problem and reduce the loss paid by taxpayers instead of the investors. Compared to issuing new stocks, investors want to avail themselves on the debt-like feature of the contingent capital: tax deductibility before the conversion and upfront and fixed recapitalization cost at conversion. (Shang, 2013:7-8)

By providing additional resources when needed, contingent capitals reduce the need for government intervention and bail out. In the European Union, the Basel Committee has included them in bank regulatory capital in 2010, under the Basel III framework. The majority of the Basel III proposals have been implemented by the Capital Requirements Regulation (Regulation (EU) No. 575/2013) ("CRR") which, together with the Directive 2013/36/EU and recasting the previous Capital Requirements Directive, form the package of legislation known as "CRD4".

Options and Swaps

Options

In the ART market there are insurers who wish to transfer risk and there are investors who can meet this demand. However, such transactions should meet the institutional needs of both the investors and the insurers.

As investors are ill-equipped to deal with counterparty risk[7] (default risk), they base the contract on the combined results of several insurers, i.e. a catastrophe index. However, trading contracts on an index introduces additional risk for the insurer, on the grounds that the money it recovers from a catastrophe contract might be much different from its own losses.

The insurer would care for a high correlation between its losses and the index, as is the case for reinsurance, so as to minimise its basis risk. The other counterparty, the investor, seeks to maximise profit while adding the least amount of risk to the total investment portfolio. Both the insurer and the investor want to quantify their risk.

Often enough, the returns on available investments have a tendency to correlate over time. For instance, stock returns tend to correlate with the general economy. If the value of the index has no correlation with the seller's other investments, the investor will undertake less risk by selling contracts on the index than if he took on an otherwise equivalent investment on the stock market. (Meyers, 1998:188-189)

Swaps

Swaps usually offer coverage for multi-year periods, not only against natural catastrophes, but against extreme mortality and longevity risks as well. They are suitable for smaller transactions, as they are not collateralised. We have two types of swaps:

1. Financial swaps, where two parties exchange risk for a commitment fee (usually a floating rate linked to the London Interbank Offered Rate - LIBOR). The payment is contingent on catastrophic insurance event (the trigger), therefore increasing the buyer's capacity.

[7] Counterparty or default risk is the risk to each party of a contract that the counterparty will not live up to its contractual obligations.
See further: Investopedia LLC. (2017). *Counterparty Risk*. Retrieved from http://www.investopedia.com/terms/c/counterpartyrisk.asp, accessed on 08/04/2017.

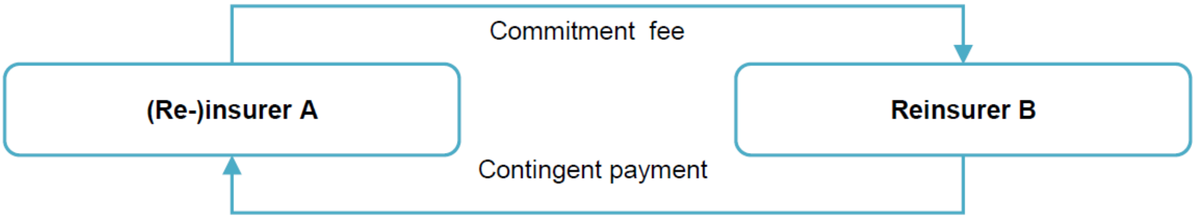


Figure 14: Financial swap transaction flow
Source: Frenz, T. (2012). 16.

This swap is much the same as an ordinary reinsurance contract. However it is reserved as a financial instrument.

2. Portfolio cat swaps, where two parties exchange uncorrelated catastrophe exposures. The goal is to achieve better diversification within their portfolio, by reducing exposure from one line of business and assuming another, diversifying, one. As the exposures are usually defined, no additional payment of a commitment fee is required by the counterparties (i.e. same expected claims). Such transactions only improve the existing capital position and not provide new one.

   In the following diagram, provided by Frenz, a reinsurer swaps a portion of his exposure to an earthquake risk in Tokyo with a fraction of a US wind risk undertaken by a domestic US insurer:

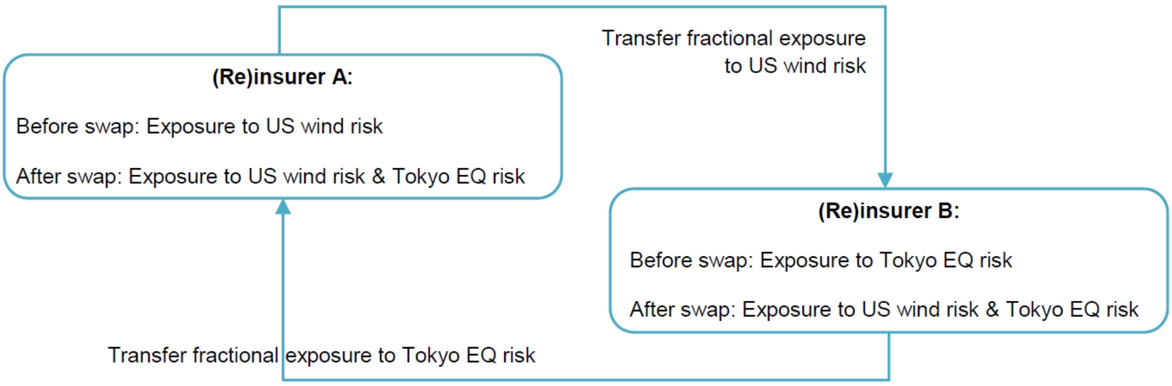


Figure 15: Portfolio cat swap transaction flow
Source: Frenz, T. (2012). 16.

Swaps like the above could be structured either as derivatives or as reinsurance contracts.

Catastrophe Bonds

Catastrophe bonds, or shortly CAT bonds, were introduced in the capital markets in the 1990s and they are the most common and accepted form of insurance linked securities. They are sponsored by insurers and reinsurers and employ securitisation to increase insurance capacity in the global reinsurance market.

A catastrophe bond transaction centres on a special purpose reinsurance vehicle (SPV), which is also known as transformer (because it transforms insurance risk into securities). The SPV issues and sells securities (catastrophe bonds) to institutional investors, and the proceeds from the sale are deposited in a collateral trust account and invested into highly rated short-term investment assets. The SPV then provides reinsurance to a ceding insurer or reinsurer (an insurance company seeking to transfer risk, henceforth the cedent or cedant), who pays a premium in exchange. The premium, as well as any income earned on the trust investments (which are often swapped for either fixed or variable returns provided by a swap counterparty), funds interest payments to investors. An interest coupon[8] is paid periodically and the principal is returned at maturity unless the bond was triggered by a loss event.

If the bond is triggered, the principal repayment and coupon could be reduced or forfeited in full, or the principal repayment delayed. In this sense, the bond provides coverage equal to its issuance value, through a single insurance policy, and is fully collateralised by the funds held in trust. The reinsurer "economises" on collateral, as the value of its collateral assets support a much larger face value of coverage than in the case of the catastrophe bond (where the value of collateral assets supports exactly the same amount of coverage). In other words, the reinsurer takes advantage of imperfect correlation among its multiple cedents to promise more in coverage than it actually holds in assets.

If no event occurs, the principal is returned to investors. A key institutional detail is that the entire face value of the bond is held in trust and available if the bond is triggered. (Lakdawalla & Zanjani, 2012:452-454)

[8] The interest coupon is usually a floating rate such as LIBOR, plus a spread.
The risk period commonly coincides with the major renewal dates (1 January or 1 July) and runs over multiple years – mostly 3 years and some up to 5 years.

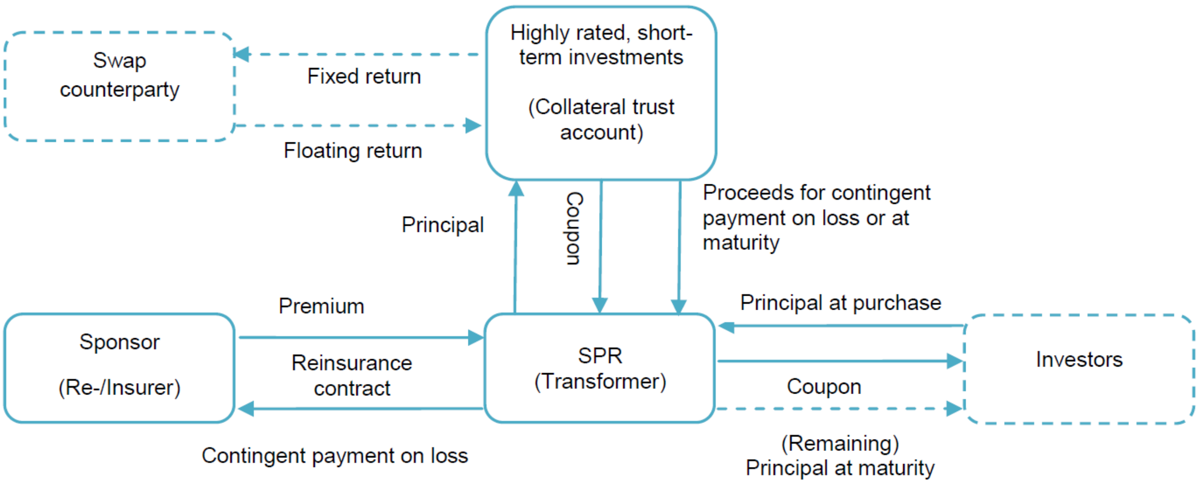


Figure 16: Typical Catastrophe Bond structure
Source: Frenz, T. (2012). 12.

Frenz (2012) records the following trigger classification:

- The indemnity trigger is based on actual financial losses to the sponsor-issuer. Indemnity triggers basically mirror excess-of-loss reinsurance.
- Industry-loss index triggers use an index that is calculated by a third-party[9]. The index measures the level of industry-wide losses instead of the individual company's loss and is based on actual insured loss information collected directly from insurance companies writing insurance business in the affected territories.
- A pure parametric trigger uses a clearly defined parametric loss metric, for instance if the rainfall, wind speed or earthquake in a defined coverage area exceeds a given threshold.
- Parametric index: A more refined form of a parametric trigger that aims to reduce basis risk by using more measurement locations and weighting factors at each location to more accurately recognise the vulnerability and value distribution.
- Modelled loss triggers are also based on a specific loss index; however the index is calculated using a predefined catastrophe simulation model and parameters. This trigger aims to model the expected loss based on the given assumptions, which can be set to mirror the sponsor's exposure.

[9] Namely risk-modeling companies that calculate in sufficient accuracy the estimated industry-wide loses for specific events.

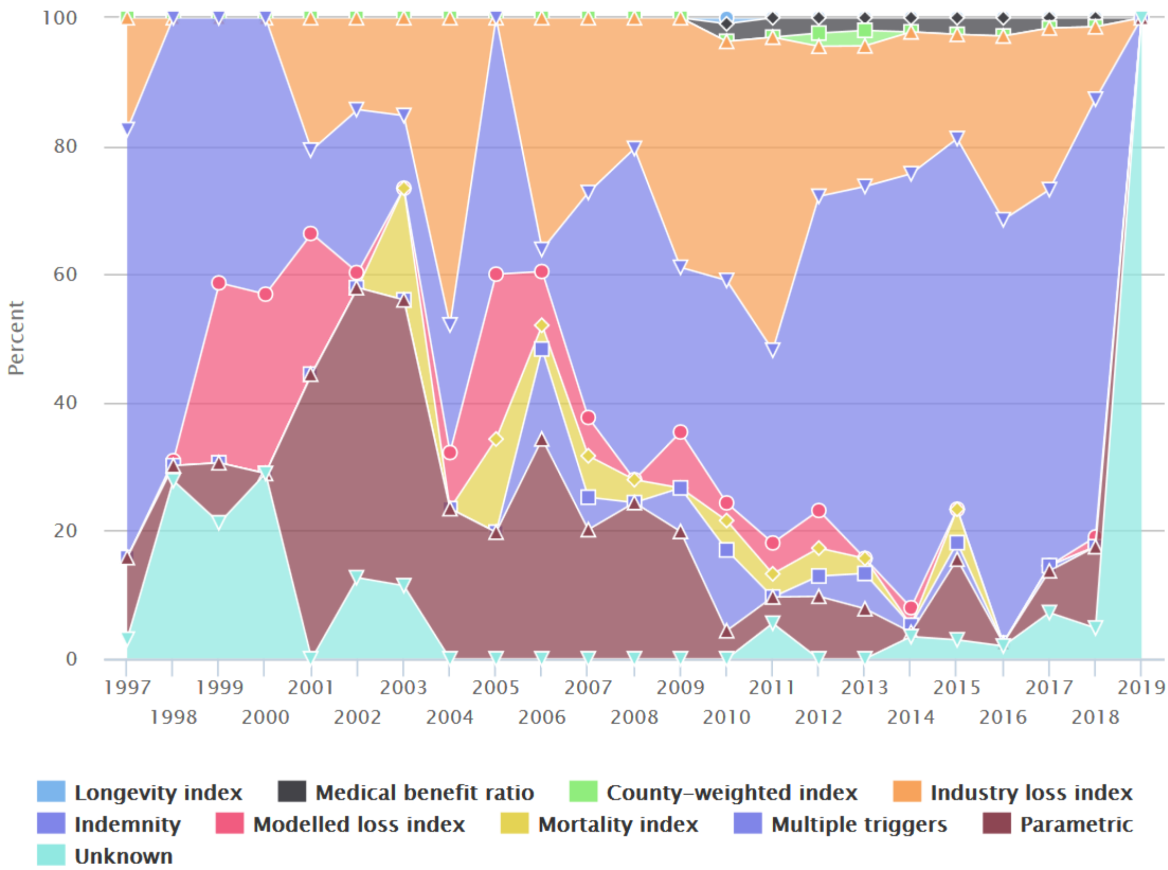
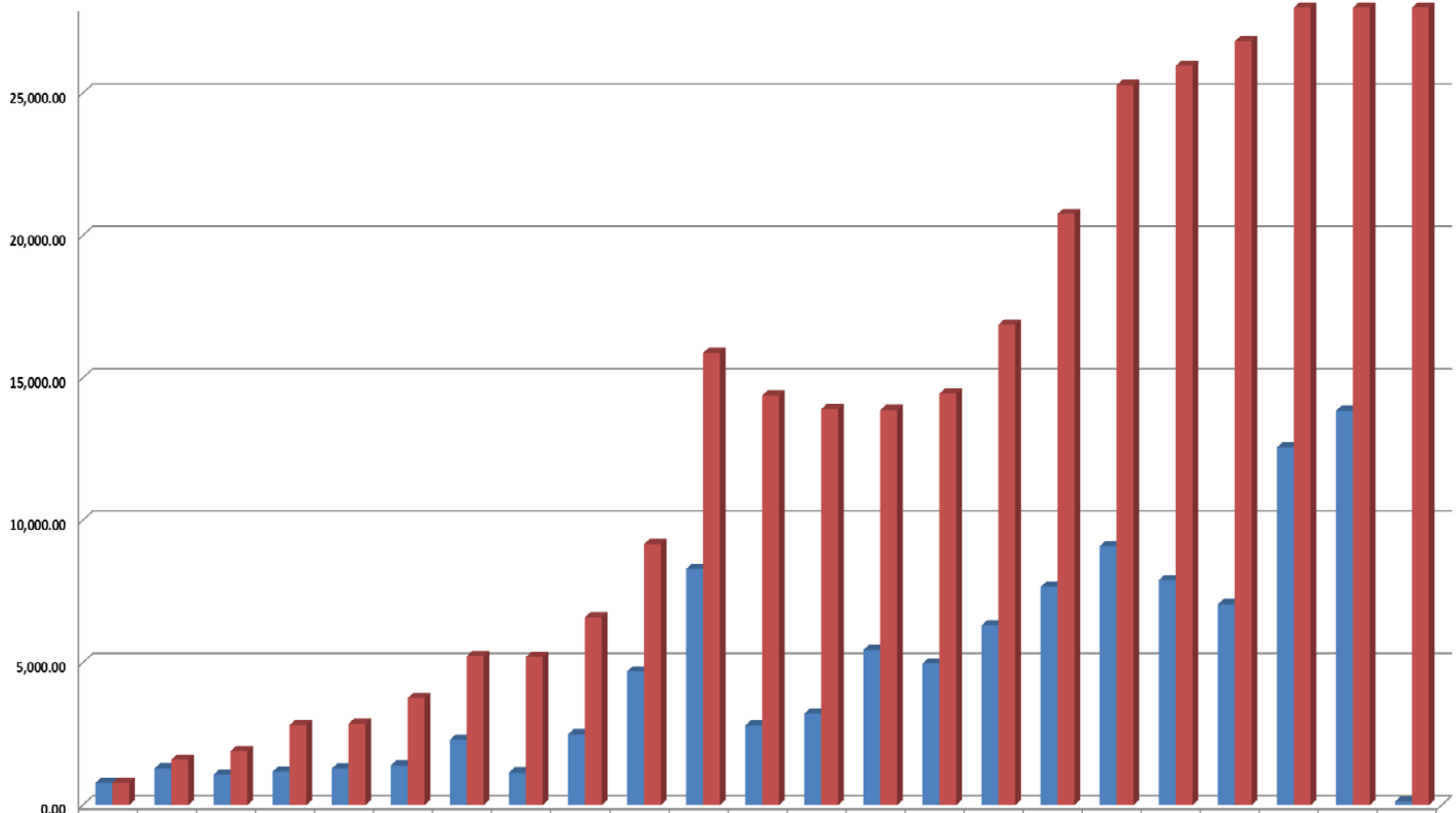


Figure 17: Catastrophe bonds and ILS issuance by trigger and by year
Source: Evans, S. (2017a).

Table 3: Overview of Indemnity vs. Parametric Protection

	Traditional (aka Indemnity)	Parametric
Trigger	Loss of damage to the physical asset	Event occurrence exceeding the pre-defined parameter threshold
Use of proceeds	Intended to cover sustained loss	Used at buyer's discretion (i.e. emergency relief, immediate infrastructure repair, compensation to people)
Loss adjustment / Administrative Process	Yes – buyer may need own claims adjusters	No – no additional administration required
Speed of payment	Subject to loss adjustment (Full settlement can be slow and lengthy)	Very rapid, 2 to 6 weeks
Basis risk	No basis risk, actual incurred loss will be covered up to limit purchased	Yes, if there is actual damage but the trigger chosen does not react as expected there will be no payment
Transparency	Wording and structure can be complex	Parametric triggers typically easy to explain
Duration of cover	Typically 1 year contracts, multiyear no longer than 3 years	Typically multi-year 2 to 5 years
Pricing Flexibility	Limited modifications	Structure can be adjusted to price
Changes of Exposures	Annual adjustments	No adjustment needed

Source: Kessler, T. (2016). 6.



	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Issued	785.50	1,289.78	1,068.85	1,176.10	1,283.90	1,396.45	2,294.48	1,142.80	2,489.12	4,694.55	8,293.73
Outstanding	785.50	1,595.28	1,892.03	2,806.13	2,858.35	3,760.95	5,235.00	5,201.23	6,599.50	9,165.65	15,877.1

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Issued	2,795.27	3,211.26	5,446.92	4,969.52	6,309.86	7,667.94	9,094.07	7,898.18	7,052.70	12,560.0	13,850.2	128.00
Outstanding	14,383.1	13,904.9	13,873.0	14,448.3	16,872.4	20,754.7	25,279.5	25,960.4	26,819.9	31,036.0	37,830.1	36,668.5

Figure 18: Catastrophe bonds & ILS issued and outstanding by year, million dollars
Source: Evans, S. (2017b).

2.4 Summary and evaluation of ART

Large US corporations use risk carriers such as captives, risk retention groups, and self-insurance to overcome capacity shortages. Captives have evolved into a global business with an increasing number of locations, including offshore financial centres, competing with each other to provide attractive business environments and taxation benefits.

Pools have been used by several industries to cover liability risk but also for states and multinational organisations to cover natural or man-made catastrophe risk.

Finite solutions are custom-made for prospective and retrospective coverage. Multi-risk products reduce the number of reinsurance counterparties, as they combine a number of risks for various non-life insurance lines.

Derivatives are bi-lateral, standardised products and rather inexpensive. Only few of the counterparties are currently apt to and interested in exchange-traded products. Therefore, liquidity is still rather low, and secondary market pricing is difficult. Over-The-Counter products like ILW are more liquid and, if traded as derivatives, based on International Swaps and Derivatives Association (ISDA[10]) standard terms and conditions.

ILWs formed as derivatives bridge reinsurance and capital markets, since a signed ILW is not treated as an insurance activity. Alternatively, ILWs can be traded as reinsurance contracts and are comparable to traditional single- or double-trigger cover.

Contingent capital is a rather limited resource, as it can hit the investor at a time when he may face his own difficulties because of an event of low probability and high severity.

Reinsurance side-cars are another product that bridges the traditional reinsurance sector and capital markets. Investors are able to take part in the reinsurance market for a limited period of time and follow the sponsor's fortune. The investor may choose between risks and further between segments with different risk profiles. (Weber, 2011: 90-91)

The various instruments used in ART transactions have both benefits and costs, which are recorded in various studies (e.g. Cummins & Lewis, 2002; Banks, 2004; Culp, 2012; Hartwig & Wilkinson, 2007; Cummins & Weiss, 2009; Maes & Schoutens, 2012; Ben Ammar, Braun & Eling, 2015). Weber (2011) presents a categorised overview of the instruments available (Figure 19), as well as a concise synopsis of the different products' characteristics (Table 4).

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[10] ISDA was established in 1985, aiming to make the global derivatives markets safer and more efficient. Its 850 member institutions from 68 countries work in three key areas: reducing counterparty credit risk, increasing transparency, and improving the industry's operational infrastructure.
See further International Swaps and Derivatives Association, http://www2.isda.org/about-isda/.

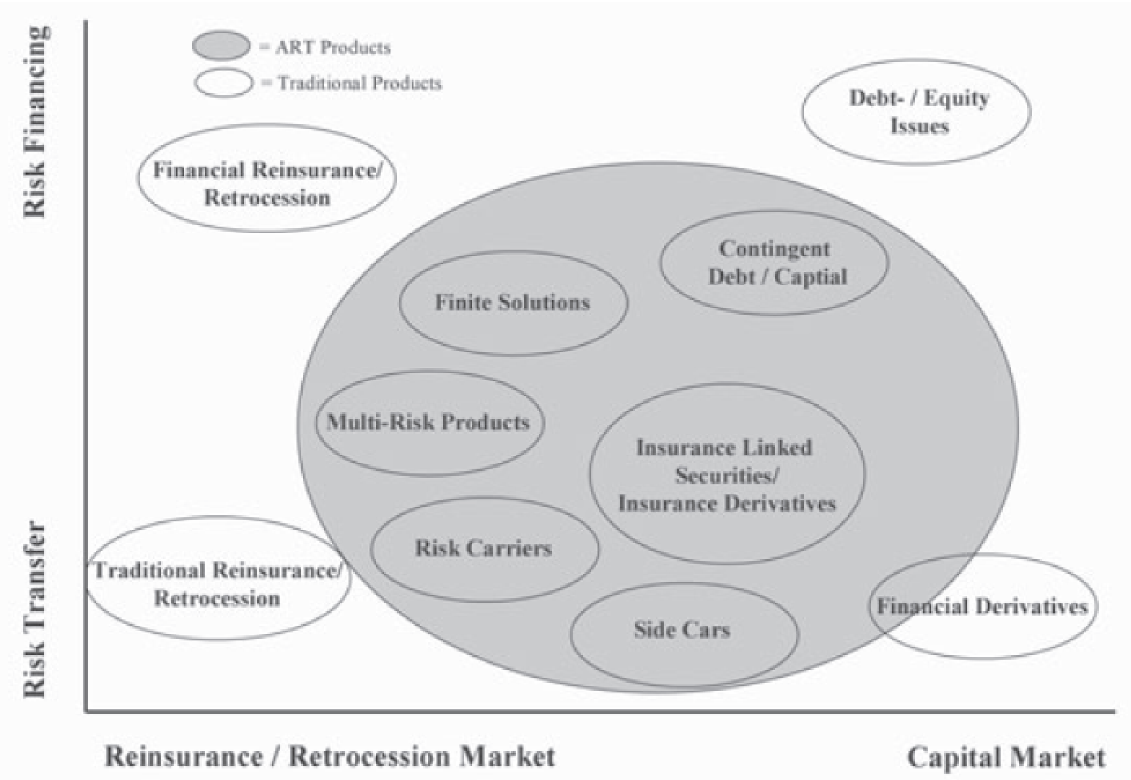

Figure 19: Spectrum of risk transfer instruments
Source: Weber, C. (2011). 90.

Table 4: Summary and evaluation of ART instruments

Type	Risk carriers	Finite Solutions	Multi-risk products	Derivatives	Contingent Capital	Side-cars
Product	captives, pools, self-insurance	Prospective / retrospective agreements	Multi-peril / multi-trigger programmes	Options / futures / ILWs / swaps	contingent debt / equity	reinsurance side-cars
Risk Types	non-life (liability risks: medical malpractice, auto, worker's, compensation, also: nuclear, terror)	life and non-life (third party liability, run-off portfolios)	non-life (commercial property, business interruption, general liability, equipment, inland marine, auto)	non-life / life (emerging)	life / non-life	non-life
Objective	Risk management: transfer of high frequency / low severity risk also low frequency / high severity (insurance pools to transfer other- wise non-insurable risk)	portfolio management: smooth losses over time; funding of losses: prospective or retrospective; capital management: increase of return-on-capital	portfolio management: consolidate the designated exposures and the number of reinsurance counterparts; inclusion of otherwise not insurable risk	risk management: hedge against natural catastrophes, also longevity	Capital management: Finance low-frequency / high-severity losses at pre-defined terms	Capital management: reduction of earnings and capital volatility; coverage for low- frequency / high-severity risk
Structure	single- or multi- parent	bi-lateral agreement to pay purchase assets with the premiums paid from the cedent to the rein-surer	combination of several perils / several triggers (can be commercial and financial)	Exchange traded / over-the-counter, mainly standardised products	bi-lateral or syndicated agreement with trigger event definition; standardised loss equity puts	quota-share agreement with a special purpose reinsurance company
Enhancement	not relevant	collateral	none	collateral for long-term life insurance	none / trust collateral (surplus note structure) / mono- line guarantees (wrap against credit losses or residual value claims)	collateral
Triggers	indemnity	indemnity / index based	indemnity / index based	indemnity / index based	indemnity / index based	index based

Source: Weber, C. (2011). 92.

Table 4 (continued)

Type	Risk carriers	Finite Solutions	Multi-risk products	Derivatives	Contingent Capital	Side-cars
Regulatory	subject to home- country control	significant reserve reductions (discounting of loss reserves)	no credit for protection bought	no credit for protection bought	amount issued after trigger event is treated as equity	reserve deduction (similar to collateralised reinsurance)
Accounting	reduction of liabilities, predictable cast flows are kept within the organisation	reduction of liabilities and improved solvency / combined-ratio in the loss year	lack of clarity on accounting regulations	no credit for protection bought	treated as policy holder's surplus rather than as liability (US)	reduction of liabilities
Rating effect	improvement of rating stability	avoidance of rating downgrades in the year of a loss; transfer of investment risk	improvement of rating stability	not recognised	capital credit based on evaluation of investment trust (AAA quality = 100% credit)	full reinsurance credit if adequate collateralisation is provided
Pricing	premiums paid to the captive reflect the present values of the expected claims to be paid	1-3% reinsurance premium depending on risk and term	reinsurance premium is lower than with single contracts	premium depending on risk and term	regular payment of non-refundable upfront fee; cheaper than post-loss financing	premium depending on risk and term
Investors	parent or group of companies	reinsurers	reinsurers	reinsurers, hedge funds, portfolio managers	reinsurers, banks	hedge funds, port- folio managers, reinsurers
Term	long-term	medium-term	medium to long term	non-life 1-3years; life up to 30 years	multi-year	finite risk period up to 3 years

Source: Weber, C. (2011). 93.

2.5 Insurance and capital market convergence

As the risk management evolved over the years, it resulted in a convergence of the various perspectives on risk management (once divided by extreme differences in vocabulary, concepts, and methods); convergence of organizational processes for managing an extraordinary variety of risks; convergence of risk management products previously offered by completely separate industries (e.g. insurance and capital markets); and, finally, convergence of risk management with the quest for optimal capital structure.

Insurance securitization is an example of this slowly evolving convergence process between the insurance and banking sectors. Industries that traditionally focus on the opposite sides of a customer's balance sheet, now manage the financial needs of customers on a holistic basis.

The use of capital market instruments in the underwriting sector offers freedom as regards to transferring risk. Moreover, it is not limited only to transferring the underwriting risk; it also provides extensive possibilities for risk management. Capital market transactions should always be viewed in the context of the insurer's objectives (e.g. hedging against a possible rise in rate levels on the international reinsurance market, hedging reinsurance costs, procuring equity capital). The integration of capital market instruments into the insurance industry provides a set of risk-policy tools that allow better planning and a more cost-effective risk transfer in overall terms by way of securitization (contrary to an exclusively capital market solution).

In the case of ART, convergence can be described as a financial deregulation that allows vertical integration and economics of scale in the insurance, banking and investment market, which are the main propellers of ART growth. This process has been driven by various factors, including the increase in the frequency and severity of the catastrophic risk, market inefficiencies generated by the (re)insurance underwriting cycles, amelioration of information and communications technologies, emergence of risk management for businesses. It reflects the evolution of the company's cash management needs, from simple banking products to a wide range of instruments: managing both currency and liquidity risks and following the direction of their treasury department.

As (re)insurers' services adapt so that they cover a wider range, their involvement in capital market solutions will continue. In this context, it is mainly the risk assessment and the formation of complex transactions on the capital market, as well as the assumption of any underlying risk, the fronting function, and the provision of any necessary bridge cover, that establish the operational sectors of the (re)insurance activity. Those sectors are also combined with interactions with additional financial cooperation partners, such as investment banks, so that the (re)insurer can offer professional support and guidance for the cedent's entry into the capital market.

For a thorough review of how the convergence of insurance and capital markets evolved since the introduction of the various ART transactions, see further Walker, Fulcher, Green et al (1999), Anon. (2001), Culp (2002a), Culp (2002b), Banks (2004), Cummins & Weiss (2009), Kampa (2010), Gatzert, Pokutta & Vogl (2014), Ben Ammar, Braun, & Eling (2015).

3. Regulatory framework

The regulation of insurance companies in the United States (US) and the European Union (EU) continues to evolve in response to market forces and the changing nature of risk but with somewhat different philosophies and at different rates.

This section provides the legal framework of the (re)insurance market, mainly focusing on the case of the European Union, as the Greek (re)insurance market operates within this context.

3.1 Solvency regulation in the United States of America

Insurance regulation in the United States is rooted in its historical legacy. Although the business of insurance is primarily regulated at state level, the US insurance sector is in a larger sense subject to an integrated federal-state framework. A state insurance regulator focuses on the financial strength (solvency) of the insurers that are subject to the jurisdiction of that regulator (based on the insurers domicile), as well as on market conduct issues (e.g., product design, pricing, and claims' payment practices). Each state is principally responsible for regulating the market practices of all insurers operating in its jurisdiction. The states use the National Association of Insurance Commissioners (NAIC) to coordinate and support their regulatory activities. The states are not compelled to adopt NAIC standards but have tended to do so in the financial regulation; with respect to market regulation the states have acted more independently.

The applied approach is heavily influenced by an accounting perspective and aims to regulate insurers' financial condition and market practices. This is reflected in an extended set of laws, regulations, rules, and other measures that govern insurers' activities and financial structure. Regulators focus on insurers' compliance with these prescriptions rather than the prudence of their management and their overall financial risk. Thereby, insurers lack the incentive to use the most efficient methods in terms of valuing assets and liabilities, calculating losses and income, and estimating their risk exposure.

In terms of federal involvement, the government is engaged, among others, with oversight of savings and loan holding companies that control insurers, as well as any insurer that may be a nonbank financial company that the Financial Stability Oversight Council (FSOC) determines should be subject to supervision by the Board of Governors of the Federal Reserve System and enhanced prudential standards.

While reinsurance serves a range of important functions, regulators recognise that it can concentrate credit risk into comparatively few counterparties. The credit risk created by reinsurance -often involving large transactions-, can be measured by the amount of reserves a reinsurer holds for losses, loss adjustment costs and life, annuity and health insurance benefits. These reserves are based on the expected future claims payments for the risks borne by the ceding insurers. This credit risk is mitigated because transactions must be conducted in accordance with a prudential regulatory framework that limits the amount of risk transferred to a reinsurer. This framework also requires the use of collateral in certain circumstances, as well as appropriate capital sums to be held by the ceding insurers.

Regulation of the business of reinsurance in the US is either direct (state insurance regulator directly regulates reinsurers domiciled and licensed in its state as well as reinsurers licensed in its state but domiciled in another state) or indirect (a large and increasing proportion of reinsurance premiums from US-based insurers are ceded to reinsurers based outside the United States that are not licensed by any US state, and thus not directly subject to prudential regulation by any state). (Klein & Wang, 2009:608-612; Federal Insurance Office, US Department of the Treasury, 2014:18-20)

Changes in the legislation regarding (re)insurance transactions are recorded and documented annually from the Federal Insurance Office, US Department of the Treasury.

3.2 Solvency regulation in the European Union

From a judicial point of view, EU countries face some of the same challenges, as the States, in coordinating and harmonizing their insurance regulatory activities. However, EU is composed of sovereign countries and its authority and influence diverge from that of the federal government in the United States. Therefore, a consensus must be achieved among its members, in order to support its regulatory standards, as well as other policies.

At present, EU member states are subject to some common, minimum standards, as set by the Solvency II EU Directive that was adopted in 2009. Beyond this Directive, the majority of jurisdictions are applying their own additional standards.

The main objective of EU policies has been to facilitate cross-border trade within the EU and to make it easier for an insurer residing in a member state to sell collateral in other member States (either across border or through founding branch companies), as well as trade beyond the European borders. EU member states will continue to regulate insurers domiciled in their respective jurisdictions, but each will do so in line with EU policies and standards.

The two most important perspectives of the EU's regulatory procedure are its guiding philosophy and program for developing a stronger and more effective approach to insurance regulation, indicated in Solvency II. The proposal for the Solvency II Directive was published by the European Commission in July 2007 and reflected the economic substance of insurance, focused on the management of risk, and grounded in risk-sensitive capital requirements.

Contrary to the United States, many European countries move with a faster pace towards applying a principles-based and prudential approach to insurance regulation. A prudential system emphasises on the maintenance of an adequate "solvency margin" by the insurer, by means of competence and judgment of the insurer's management. The ultimate focal point is the insurer's financial risk.

Many EU countries were also quicker to embrace a financial/economic outlook for regulating insurance companies, than their US counterparts. Therefore, although Solvency II will promote and harmonise regulatory standards, it is in line with the regulatory philosophy of most EU countries. (Klein & Wang, 2009:612-613)

3.2.1 Solvency I

The adoption of the first non-life insurance Directive (Directive 73/239/EEC) in 1973, and of the first life assurance Directive (Directive 79/267/EEC) six years later, were the first steps towards harmonisation of insurance supervision in Europe. Implementation of the Directives resulted in harmonised solvency requirements in the EU member states. The supervisory regime Solvency I was perfected by the second and third Directives (Directives 88/357/EEC, 90/619/EEC, 92/49/EEC and 92/96/EEC), which, inter alia, implemented the freedom to provide services in the insurance sector.

Title I of the Council Directive 73/239/EEC of 24 July 1973, also known as Solvency I, sets its scopes and limits. The Directive concerns direct insurance provided by insurance undertakings (companies) domiciled in a member state, as well as classes of insurance defined in its annex. It specifically excludes life assurance and other supplementary insurance, annuities, insurance as part of social security, and health insurance in the cases of Ireland and the United Kingdom. It also lists a number of institutions in Germany, France, Italy, Ireland, and United Kingdom, who either enjoy monopoly, or are partly under public control.

Title II states the rules applied to undertakings whose head offices are situated within the Community. According to *Article 16* the solvency margin shall correspond to the assets of the company, free of any foreseeable burden, less intangible assets. Moreover, it shall be determined based on either the annual premium, or contributions, or the average charge for the last three financial years. As stated in *Article 17* one-third of the solvency margin shall constitute the guarantee fund, while the minimum units of account vary accordingly. All undertakings are obliged to comply with the provisions of the Directive and produce an annual account, covering all types of operation, of their financial situation and solvency; free disposal of assets is prohibited in case of no compliance. Moreover, member states shall facilitate an undertaking to assign all or part of its portfolio of policies if the assignees possess the necessary solvency margin, due account being taken of the assignment. (Council of the European Communities, 1973)

3.2.2 The transition

Work aimed at improving and providing a new focus for the existing EU solvency rules began at the European level in the 1990s. A Working Group, led by former president of the Federal Insurance Supervisory Office (Bundesaufsichtsamt für das Versicherungswesen – BAV), Dr Helmut Müller, proceeded to a comparative examination of the European solvency rules. The so called Müller Report stated that solvency in Europe had stood the test of time. However, the (rather complex) existing provisions on own funds did not adequately account for all risks to which an insurer is exposed.

Consequently, a reform was decided resulting, initially, in the implementation of the most urgent changes to Solvency I: the life assurance Directive (Directive 2002/83/EC) and the Directive regarding the solvency margin requirements for non-life insurance undertakings (Directive 2002/13/EC). Still, these two Directives only represented a transitional solution towards a new risk-based supervisory system. The fundamental reform of the solvency rules for insurers remained the preserve of the supervisory regime Solvency II, while the Solvency I rules remain applicable to undertakings to which Solvency II does not apply (small insurance undertakings, institutions for occupational retirement provision and death benefit funds). (Bundesanstalt für Finanzdienstleistungsaufsicht, 2016)

3.2.3 Solvency II

Solvency I represented 14 EU Directives and foresaw the existence of 28 national supervisory regimes. As of 1 January 2016, these 14 EU Directives were replaced by Solvency II.

The new harmonised, risk based, robust, and proportionate prudential supervisory common regime for insurance and reinsurance companies shall be applied by all 28 EU Member States[11].

The Solvency II supervisory regime consists of the three pillars, of equal importance:

1. Pillar I - Calculation of capital reserves: One characteristic of the financial crisis was the underestimation of risks. The first pillar outlines the standard formula insurance companies across the European Union have to use for the calculation of their capital reserves, covering all types of risks.
2. Pillar II - Management of risks and governance: It contains the requirements for the management of potential risks and for governance. Companies will be provided incentives to clearly identify and manage the risks they are facing.
3. Pillar III - Reporting and disclosure: It describes the information and reporting insurance companies across the European Union have to submit to the national supervisor and disclose publicly. Supervisors will have the possibility to timely act and their interventions can be better targeted.

The benefits of Solvency II can be summarised as follows:

- Enhanced protection of consumers of insurance products. Through risk and governance management, as well as by requiring a market-consistent valuation of insurers' assets and liabilities, the latter will enjoy full benefits off their insurance contracts.
- Less administrative burden for insurance conglomerates based in several EU countries as they will report to one supervisory authority instead of reporting to each national supervisor in different countries. This, along with abolishing advantages some cross-border groups had under Solvency I, will also enhance fair competition and create level-playing field in the insurance market.
- Safeguarding financial stability in Europe, as transparency in application, reporting and disclosure will allow supervisors to compare companies and by that to better and timely analyse the risks and vulnerabilities of the European (re)insurance market as a whole.

The Solvency II regime is to be reviewed in 2018. (European Insurance and Occupational Pensions Authority, n.d.)

[11] For the time being, the United Kingdom remains a full member of the EU and rights and obligations continue to fully apply in and to the UK.

Table 5: Solvency I versus Solvency II at a glance

Solvency I	Solvency II
Several supervisory regimes differing from each other	Single supervisory regime for the whole EU
Companies don't need to closely look at several types of risks	Companies better understand and, thus, more efficiently mitigate the risks they face
Consumers always suffer the most if their company is affected by the economic reality	Robust risk management and governance means well protected consumers
Supervisors don't have a full picture about the companies' profiles'	Enhanced reporting allows supervisors to see the upcoming problems and to timely react

Source: European Insurance and Occupational Pensions Authority (n.d.).

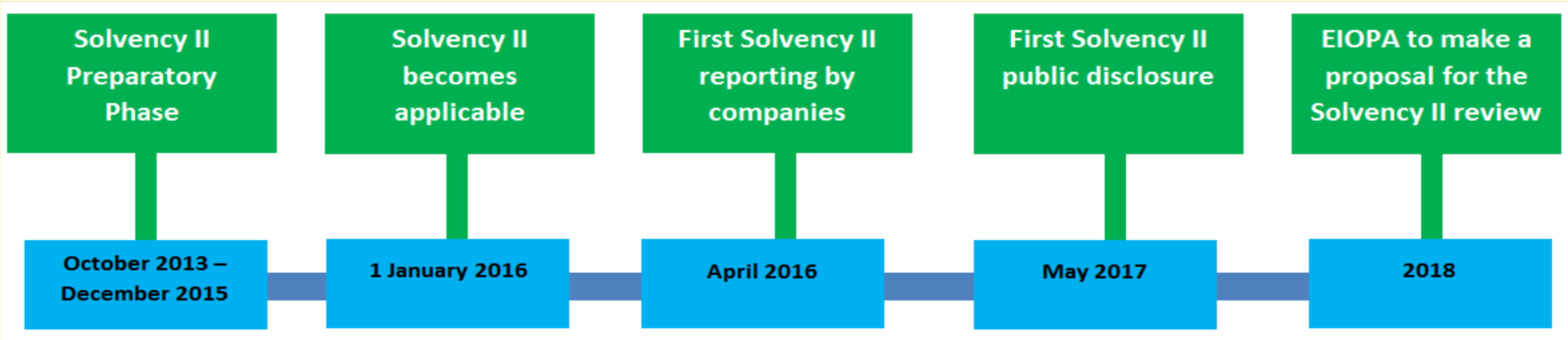

Figure 20: Solvency II Timeline
Source: European Insurance and Occupational Pensions Authority (n.d.).

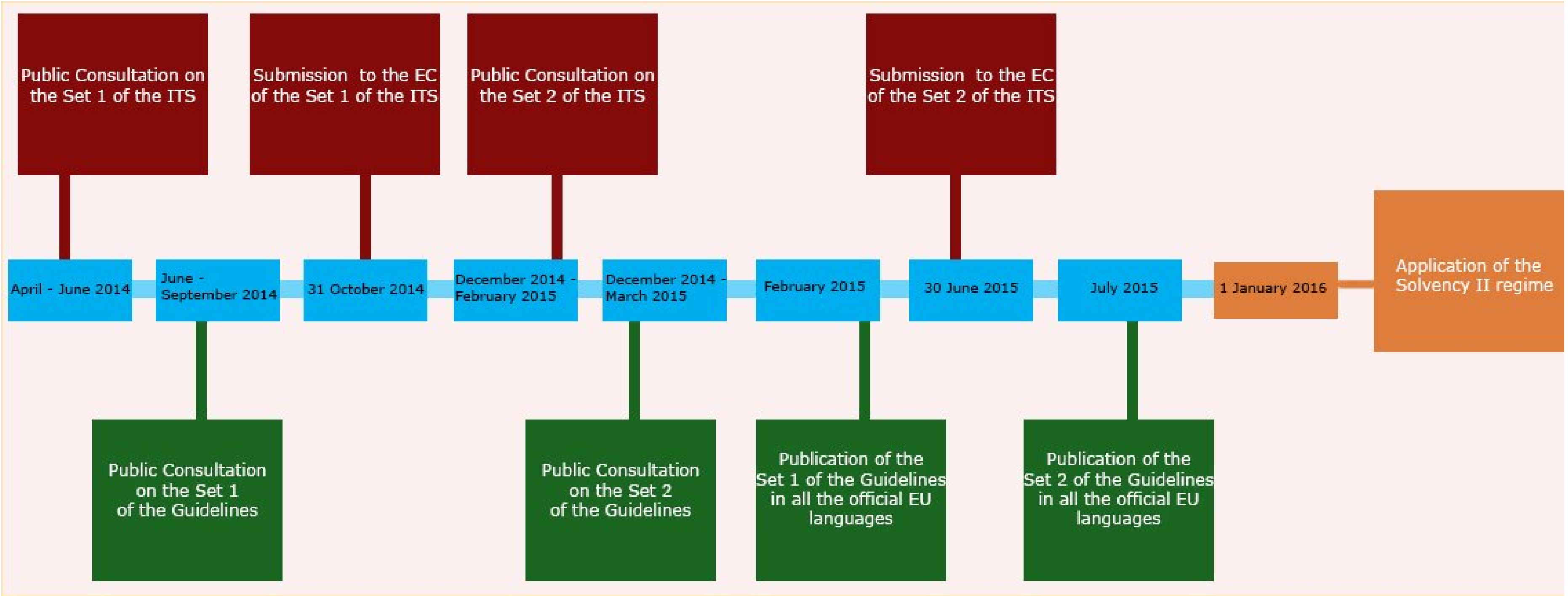

Figure 21: Solvency II Preparatory Phase
Source: European Insurance and Occupational Pensions Authority (n.d.).

4. Exploring the probability of a flood Catastrophe bond issuance in Romania

In July 2017 Italian based global insurer Assicurazioni Generali SpA completed its latest and third catastrophe bond, Lion II Re DAC[12], worth 200 million Euros. This is the first European multi-peril catastrophe bond since 2000, indicating how rare a cat bond exposed to multiple natural perils in Europe can be. Coverage will be across a four-year term, on a per occurrence basis and with the trigger being indemnity under Rule 144A[13]. European windstorm coverage is for all of the countries exposed to that peril, while European flood coverage will be a subset, including the UK (but not Northern Ireland), Germany, Austria, Hungary, Czech Republic, Slovakia, Poland and Switzerland. Italian earthquake coverage is for the entire country.

At launch, the €200 million of notes issued by Lion II Re, which had an initial expected loss of 2.24%, were marketed to ILS investors with coupon guidance in a range from 3.5% to 4%, a range that then fell to a spread guidance of 3% to 3.5% (Table 6).

By the time of issuance, the cat bond had been priced at the lowest end, of 3%, making this transaction one of the lowest multiple deals for that level of expected loss we have ever seen, at 1.33 times the expected loss of 2.24%. Such a low multiple suggests that investors understood that the flood exposure is a minor contributor to the expected loss, while the main contributor of Italian quake risk would actually require a really major event to trigger the bond, given the dearth of earthquake insurance penetration in the region. (Evans, 2017c).

Table 6: Characteristics of the Lion II Re DAC cat bond

Size	Covered Perils	Scheduled Maturity	Initial Annual Modeled Expected Loss	Coupon
€200,000,000	Europe windstorm, Italy earthquake, and Europe Flood*	July 15, 2021	2.24%	Permitted Investments Yield + 3.00%

* selected countries

Source: Guy Carpenter & Company, LLC. (2017).

[12] Irish special purpose vehicle.

[13] As noted by Generali "*Rule 144A offerings are offerings of securities conducted on a private placement basis for the purposes of the U.S. Securities Act of 1933 and that limit initial distribution and secondary sales of the securities to entities that are Qualified Institutional Buyers as defined in Rule 144A under the U.S. Securities Act of 1933. The offering of securities in a Rule 144A offering does not require registration of the issuer or the securities with the U.S. Securities Exchange Commission.*"

See further: Assicurazioni Generali S.p.A. (2017). *Lion II Re: new catastrophe bond issued by Generali*. Retrieved from https://goo.gl/E8bzCa, accessed on 11/10/2017.

From June 1st 2009 to May 31st 2012, leading European geologists, seismologists and engineers cooperated within the SHARE (Seismic Hazard Harmonization in Europe) project, with the objective to provide a community-based seismic hazard model for the Euro-Mediterranean region with update mechanisms. In 2013, when the project officially ended, SHARE successfully delivered a pan Euro-Mediterranean probabilistic seismic hazard assessment across multiple disciplines spanning from geology to seismology and earthquake engineering (Seismic Hazard Harmonization in Europe, n.d.). According to the researchers, Italy, the Balkans, Greece, Bulgaria, Romania and Turkey are among the most exposed regions of the continent. (Horizon, The EU Research & Innovation Magazine, 2014)

4.1 Seismicity of Romania

The seismogenic zones are areas of grouped seismicity in which the seismic activity and stress field are assumed to be relatively uniform. The identification of long-term characteristics of the earthquake generation process in each seismogenic zone is of great significance for the seismic hazard assessment.

The most dangerous seismogenic zone in Romania is located in the subcrustal lithosphere at the bending of the Eastern Carpathians – Vrancea region. Beside this intermediate-depth source, several shallow-depth seismic areas of local importance for the seismic hazard are pointed out: the East-Vrancea, Făgăraş – Câmpulung, Danubian, Banat and Crişana – Maramureş zones, the Bârlad Depression[14], the Predobrogean Depression, the Intramoesian Fault, and the Transylvanian Depression. The background seismicity – crustal events with magnitude Mw < 5 – is sporadically observed, mainly in northern Oltenia, Haţeg Depression, eastern part of the Romanian Plain, Moldavian Platform, Eastern Carpathians orogen. (Institutul National de Cercetare Dezvoltare pentru Fizica Pamantului, Romania, n.d.)

The geographical distribution of the seismogenic zones and the distribution of the epicenters of the crustal earthquakes are given in Figure 22, as described by Radulian et al

[14] Depression: Any relatively sunken part of the earth's surface; especially a low-lying area surrounded by higher ground. A closed depression has no natural outlet for surface drainage (e.g., a sinkhole). An open depression has a natural outlet for surface drainage.

Closed depression: A generic name for any enclosed area that has no surface drainage outlet and from which water escapes only by evaporation or subsurface drainage; an area of lower ground indicated on a topographic map by a hachured contour line forming a closed loop.

Open depression: A generic name for any enclosed or low area that has a surface drainage outlet whereby surface water can leave the enclosure; an area of lower ground indicated on a topographic map by contour lines forming an incomplete loop or basin indicating at least one surface exit. See further U.S. Department of Agriculture, Natural Resources Conservation Service. (n.d.). *National soil survey handbook, title 430-VI*. Available at http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcs142p2_054242, accessed on 15/02/2019.

(2000). The Shabla zone, situated in the northeastern part of Bulgaria close to the border with Romania, is also taken into account. To the east, the earthquakes are related to the subduction process at the Carpathians arc bend (Vrancea region); to the west, they follow the contact between the Pannonian Depression and the Carpathians orogen. The eastern segment of the Carpathians in Romania is practically aseismic, except the southern extremity (Vrancea region). The western segment (Apuseni Mountains) is aseismic as well. The southern Carpathians are considerably more seismically active, especially in the eastern (zone FC) and western (zone DA) extremities. The platform regions are stable, except the small strip crossing the Carpathians foredeep area on a SW–NE direction, in front of Vrancea region. Several active faults are identified here following the same SE–NW orientation (Intramoesian, Perceneaga-Camena, Sfântul Gheorghe and Trotuş faults). They mark the contact between different tectonic units, where a relative enhancement of seismicity appears. The Transylvanian Depression is almost aseismic at present. The small isolated seismogenic zone (TD) delimited there is defined only on the basis of historical earthquakes. (Radulian et al, 2000: 58-59)

The strong seismic events originating from Vrancea area can generate the most destructive effects experienced in Romania, and may seriously affect high risk man-made structures such as nuclear power plants (Cernavoda, Kosloduj, etc.), chemical plants, large dams and pipelines located within a wide area from Central Europe to Moscow. The earthquakes are localized to a restricted area in the bending zone between the Eastern and Southern Carpathians, where at least three units are in contact: the East European plate, Intra-Alpine and Moesian sub-plates. Earthquakes in the Carpathian-Pannonian region are confined to the crust, except the Vrancea zone, where earthquakes with focal depth down to 200km occur. (Marmureanu, Cioflan, Marmureanu, 2011: 226-227)

For a basic glossary on earthquakes and more information about Romania’s seismicity, see Appendix A and Appendix B respectively.

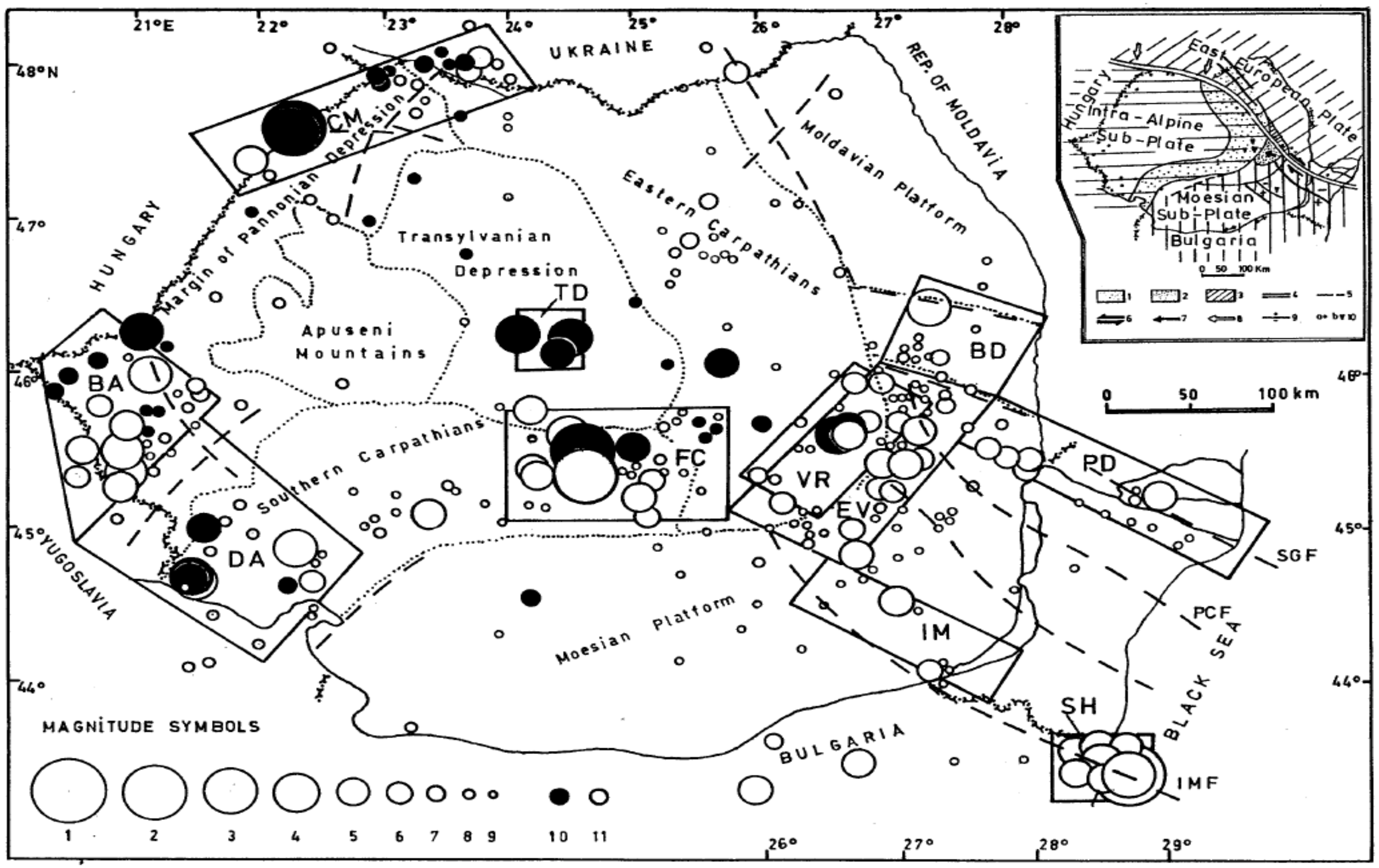

Figure 22: Geographical distribution of the seismogenic zones and crustal seismicity
Source: Radulian et al, 2000, 59.

VR: Vrancea; EV: East Vrancea; BD: Bârlad Depression; PD: Predobrogean Depression; IM: Intramoesian Fault; SH: Shabla; FC: Făgăraş-Câmpulung; DA: Danubian Zone; BA: Banat; CM: Crişana-Maramureş; TD: Transylvanian Depression. *Solid lines*: border limits of the seismogenic zones; *dotted lines*: border of tectonic units, *dashed lines*: major active faults. IMF: Intramoesian Fault; PCF: Peceneaga - Camena Fault; SGF: Sfântul Gheorghe Fault; TF: Trotuş Fault.

Inset: Tectonic sketch of Romania: 1 = Carpathian orogenic belt; 2 = Focşani-Odobeşti Depression; 3 = Fore-Carpathian zone; 4 = plate-subplate boundary; 5 = subplate - subplate boundary; 6 = strike-slip fault; 7 = active subduction; 8 = Neogene “frozen” subduction; 9 = intra-plate crustal fracture; 10 = (a) crustal and (b) subcrustal earthquake epicenters.

4.2 Modelling the Catastrophe Bond

The goal of this section, given the information provided above, the data presented in Appendix B, and considering that earthquake hazard in Romania is excluded from the coverage provided by Lion II Re DAC, is to provide a general types of earthquake catastrophe bond, which is based on magnitude of earthquakes as a parametric trigger.

4.2.1 Pricing Catastrophe Bonds

According to Cox and Pedersen (2000), the difference between corporate and insurance-based securities, such as catastrophe risk bonds, is that the default risk of the latter is not correlated with the underlying financial market and economic variables (e.g. interest rate levels or aggregate consumption) rather than depends on catastrophic events. Consequently, neither the payments from a catastrophe risk bond nor the bond itself can be counterbalanced by a portfolio comprised of traditional assets (e.g. traditional bonds or common stocks, the so-called primitive securities) that already trade in the market.

It is, therefore, evident that the pricing of a CAT bond requires an incomplete market framework, as it is simpler than the case of significant correlation and offers a variety of alternative pricing mechanisms that are tied to the specific nature of each market. In an incomplete market one can construct several different hedging portfolios by selecting the proper risk-neutral probability measure in order to obtain the price of a derivative.

4.2.2 Methodology

Using the abovementioned approach and the theory of equilibrium pricing, in 2007 Zimbidis, Frangos, and Pantelous developed a simple one-period and one more complicated multi-period model for pricing catastrophe bonds[15]. This model will be applied in the case of Romania as well.

The valuation is performed in two stages. The first stage is the estimation of risk dynamics, i.e. the distribution function of the annual maximum earthquakes of the broader area of Romania, using the tools of Extreme Value Theory. The statistical analysis of extremes is a key factor to many of the risk management problems related to Insurance, Reinsurance and Finance in general. The second stage requires the selection or estimation of the interest rate dynamics. (Zimbidis, et al, 2007:166-167)

[15] In 2015, Shao extended the model by adding a financial risk (inflation rates) and a catastrophe risk (depth). See further Shao, J. (2015). *Modelling Catastrophe Risk Bonds*. Thesis submitted in accordance with the requirements of the University of Liverpool for the degree of Doctor in Philosophy in Mathematical Science.

4.3 One period (basic) Model

In this subsection the simple one-period model, where the interest rate dynamics are restricted to constant values of different rates, will be presented. The necessary symbols and the respective notation are defined as follows:

T: maturity date for the CAT bond.

K: is the face amount of the CAT bond.

r(t): is the risk free rate continuously compounding, up to maturity date (e.g. 1-year Romanian Treasury Certificates).

e: is the extra premium loading for bearing earthquake risk (normally, this is a positive quantity reflecting the respective risk aversion of the buyers of such a security).

R(t): is the basic element for the determination of the coupon payment rate for the one year period as long as a specified catastrophic event does not occur (e.g. 12-month US LIBOR rate on the bond issuance date).

M(t): is the maximum magnitude level of the earthquake in the broader area of Romania. M is a random variable following the distribution obtained in subsection 4.3.4 (see Table 8, page 62). Moreover, M is measured in moment magnitude (Mw) scale[16].

P_{CAT}: is the price of the CAT bond at the time of issuance.

$C(R;\ M)$: is the cash value of the CAT bond at the maturity date depending upon the value of M.

As we are working in a one-period model, we assume, from this point on, that T = t = 1. Thus one can simplify the notations as r_1; *e*; *R*; and *M* and assume the dynamics of financial risks (risk-free interest rate, and LIBOR rate) are constant.

Figure 23: The diagram for the one period model
Source: Zimbidis et al, 2007, 169.

[16] The magnitude is a number that characterizes the relative size of an earthquake. Magnitude is based on measurement of the maximum motion recorded by a seismograph. Most commonly used scales are (1) local magnitude (ML), commonly referred to as "Richter magnitude", (2) surface-wave magnitude (Ms), (3) body-wave magnitude (Mb), and (4) moment magnitude (Mw). Scales 1-3 have limited range and applicability and do not satisfactorily measure the size of the largest earthquakes. The moment magnitude (Mw) scale, based on the concept of seismic moment, is uniformly applicable to all sizes of earthquakes and measures the size of events in terms of how much energy is released. However it is more difficult to compute than the other types. All magnitude scales should yield approximately the same value for any given earthquake. See further United States Geological Survey, *Earthquake Glossary*. Available at https://earthquake.usgs.gov/learn/glossary/?term=magnitude.

Signify *C(R;M)* as pay-off function of the CAT bond with piecewise cash flow on maturity. In this case the CAT bond cash flows depend only on the catastrophic risk variables and their structure is given in the following expression:

$$C(R;M) = \begin{cases} K*(1+3R), & if\ M \in [0,\ 5.4] \\ K*(1+2R), & if\ M \in [5.4,\ 5.8] \\ K*(1+R), & if\ M \in [5.8,\ 6.2] \\ K, & if\ M \in [6.2,\ 6.6] \\ \frac{2}{3}K, & if\ M \in [6.6,\ 7.0] \\ \frac{1}{3}K, & if\ M \in [7.0,\ 7.4] \\ O, & if\ M \in [7.4,\ \infty^{17}] \end{cases} \qquad (4.3.1)$$

The pre-determined magnitude levels in expression (4.3.1) are the trigger points of the CAT bond. Their selection has an impact on the securitization level of the bond, which an individual company should poise between profit and commerciality by analysing historical earthquake loss data.

In the one-period case, we assume that *K*, r_1, *R*, and *e* are constant. Therefore, cash flow is independent of financial risks, and the price of the CAT bond can be approximated according to equilibrium pricing theory as follows:

$$P_{CAT} = E_{Q1}[e^{-(r+e)}C(R;M)] \qquad (4.3.2)$$

where E_{Q1} is the probability measure corresponding to the distribution of magnitude M (obtained in Table 8), which affects the payoff value C. (Zimbidis, et al, 2007:168-169; Shao, 2015:38-41)

In our case we run 50,000 simulations in R, to obtain the values of $C(R;\ M)$, depending on the earthquake's magnitude, as set in the intervals of expression 4.3.1. We then multiply the values of $C(R;\ M)$ by the discount $e^{-(r+e)}$ ($P = C * discount$). The final price P of the CAT bond is the mean price of ($C * discount$).

See appendix C, part A for the R code for the one-period model. This code produces a $C(R;\ M)$ value for each one of the intervals set in expression (4.3.1). Note that the code is an adaptation of the code originally produced by Shao, 2015, pp.98-101.

[17] In theory, the largest magnitude of an earthquake is 12 in Richter scale.

4.3.1 Generalized Extreme Value (GEV) Distribution for defining extremes in Earthquake Magnitude

Extreme Values Theorem

Let $X_1, X_2, \ldots, X_n$ be independent and identically distributed random variables with cumulative distribution function F, let $M_n = \max(X_1, X_2, \ldots, X_n)$ represent the maximum, and suppose that exist sequences of constants $a_n > 0$ and $b_n \in \mathbb{R}$, such that:

$$P\left(\left(\frac{M_n - b_n}{a_n}\right) \leq z\right) \to G(z), \text{ when } z \to \infty$$

where G(z) is a distribution function.

Generalized Extreme Value (GEV) Distribution

Richard Von Mises (1954) and A.F. Jenkinson (1955) independently derived the Generalised Extreme Value distribution (GEV), often denoted $G(\mu, \sigma, \xi)$, whose cumulative distribution function (CDF) is given by:

$$G(x; \mu, \sigma, \xi) = \exp\left\{-\left[1 + \xi\left(\frac{x-\mu}{\sigma}\right)\right]_+^{-\frac{1}{\xi}}\right\} \quad (4.3.1.1)$$

By differentiating (4.3.1.1) with respect to x, we could get the probability density function for GEV as:

$$g(x; \mu, \sigma, \xi) = \frac{1}{\sigma}\left(1 + \xi\left(\frac{x-\mu}{\sigma}\right)^{-1-\frac{1}{\xi}}\right) \exp\left[-\left(1 + \xi\left(\frac{x-\mu}{\sigma}\right)\right)^{-\frac{1}{\xi}}\right] \quad (4.3.1.2)$$

where $-\infty < \mu < +\infty$, $\sigma > 0$ and $-\infty < \xi < +\infty$, are location (position of the GEV mean, shows the central tendency and range), scale (multiplier that scales function, indicates central tendency and dispersion) and shape (describes the relative distribution of the probabilities, provides the dispersion and moments of high order) parameters respectively. The value of the shape parameter ξ differentiates between the three types of extreme value distribution. When $\xi = 0$ is the limit of Eq. (4.3.1.1) as $\xi \to 0$, the model corresponds to the Gumbel distribution. For the cases $\xi > 0$ and $\xi < 0$, Eq. (4.3.1.1) leads to Frechét and Weibull family distributions, respectively.

The GEV parameters need to be estimated beforehand (meaning that the data need to be pre–processed in order to have a filtered set of extremes – in particular, block, or annual, maxima $M_{n,i}$), so in practice the normalisation constants are ignored and the GEV is fitted directly to the set of maxima. (Ayuketang Arreyndip & Joseph, 2016:5-6).

4.3.2 Data pre-processing

In the case of the Romanian Cat Bond modelling, the analysis is based on the series of annual maximum magnitude of the earthquakes in the broader area, over the period 1969-2018 (see Table 7).

Figure 24 shows a time series plot of the 50 annual maxima, which was produced using RStudio. It is reasonable to assume that the patterns of variation have stayed constant over the observed period, which suggests that the data are independent observations from the GEV distribution.

Table 7: Annual Maximum Magnitude of Earthquakes in Romania

Year	Magnitude (MW)	Year	Magnitude (MW)
1969	5.2	1994	4.3
1970	4.7	1995	4.1
1971	3.8	1996	4.6
1972	3.8	1997	4.7
1973	6	1998	4.7
1974	4.9	1999	5.3
1975	5.3	2000	5
1976	3.9	2001	4.9
1977	7.4	2002	4.7
1978	5.2	2003	4.7
1979	5.3	2004	6
1980	5.1	2005	5.5
1981	5.5	2006	4.7
1982	4.3	2007	4.4
1983	5.6	2008	4.3
1984	4.7	2009	5.4
1985	5.8	2010	4.6
1986	7.1	2011	4.9
1987	4.8	2012	4.4
1988	4.6	2013	5.2
1989	4.4	2014	5.7
1990	6.9	2015	4.3
1991	5.7	2016	5.6
1992	4.6	2017	4.8
1993	4.4	2018	5.8

Source: Institutul National de Cercetare Dezvoltare pentru Fizica Pamantului, Romania. n.d.

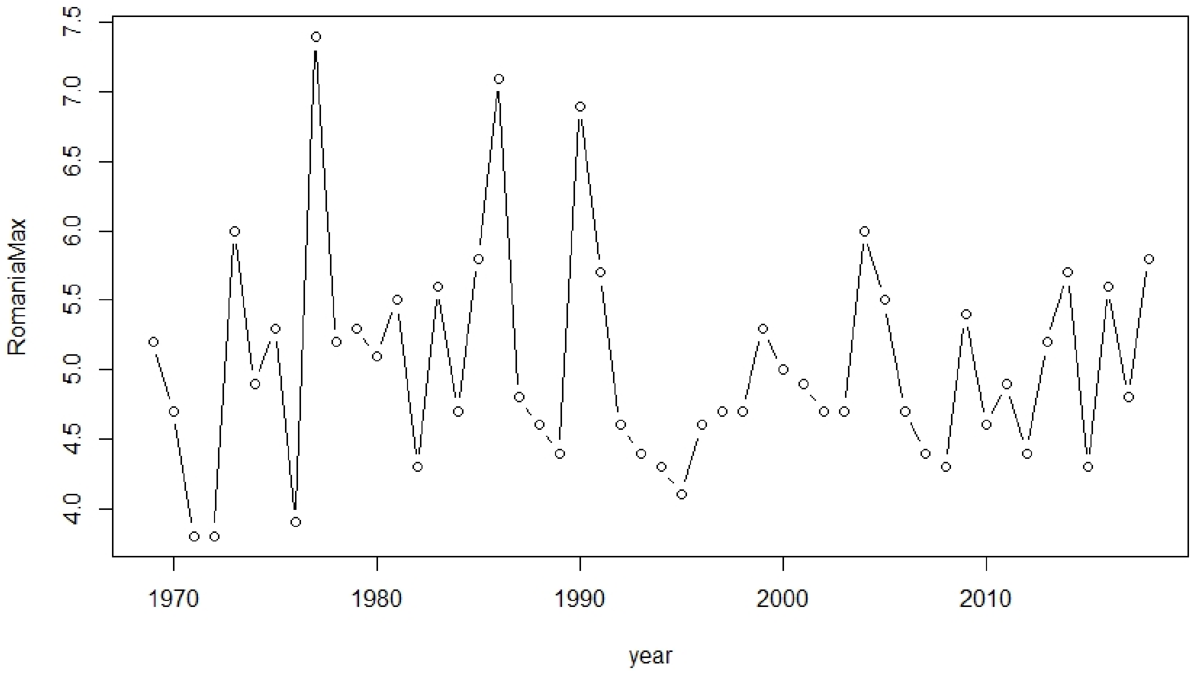

Figure 24: Times series scatter plot of the Annual Maximum Magnitude of Earthquakes in Romania
Source: Data analysis in RStudio.

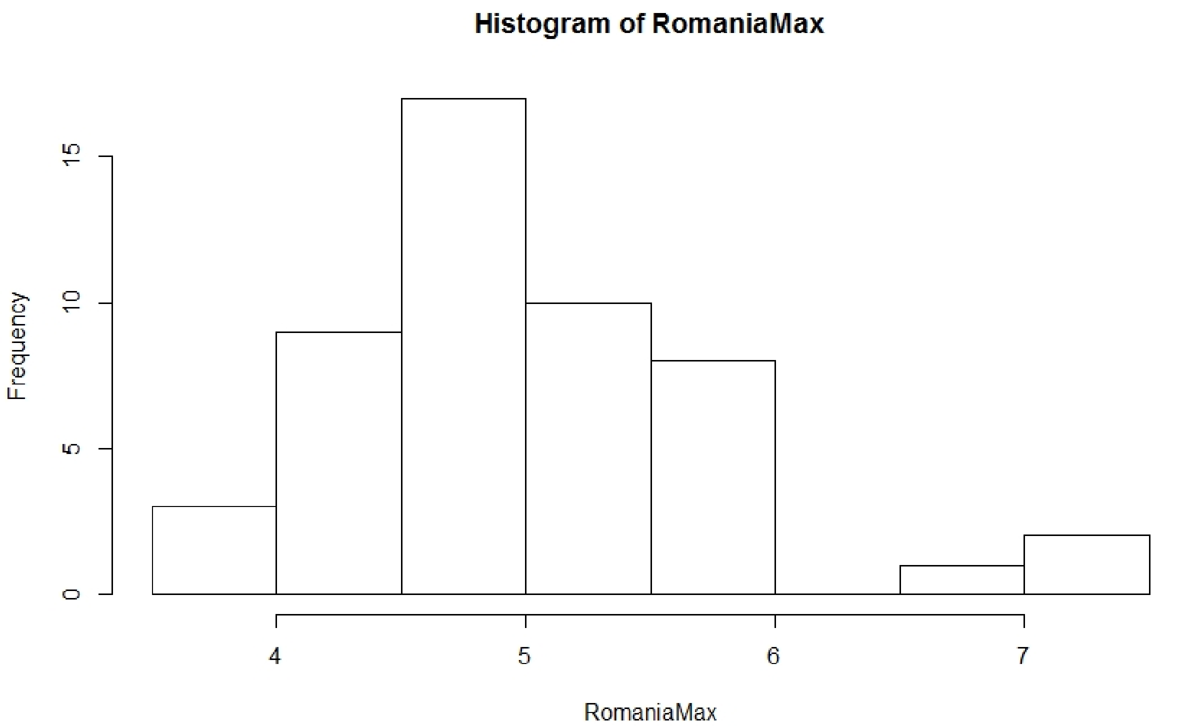

Figure 25: Histogram of the Annual Maximum Magnitude of Earthquakes in Romania
Source: Data analysis in RStudio.

4.3.3 Using R to estimate the GEV parameters

Maximization of the GEV log-likelihood for the data presented in Table 7 leads to the following estimates:

$\hat{\mu}$ (location estimate) = 4.687832990, $\hat{\sigma}$ (scale estimate) = 0.601971476,

$\hat{\xi}$ (shape estimate)= -0.005990949,

for which the log-likelihood is 53.33175. The approximate variance-covariance matrix of the parameter estimates is:

$$V = \begin{bmatrix} 0.009078041 & 0.002389238 & -0.003233565 \\ 0.002389238 & 0.004694901 & -0.001831653 \\ -0.003233565 & -0.001831653 & 0.009868771 \end{bmatrix}$$

* Columns, from left to right: location estimate, scale estimate, shape estimate
Rows, from top to bottom: location estimate, scale estimate, shape estimate

The diagonals of the variance-covariance matrix correspond to the variances of the individual parameters of (z, s, m). Computing square roots, the standard errors are 0.09527876 0.06851935, and 0.09934169, for μ, σ, and ξ respectively. Combining estimates and standard errors, approximate 95 % confidence intervals for each parameter are:

$\hat{\mu} \in (4.59255423,\ 4.78311175)$,

$\hat{\sigma} \in (0.670490826,\ 0.670490826)$,

and $\hat{\xi} \in (-0.105332639,\ 0.093350741)$

Greater accuracy of confidence intervals can usually be achieved by the use of profile likelihood. Figure 26 shows the profile log-likelihood for ξ, from which a 95% confidence interval is obtained:

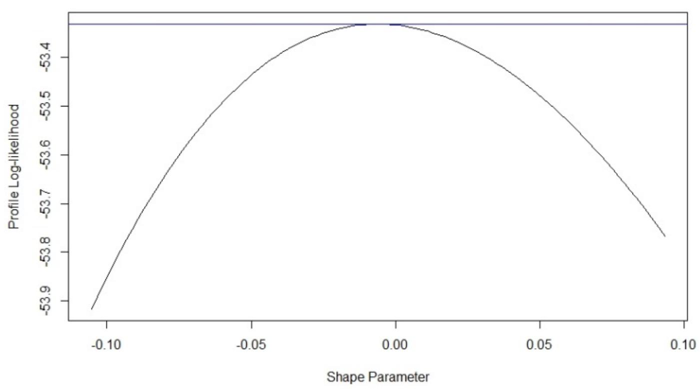

Figure 26: Profile log-likelihood of ξ for the Annual Maximum Magnitude of Earthquakes in Romania
Source: Data analysis in RStudio.

The various diagnostic plots for assessing the accuracy of the GEV mode,l fitted to the Annual Maximum Earthquakes in Romania data are presented in Figure 27.

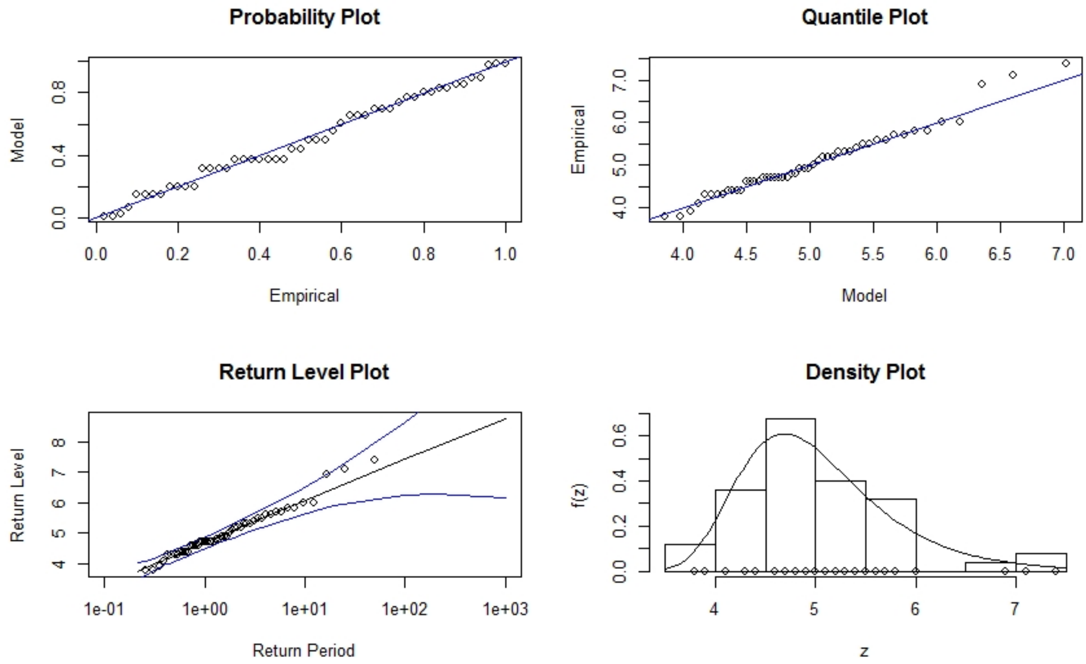

Figure 27: Diagnostic plots for GEV fit to the Annual Maximum Magnitude of Earthquakes in Romania
Source: Data analysis in RStudio.

The quantile plot compares the model quantiles against the data (empirical) quantiles. The fact that it does not deviate from a straight line suggests that the model assumptions are valid for the data plotted.

The return level plot shows the return period against the return level, and shows an estimated 95% confidence interval. The return level is the level (in this case magnitude) that is expected to be exceeded, on average, once every m time points (in this case, 50 years). The return period is the amount of time expected to wait for the exceedance of a particular return level. The return level curve converges asymptotically to a finite level as a consequence of the negative estimate of ξ, though the estimate is close to zero and the respective estimated curve is close to a straight line. The curve also provides a satisfactory representation of the empirical estimates, especially once sampling variability is taken into account.

Finally, the corresponding density estimate seems consistent with the histogram of the data presented in Figure 25. Consequently, all four diagnostic plots provide support to the fitted GEV model.

The sample mean excess function ê(u) is an empirical estimate of the mean excess function which is defined as ê(u) = E[X – u |X > u], that describes the estimated overshoot of a threshold given the exceedance occurs. The mean residual life plot depicts the Thresholds (u) vs Mean Excess flow. The idea is to find the lowest threshold where the plot is nearly linear taking into account the 95% confidence bounds. The downward trend suggests a very short tail behaviour for the Annual Maximum Magnitude Earthquakes in Romania.

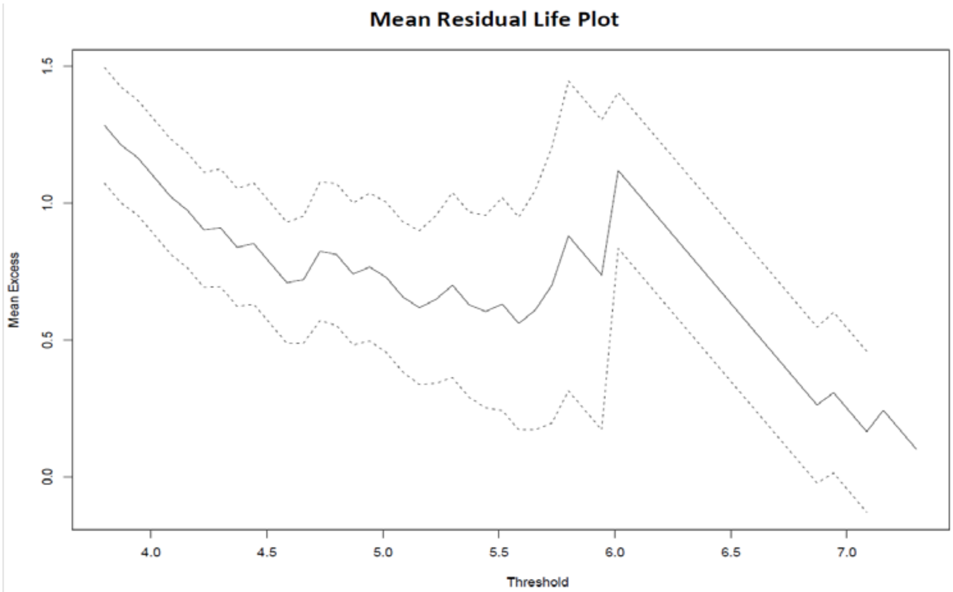

Figure 28: Sample mean excess for Annual Maximum Magnitude of Earthquakes in Romania $M^1(t)$, with 95% confidence interval
Source: Data analysis in RStudio.

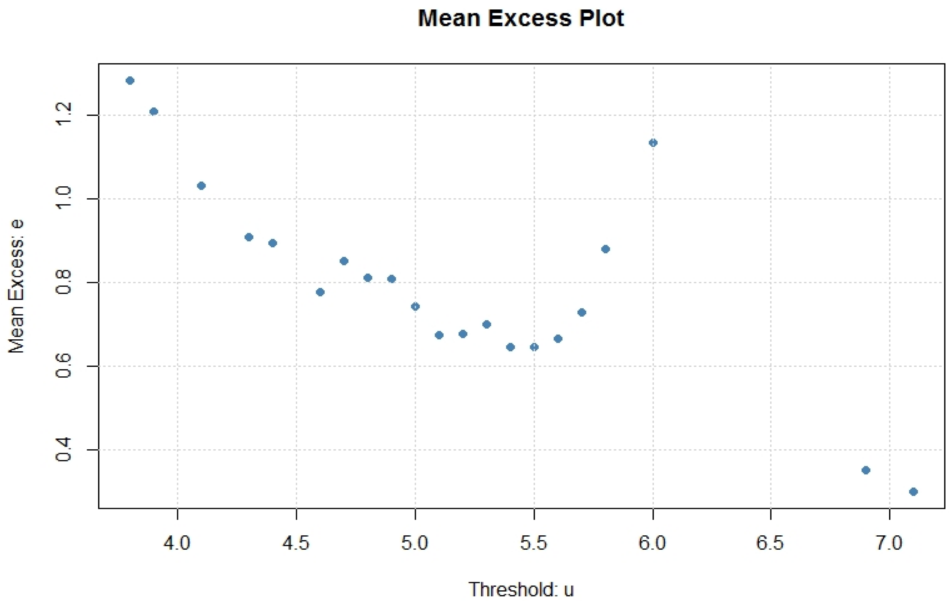

Figure 29: Sample Mean Excess Plot for Annual Maximum Magnitude of Earthquakes in Romania
Source: Data analysis in RStudio.

Maximization of the GEV returned a rather small $\hat{\xi}$ = -0.005990949, which can be considered equal to zero (0), therefore the limiting distribution for Annual Maximum Earthquakes in Romania is a type of Gumbel that. However, in our case we use the Standard Extreme Value distribution, as discussed in section 4.3.1, which groups the three forms of G (namely Gumbel, Fréchet, Weibull) and has the following cumulative distribution function:

$$G(z) = P(M_k \leq m_k) = \exp\left\{-\left[1+\xi\left(\frac{z-\mu}{\sigma}\right)\right]^{-\frac{1}{\xi}}\right\} \quad (4.3.3.1)$$

where parameters are $\hat{\mu}$ = 4.687832990, $\hat{\sigma}$ = 0.601971476, $\hat{\xi}$ = -0.005990949.

Equation (4.3.3.1) gives the probability that the annual maximum magnitude earthquake M_k will be less than or equal to a magnitude m_k.

See Appendix C, part 2 for the sequence of orders in R for obtaining the results presented in subsections 4.3.2 and 4.3.3.

4.3.4 Calculating the probability measure corresponding to the GEV distribution for Magnitude

For the purpose of obtaining the probability measure corresponding to the GEV distribution for magnitude M, we use the trial version of *EasyFit 5.6 Professional Evaluation Version™*, a software application developed by MathWave Technologies[18]. This particular application was chosen for its easiness to use, as it allows to automatically or manually fit a large number of distributions to the data available. The trial version allows an input of data up to 5,000 records.

Out of the 50,000 earthquake simulations mentioned above, 5,000 were selected with respect to the frequency of each magnitude in the original simulations' sample. Fitting the data to the GEV, with the parameters $\hat{\mu}$, $\hat{\sigma}$, $\hat{\xi}$ of the maximized GEV log-likelihood, *EasyFit 5.6* returns the probabilities shown in the following table (see Appendix D for the process):

Table 8: Probabilities of an earthquake of magnitude M occurring within intervals set by expression 4.3.1

P(5.0 < M < 5.4)	P(5.4 < M < 5.8)	P(5.8 < M < 6.2)	P(6.2 < M < 6.6)	P(6.6 < M < 7.0)	P(7.0 < M < 7.4)	P(> 7.4)
0.18545	0.11846	0.06796	0.03682	0.01934	0.00999	0.01033

Source: Data analysis in *EasyFit 5.6*.

[18] For further information about the company and the application and its trial version, see http://www.mathwave.com/en/home.html, accessed on 15/02/2019.

Note that, according to expression (4.3.1) our capital may decrease only if the magnitude of the earthquake exceeds 6.6 Mw. From Table 8, the possibility of an earthquake of magnitude greater than 6.6 Mw (i.e. 6.7 $\rightarrow\infty$) occurring in Romania is around 4%, so we can introduce a CAT bond with 96% capital guarantee which makes it rather attractive for conservative investors.

4.3.5 Numerical example for the one-period model

Consider a one-period model with face value K = RON 4,748 (the equivalent of 1,000€ in Romanian leu, as of 19/02/2019), interest rate r = 3.16% (yield of 1-year Romanian Treasury Certificate, issued on December 17th 2018, with maturity date December 16th 2019), Libor rate R=2.90713% (as of 18/02/2019[19]), and extra risk premium e = 5%, we obtain (according to expression 4.3.1 and equation 4.3.4) P= RON 4,481.291.

[19] Accessed on 19/02/2019, https://www.homefinance.nl/english/international-interest-rates/libor/usdollar/libor-rates-12-months-usd.asp.

5. Conclusions

As the severity of natural catastrophes continues to intensify, in terms of the economic, environmental and human impacts, disaster risk management is becoming increasingly significant. The financing of catastrophe risks requires an economically solid and collaborative scheme among private insurers/reinsurers, capital markets, and governments. As a means to expand the capacity of the insurance markets and reduce the cost of risk over time, insurers and reinsurers utilize Alternative Risk Transfer (in essence, financing) mechanisms.

Among the most commonly used ART instruments are index-linked catastrophe loss instruments such as index-based Catastrophe (CAT) bonds or Industry Loss Warranties (ILWs), which are mainly characterised by their dependence on an industry loss index and, also, on the company-specific loss as a result of a natural catastrophe. Almost thirty years since the issuance of the first Catastrophe (CAT) bond, today the CAT bond market is well developed with an increasingly relevant secondary market. This rapid growth is the consequence of the rising number of natural disasters and their economic and social costs over the past decades, as well as the augmenting number of institutions seeking to alleviate the impact of these catastrophes.

The entry into force of the Solvency II regulatory regime in the European Union compels insurance companies to evaluating their balance sheet in terms of market consistency, including the financial options and guarantees embedded in life with-profit funds. The robustness of these valuations is decisive for insurance companies in order to deliver solid estimates and proper risk management strategies, in particular for liability-driven products such as with-profit saving and pension funds. It is without a doubt that, in the future, the implementation of Solvency II will provide more consistency and transparency in the insurance industry, as well as strict risk-based capital requirements.

One of the standard approaches to studying risks is using the Extreme Value Theory, which aims to predict occurrence of rare events (e.g. earthquakes of large magnitude, severe flooding, tsunamis etc.), outside the range of available data. Zimbidis et al (2007) use Extreme Value Theory to model the risk dynamics of the magnitude of the earthquakes and, subsequently, design and implement a CAT bond, under stochastic interest rates and within an incomplete and arbitrage-free market framework (introduced by Cox and Pedersen in 2000). Shao (2015) extends their model by bringing in two more risks, a financial one (inflation rates) and a catastrophe one (earthquake depth).

Using these examples as a guide, the modeling of a CAT bond covering earthquake hazard in Romania was attempted. The data-set consists of 50 largest earthquakes in Romania, from 1969 to 2018, and is analysed with the use of Generalized Extreme Value (GEV) Distribution, in order to define the extremes in earthquake magnitude. The findings of the data analysis are consistent with the ones in the abovementioned research, resulting in a rather attractive CAT bond, with 96% capital guarantee, that can generate sufficient funds for insurance claims indemnification and post-disaster reconstruction costs coverage, in the event of a catastrophic earthquake in Romania.

Moreover, the adopted assumptions are quite standard and realistic. To further simplify the model, all the risks are mutually independent. Since earthquakes are mostly regional, such events have little effect on global scale, in terms of exchange and production level and the economic environment. However, the dependence between the different risk variables could not be used within the chosen methodology and framework for bond pricing, as it constitutes a separate issue. Note, that only the one-period (basic) model is presented, as the multi-period (advanced) one exceeds the requirements of a master's dissertation.

To summarise, the main purpose of this dissertation has been to present the different ways of financing catastrophic risk, using the instruments provided by Alternative Risk Transfer. The variety of stakeholders taking part in such tradeoffs results in different quandaries that should be further addressed. To name a few:

- Imperfect information on the probability and losses correlated with risks from natural hazards. This affects the premium required by insurers and reinsurers, as well as the return required by investors.
- Capacity constraints in terms of reinsurance, following a major disaster. In this case either insurers seek other sources of funds, like CAT bonds, or reinsurers employ such sources themselves.
- Willingness and capacity of insurers to eliminate most of the basis risk, by adopting a model-indexed custom policy. Whether they will hold the residual model risk as well, will depend on the moral hazard magnitude.
- Double role of the government as "reinsurer of last resort" and imposer of taxes on property owners. It should be investigated whether governments can supplement a bond/reinsurer combination, on what terms and when (the optimal timing), and how would they distribute the yields.

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Appendix A

Earthquake glossary

- Active fault: A fault that is likely to have another earthquake sometime in the future. Faults are commonly considered to be active if they have moved in the last 10,000 years.
- Crust: The outermost layer of the earth, ranging from 10 to 65 km in thickness worldwide. The uppermost 15-35 km of crust is brittle enough to produce earthquakes.
- Epicentre: The point on the earth's surface vertically above the hypocentre.
- Fault: A fracture, along which the blocks of crust on either side have moved relative to one another in a direction parallel to the fracture.
- Fissure: A long narrow crack in the ground caused by earthquakes.
- Focal depth: The depth of an earthquake's hypocentre.
- Focus: Same as Hypocentre.
- Hypocentre: The point on the fault plane where the rupture starts.
- Intensity: A measure of how strongly an earthquake manifests at the surface, based on its observable effects on people, buildings and the environment. Intensity is usually ranked using the 12 point Modified Mercalli Intensity (MMI) scale.
- Magnitude: A measure of the energy released by an earthquake at its source. Magnitude is commonly determined from the shaking recorded on a seismograph. Each unit of magnitude on the scale represents a substantial increase in energy, for example a magnitude 5 releases 30 times more energy than a magnitude 4.
- MMI: An abbreviation for Modified Mercalli Intensity (see Intensity above).
- Subduction zone: The area or zone where two tectonic plates come together, one riding over the other.
- Tectonic uplift: Elevation of the ground caused by plate movement.

(GeoNet - Geological hazard information for New Zealand, n.d.)

Appendix B

Seismicity of Romania

Intermediate - depth seismic zone

Vrancea subcrustal Zone (VR): The Vrancea region is a complex seismic region of continental convergence characterized by (at least) three tectonic units in contact: the East European plate, Intra-Alpine and Moesian subplates. The strongest seismic activity of Romania concentrates at intermediate depths (60–200 km) in an almost vertical downgoing high-velocity lithospheric body. Enhanced activity is observed within two depth ranges – 80 to 100 km, and 120 to 160 km, respectively.

Normal - depth seismic zones

East Vrancea Zone (EV): The shallow seismicity in the Vrancea region spreads diffusely eastward relative to the Carpathians arc bend, in the strip delimited by the Peceneaga-Camena fault to the north and Intramoesian fault to the south (so-called Black Sea subplate). It consists of only moderate-size earthquakes, not exceeding magnitude Mw=6. Bursts of seismic activity – earthquake sequences or swarms – are relatively common in this zone (e.g., in Râmnicu Sărat – Focşani region, in Vrâncioaia area).

Făgăraş – Câmpulung Zone (FC): It is sited in the eastern part of the Southern Carpathians. It is characterized by shocks as large as Mw~6.5, which are the largest shallow earthquakes recorded on the Romanian territory. The last major event occurred on January 26, 1916 (Mw=6.4), and was followed by significant aftershock activity. The epicenter distribution outlines two clusters: one located to the west, which includes the largest shocks (Mw~6), the other one located to the east (Sinaia region), with smaller events (Mw<5).

Danubian Zone (DA): The seismogenic Danubian Zone represents the western extremity, adjacent to the Danube River, of the orogenic unit of the Southern Carpathians. The rate of seismic activity is relatively high, especially at the border and beyond the border with Serbia, across the Danube river. The magnitude does not exceed Mw=5.6.

Banat Zone (BA): The contact between the Panonnian Depression and the Carpathian orogen lies entirely along the western part of the Romanian border. The seismicity of the Banat zone is characterized by many earthquakes with magnitude Mw>5, but not exceeding 5.6. In general, the larger shocks, which are frequently followed by aftershock sequences, occur in clusters (within a few month intervals).

Crişana-Maramureş Zone (CM): The historical earthquake catalogues report the occurrence of events greater than magnitude Mw=6 in Crişana-Maramureş. Several damaging earthquakes with magnitude above Mw=5 are also reported on the basis of historical information.

Bârlad Depression (BD): The Bârlad Depression is a subsiding depression situated to the NE of the Vrancea region on the Scythian platform, and it represents the prolongation towards the NW of the Predobrogean Depression. Only moderate-size events are observed, not exceeding Mw=5.6.

Predobrogean Depression (PD): This seismogenic zone belongs to the southern margin of the Predobrogean Depression, following the Sfântul Gheorghe fault alignment. Roughly, the seismicity and focal mechanism characteristics are similar to those outlined for the Bârlad Depression, e.g. the moderate seismic activity (Mw≤5.3), clustered especially along the Sfantul Gheorghe fault, and the extensional regime of the deformation field. This consistently reflects the affiliation of the two zones to the same tectonic unit – the Scythian platform.

Intramoesian Fault (IM): The Intramoesian fault crosses the Moesian platform in a SE–NW direction, separating two distinct sectors with different constitution and structure of the basement. Although it is a well-defined deep fault, reaching the base of the lithosphere, and extending southeast to the Anatolian fault region, the associated seismic activity is scarce and weak (only two events above magnitude Mw=5, both reported in the instrumental period). The focal depth (whenever it can be constrained) has relatively large values (h~35 km), suggesting active processes in the lower crust or in the upper mantle.

Transylvanian Depression (TD): This seismogenic zone is defined only on the basis of historical information. The seismic activity is mostly absent at present; nevertheless, several earthquakes with magnitude above Mw=5 (a couple of events with Mw > 5.5) have been reported on the basis of historical documents, which notify important damaging effects in Transylvania. (Institutul National de Cercetare Dezvoltare pentru Fizica Pamantului, Romania, n.d.)

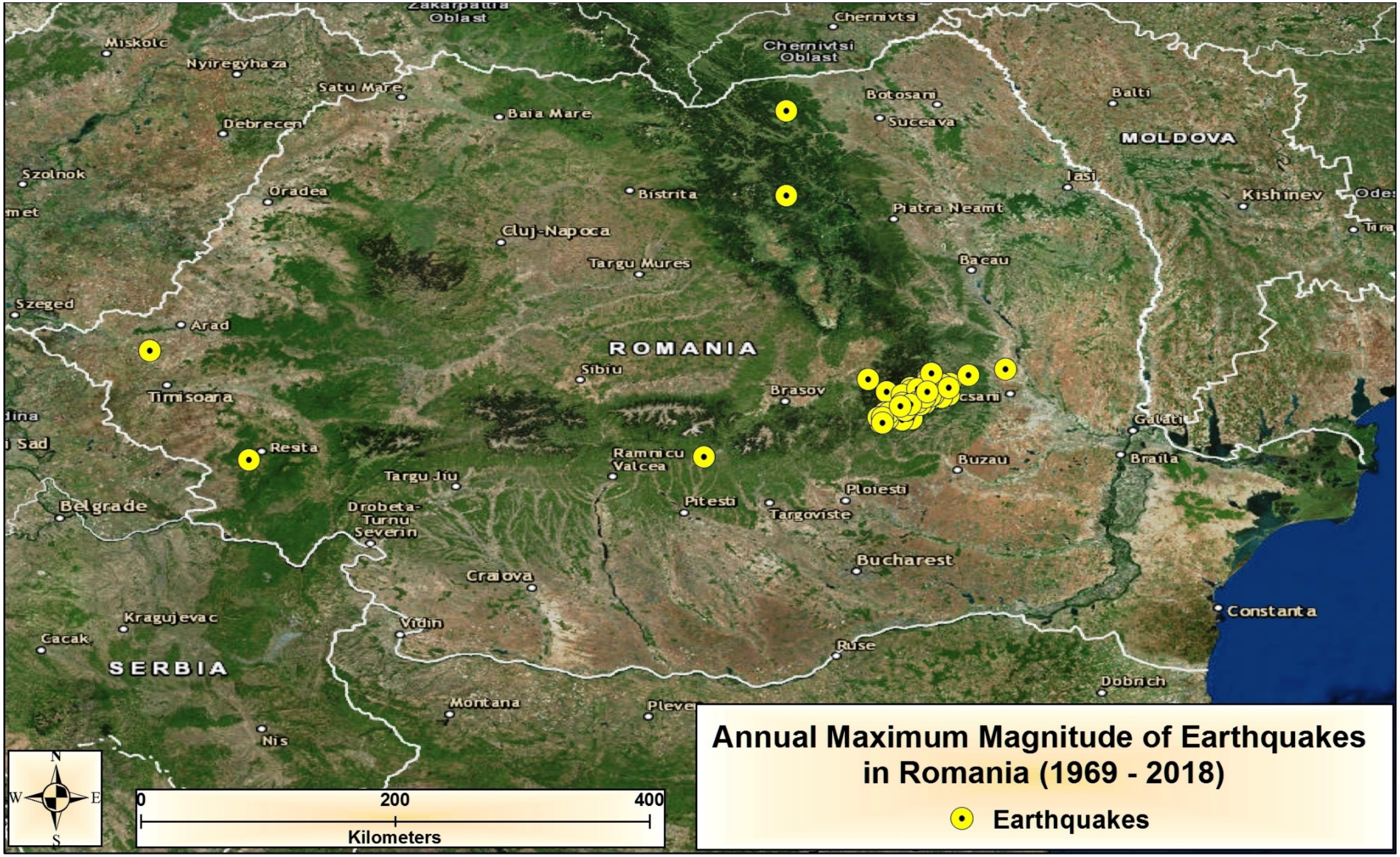


Figure B.1 Map of Romania showing Annual Maximum Magnitude of Earthquakes, 1969-2018
Source: Data processing in ArcGIS.

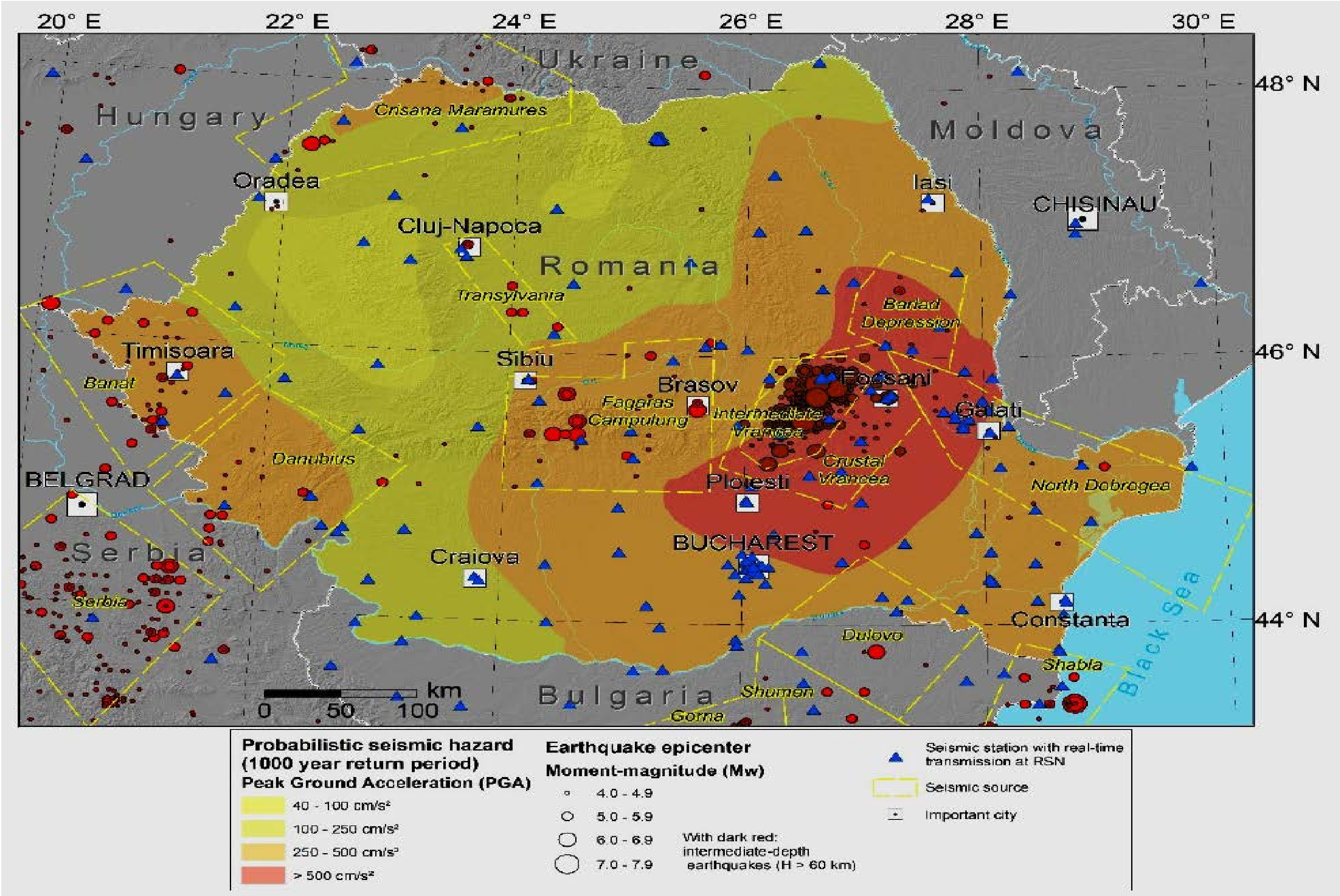


Figure B.2 Map of Romania showing earthquakes with Mw ≥ 4 and seismic sources according to the BIGSEES Catalog (NIEP, 2017), results of the probabilistic seismic hazard analysis of the RO-RISK Project and seismic stations with real-time transmission at the Romanian Seismic Network (RSN)
Source: Toma-Danila et al. 2018. 3.

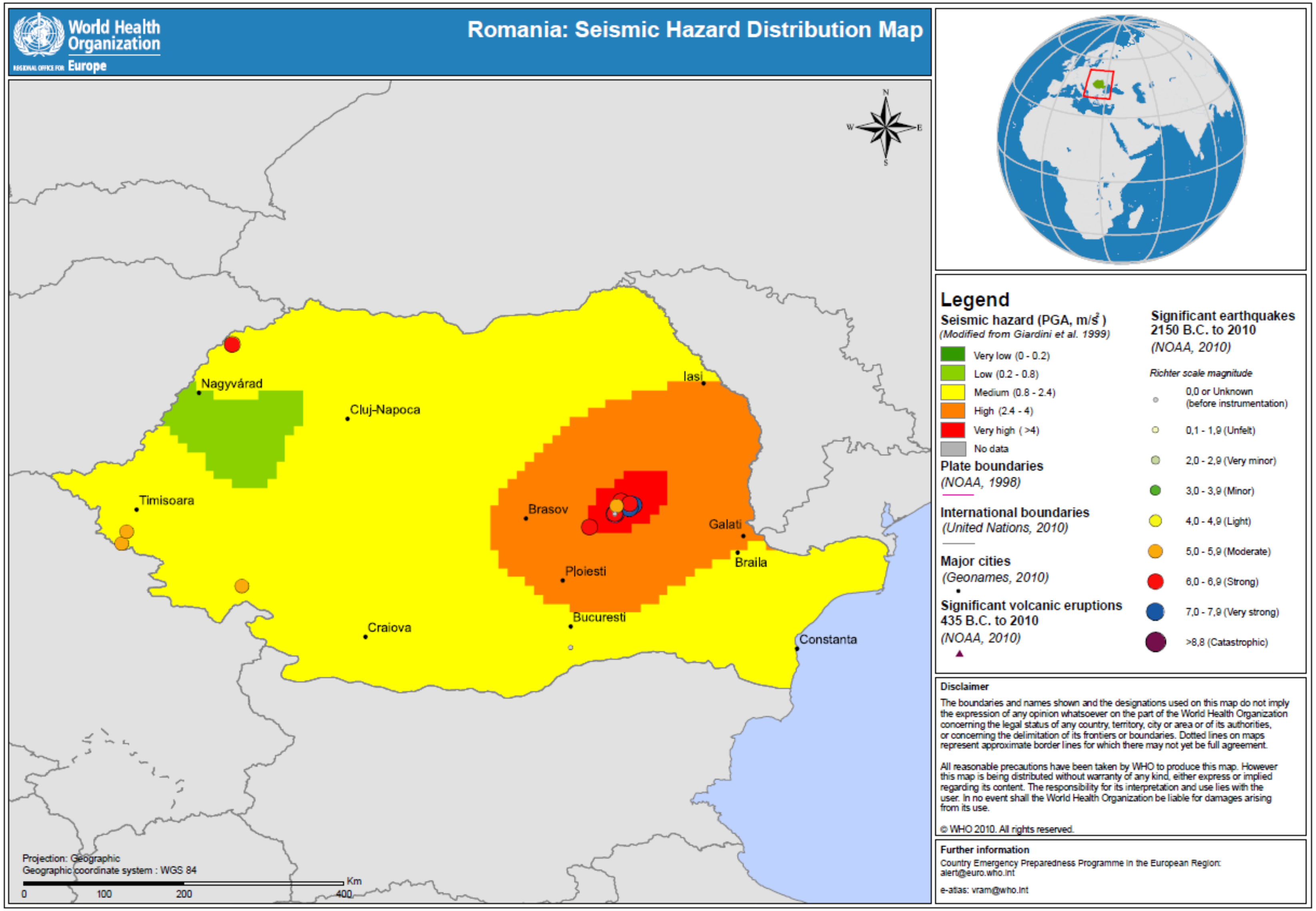


Figure B.3 Seismic Hazard Distribution Map
Source: World Health Organization. 2010.

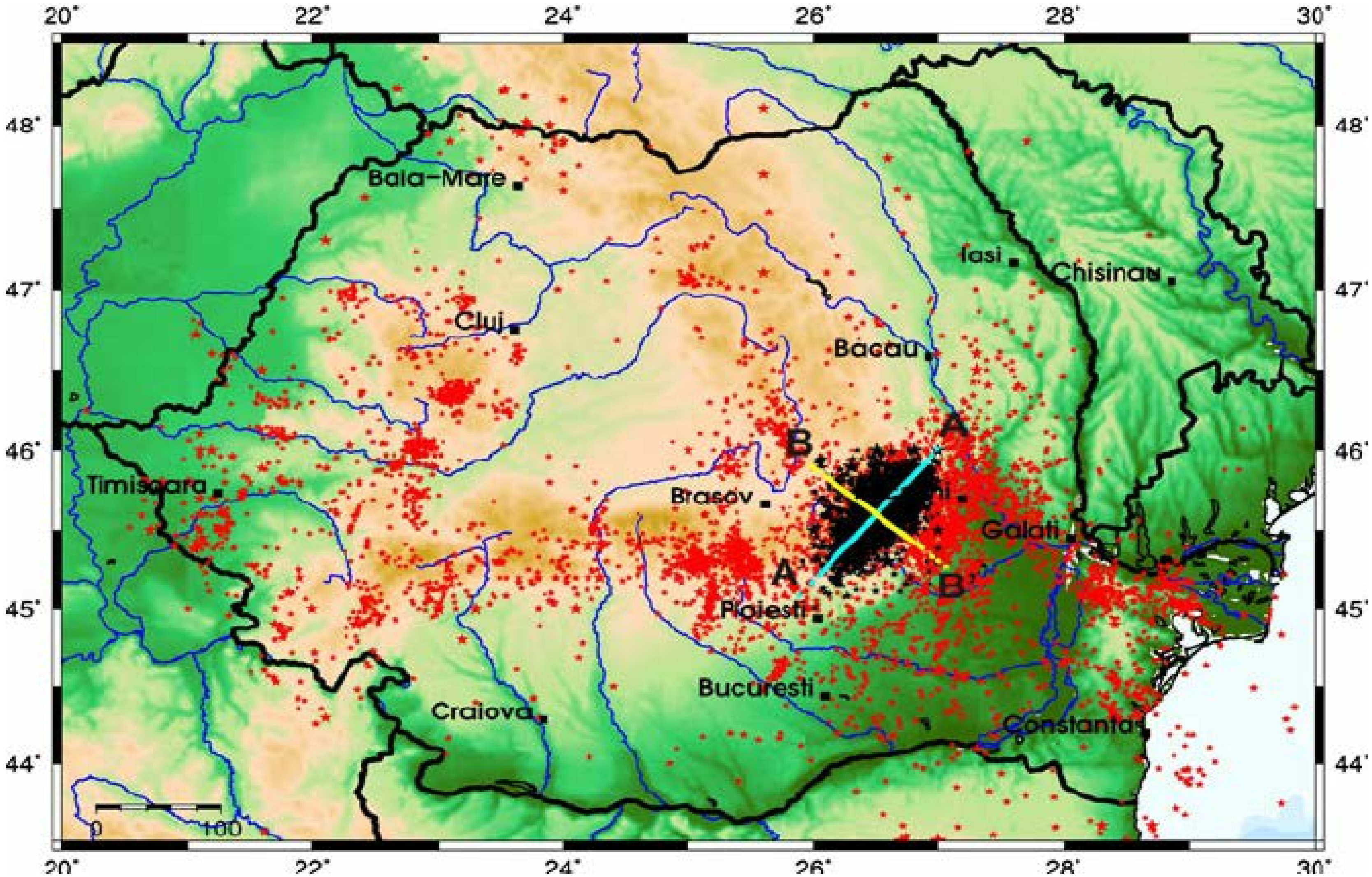


Figure B.4 Top Epicentral map of the earthquakes on the Romania territory and the Vrancea seismic source location. The crustal events (h < 60 km) are plotted in red ; the subcrustal events (h ≥ 60 km) are plotted in black
Source: Carbunar, O. F., & Radulian, M. (2011). 581.

Appendix C

Part 1 – R code for producing *h*=50,000 simulations in RStudio Version 1.1.463 – © 2009-2018 RStudio, Inc.

```
> setwd("C:/Users/MP/Desktop")          # Setting the working directory
> library(fExtremes)                    # Loading the library needed for the analysis
> T<-1                                  # time period
> m <-50000                             # simulation time h
> e <-0.05                              # extra risk premium
> r<-0.0316                             # risk free interest rate
> R<-rep(0.029,m)                       # LIBOR rate
> K=4748                                # face value of the CAT bond
## generate m cases for Magnitude
> Mag <- rgev(m, -0.005990949, 4.687832990, 0.601971476)
> C=rep(NA,m)                           # value of payoff function

# Price payoff function PCAT is
> for (i in 1:m){if(Mag[i]<5.4) C[i]=K*(1+3*R)
+ if(Mag[i]<5.8 && Mag[i]>=5.4) C[i]=K*(1+2*R)
+ if(Mag[i]<6.2 && Mag[i]>=5.8) C[i]=K*(1+R)
+ if(Mag[i]<6.6 && Mag[i]>=6.2) C[i]=K
+ if(Mag[i]<7.0 && Mag[i]>=6.6) C[i]=(2/3)*K
+ if(Mag[i]<7.4 && Mag[i]>=7.0) C[i]=(1/3)*K
+ if(Mag[i]>7.4) C[i]=0}


> write.csv2(Mag, file="Mag.csv")       # Saving the Results for magnitude M in a csv file in our working directory
> write.csv2(C, file="C.csv")           # Saving the Results for payoff value C in a csv file in our working directory
```

Part 2 – Data processing in RStudio Version 1.1.463 – © 2009-2018 RStudio, Inc.

Loading libraries needed for the analysis

```
> library(extRemes)        # functions for performing extreme value analysis
> library(ismev)           # includes functions like: maxima/minima, order statistics, peaks over thresholds, point processes
> library(evd)             # functions for maximum likelihood estimates for maxima models
> library(evmix)           # maximum likelihood inference and model diagnostics for univariate stationary extreme value mixture models
```

Typing data into R Console:

```
> RomaniaMax=c(5.2, 4.7, 3.8, 3.8, 6.0, 4.9, 5.3, 3.9, 7.4, 5.2, 5.3, 5.1, 5.5, 4.3, 5.6, 4.7, 5.8, 7.1, 4.8, 4.6, 4.4, 6.9, 5.7, 4.6, 4.4, 4.3, 4.1, 4.6, 4.7, 4.7, 5.3, 5.0, 4.9, 4.7, 4.7, 6.0, 5.5, 4.7, 4.4, 4.3, 5.4, 4.6, 4.9, 4.4, 5.2, 5.7, 4.3, 5.6, 4.8, 5.8)
```

Setting up a year counter (from 1969 to 2018):

```
> year=seq(1969,2018,1)
```

Producing the plots shown in Figures 24 and 25, page 59:

```
> plot(RomaniaMax~year,type='b')       # Scatter Plot
> hist(RomaniaMax)                     # Histogram
```

Fitting the data in Generalized Extreme Value Distribution

```
> a<-gev.fit(RomaniaMax)          #setting object a as the GEV fitted distribution of our data
$conv                    # The convergence code, a zero indicates successful convergence
[1] 0

$nllh          # The negative logarithm of the likelihood evaluated at the maximum likelihood estimates
[1] 53.33175                      # maximized log-likelihood

$mle                              # maximized log-likelihood estimators for parameters μ, σ, ξ
[1]  4.687832990  0.601971476  -0.005990949

$se                               # standard errors of parameters μ, σ, ξ
[1] 0.09527876 0.06851935 0.09934169
```

```
> a$cov                    # produces the covariance matrix of the GEV distribution
            [,1]         [,2]         [,3]
[1,]  0.009078041  0.002389238 -0.003233565
[2,]  0.002389238  0.004694901 -0.001831653
[3,] -0.003233565 -0.001831653  0.009868771
```

```
> gev.profxi(a, -0.105332639, 0.093350741)
```
Produces profile log-likelihood of shape parameter. "a" the object returned by gev.fit, followed by the lower and upper bound of the 95 % confidence interval of the shape parameter

```
> gev.diag(a)
```
produces the diagnostic plots for assessing the accuracy of the GEV model

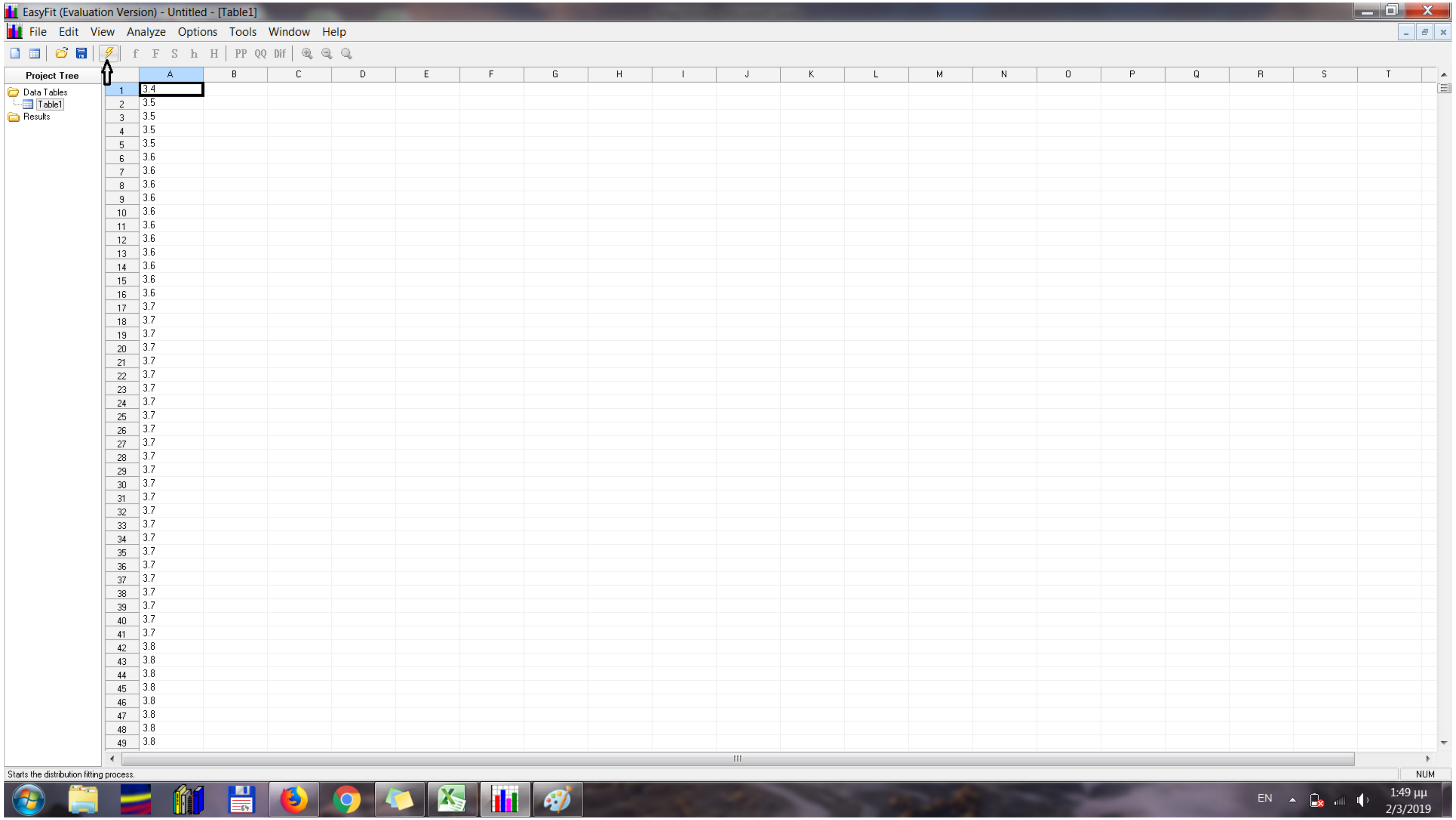
```
> mrl.plot(RomaniaMax, umin = min(RomaniaMax), umax = max(RomaniaMax) - 0.1,
+     conf = 0.95, nint = 100)
```
produces the sample Mean Residual Life plot, includes 95% confidence bounds for the mean excess

```
> mePlot(RomaniaMax, doplot = TRUE, labels = TRUE)
```
produces the Sample Mean Excess Plot

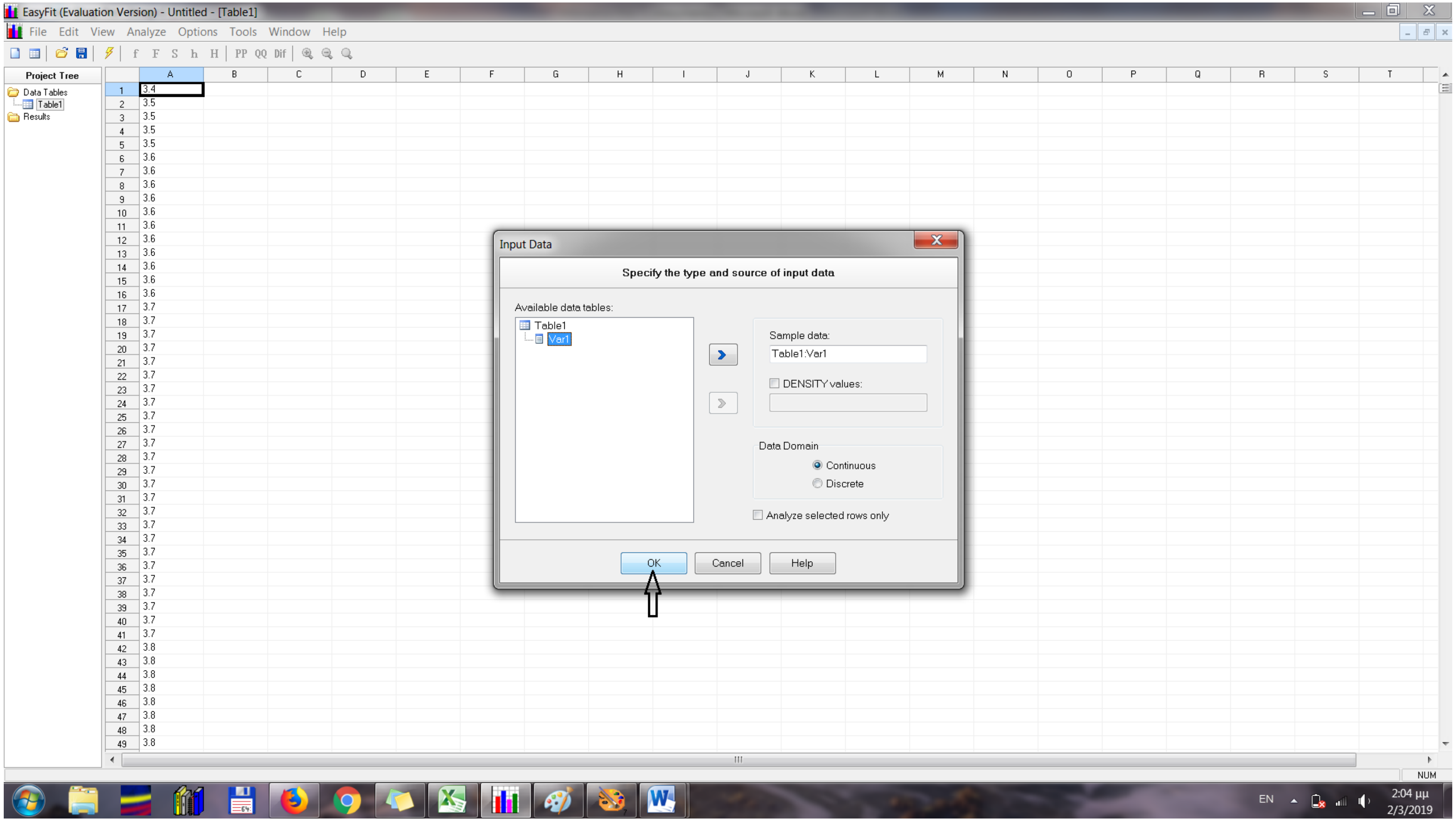
Appendix D

Using *EasyFit 5.6* (trial version) to obtain earthquake probabilities

The trial version of *EasyFit 5.6* is free to use for 30 days. Once we install it, we can copy the data from an Excel sheet and paste them in column A of *EasyFit 5.6*. We then press the “bolt” button:

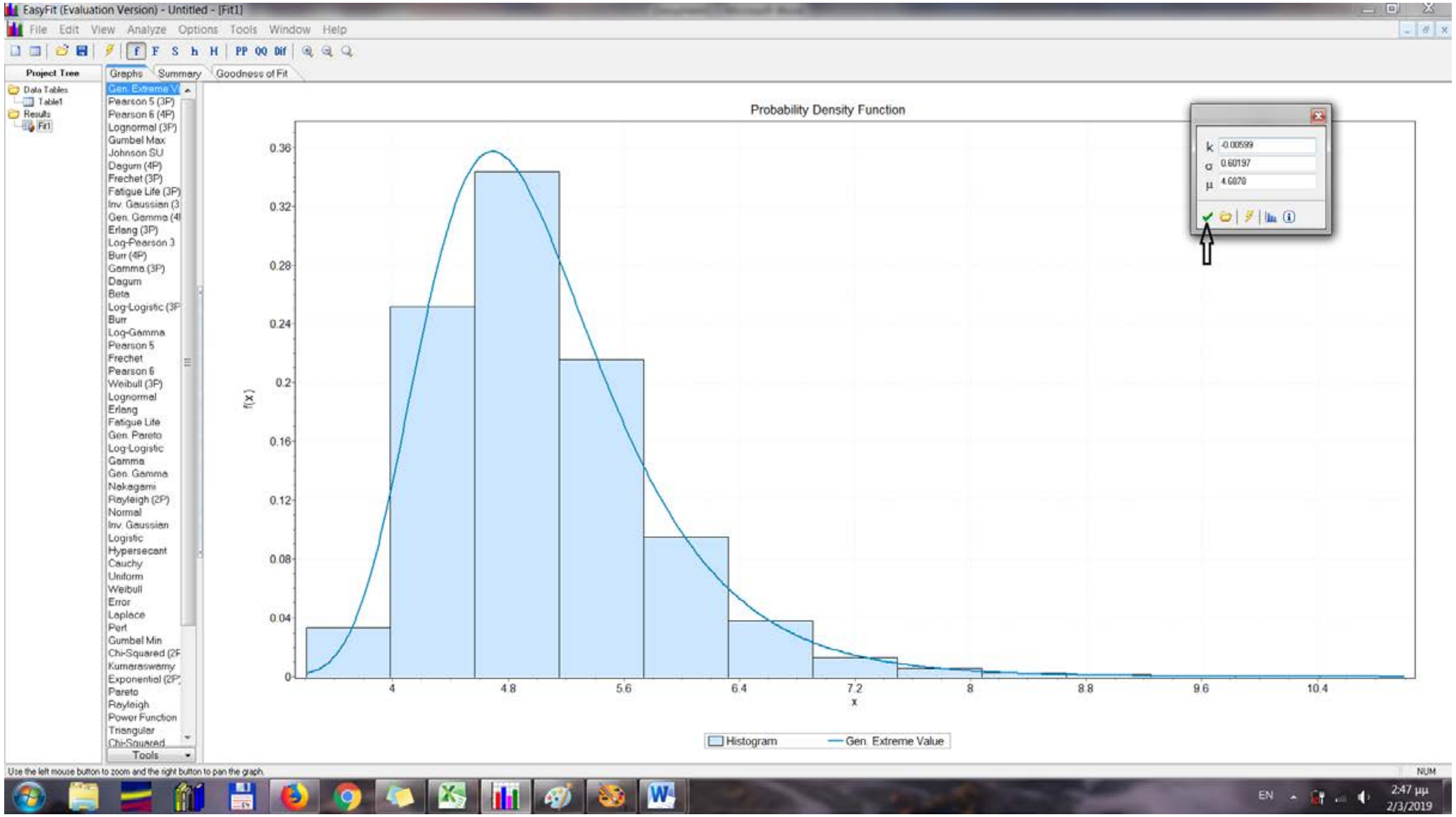


We click "OK" on the pop up window in order for the application to run the available distributions and fit them to our data:

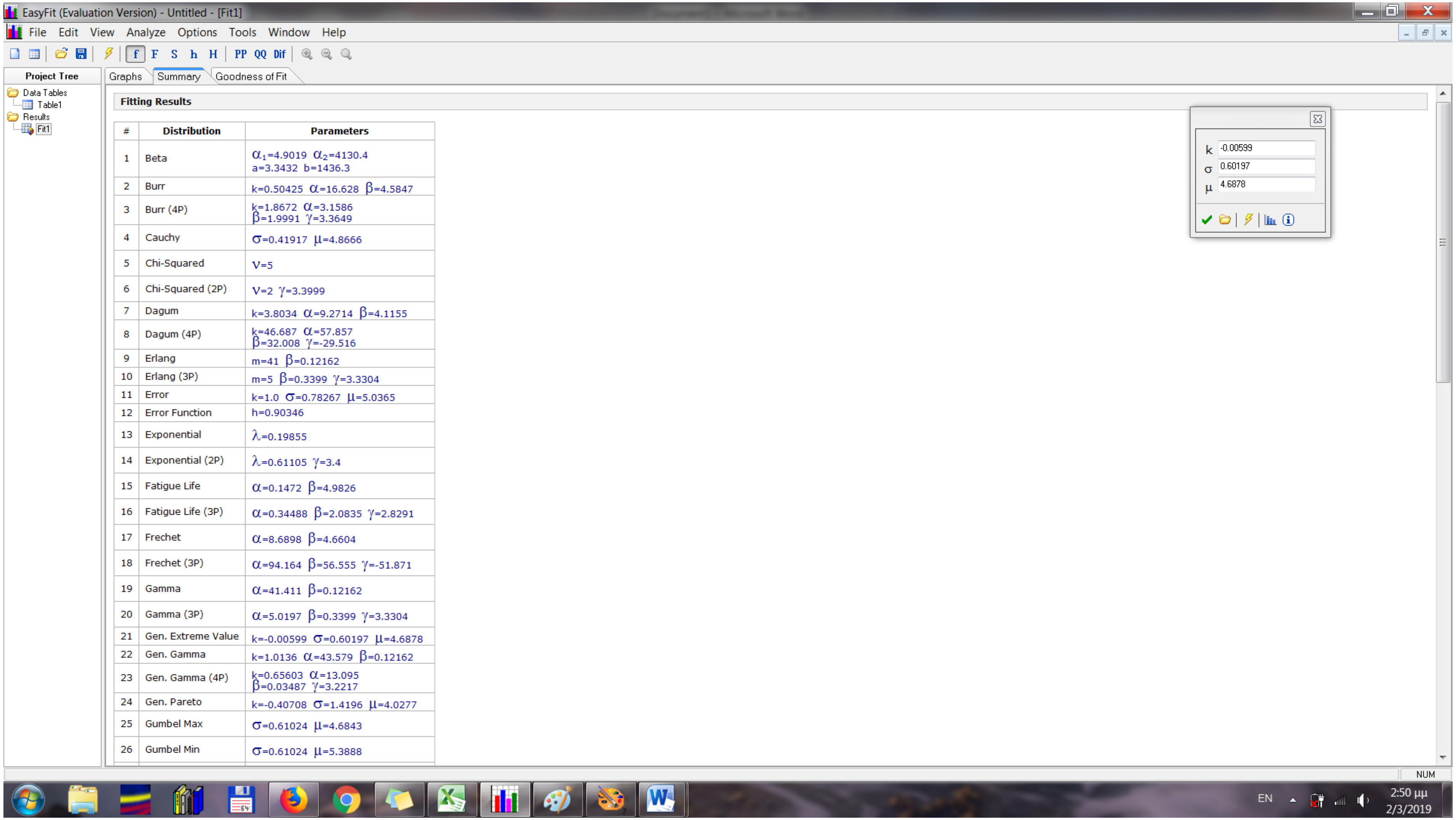


Once the fitting is done, we get the following:

- In "Graphs" tab: on the left hand-side of the screen a column with all the available distributions (we choose Generalized Extreme Value Distribution), a graph of the chosen distribution, as well as a smaller window on the right top corner with the parameters of the distribution. Note that in *EasyFit 5.6* k is the ξ parameter of our analysis. Moreover, one can change the parameters, accordingly. In our case we copy-paste the $\hat{\mu}$, $\hat{\sigma}$ and $\hat{\xi}$ estimates of the maximized log-likelihood of GEV that we obtained from R and click the green "tick" button for the fitting.

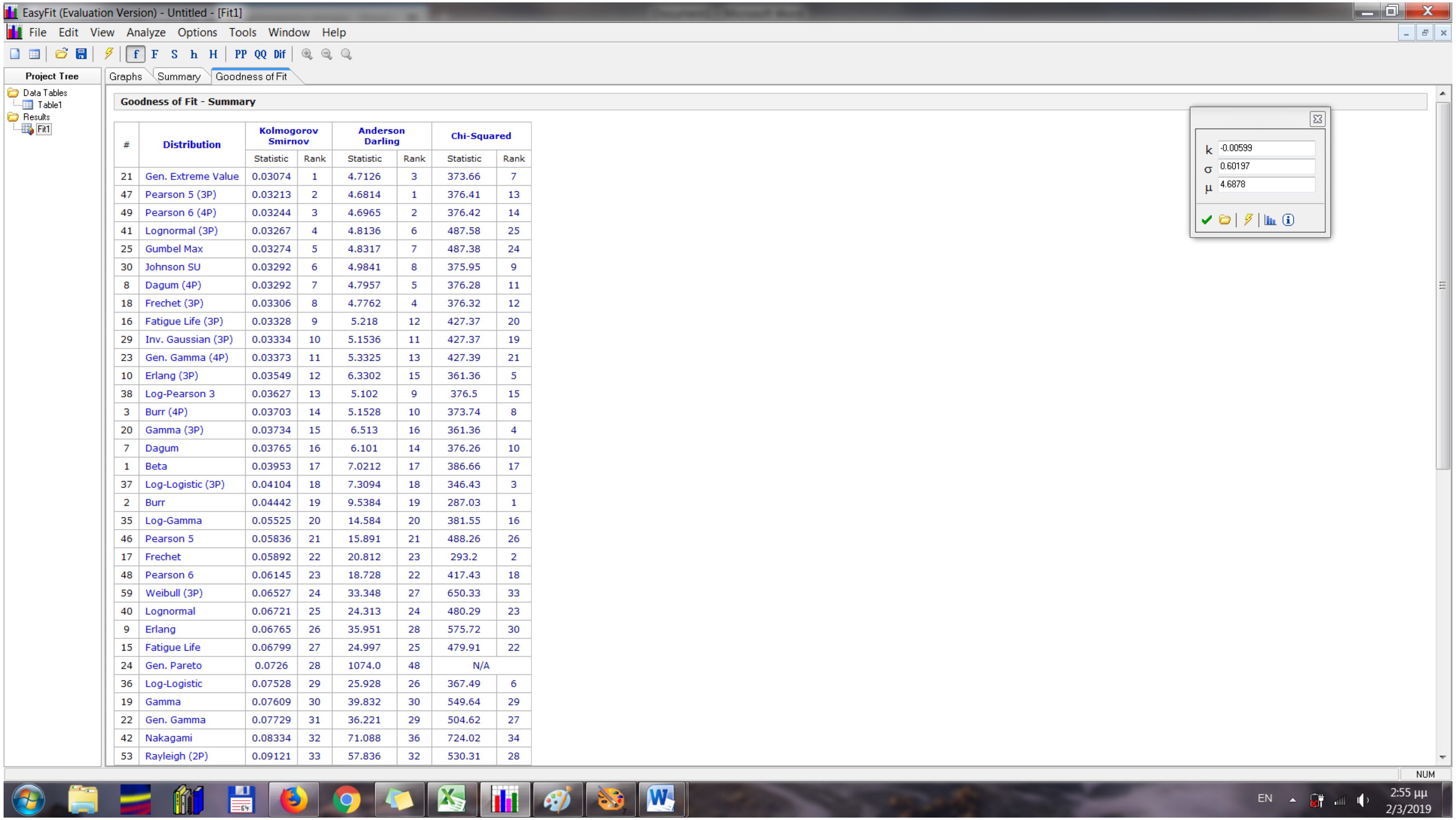


- In “Summary” tab one can see the fitting results for each distribution, in alphabetical order.



#	Distribution	Parameters
1	Beta	α_1=4.9019 α_2=4130.4 a=3.3432 b=1436.3
2	Burr	k=0.50425 α=16.628 β=4.5847
3	Burr (4P)	k=1.8672 α=3.1586 β=1.9991 γ=3.3649
4	Cauchy	σ=0.41917 μ=4.8666
5	Chi-Squared	ν=5
6	Chi-Squared (2P)	ν=2 γ=3.3999
7	Dagum	k=3.8034 α=9.2714 β=4.1155
8	Dagum (4P)	k=46.687 α=57.857 β=32.008 γ=-29.516
9	Erlang	m=41 β=0.12162
10	Erlang (3P)	m=5 β=0.3399 γ=3.3304
11	Error	k=1.0 σ=0.78267 μ=5.0365
12	Error Function	h=0.90346
13	Exponential	λ=0.19855
14	Exponential (2P)	λ=0.61105 γ=3.4
15	Fatigue Life	α=0.1472 β=4.9826
16	Fatigue Life (3P)	α=0.34488 β=2.0835 γ=2.8291
17	Frechet	α=8.6898 β=4.6604
18	Frechet (3P)	α=94.164 β=56.555 γ=-51.871
19	Gamma	α=41.411 β=0.12162
20	Gamma (3P)	α=5.0197 β=0.3399 γ=3.3304
21	Gen. Extreme Value	k=-0.00599 σ=0.60197 μ=4.6878
22	Gen. Gamma	k=1.0136 α=43.579 β=0.12162
23	Gen. Gamma (4P)	k=0.65603 α=13.095 β=0.03487 γ=3.2217
24	Gen. Pareto	k=-0.40708 σ=1.4196 μ=4.0277
25	Gumbel Max	σ=0.61024 μ=4.6843
26	Gumbel Min	σ=0.61024 μ=5.3888

- In “Goodness of Fit” tab one can check which is the best fitting distribution, according to the following probability tests: Kolmogorov-Smirnov, Anderson-Darling, and Chi-Squared. By clicking to each test title we get the rank from best- to worst-fitting, of each distribution. In our case GEV is ranked as no 1 in the Kolmogorov-Smirnov test.

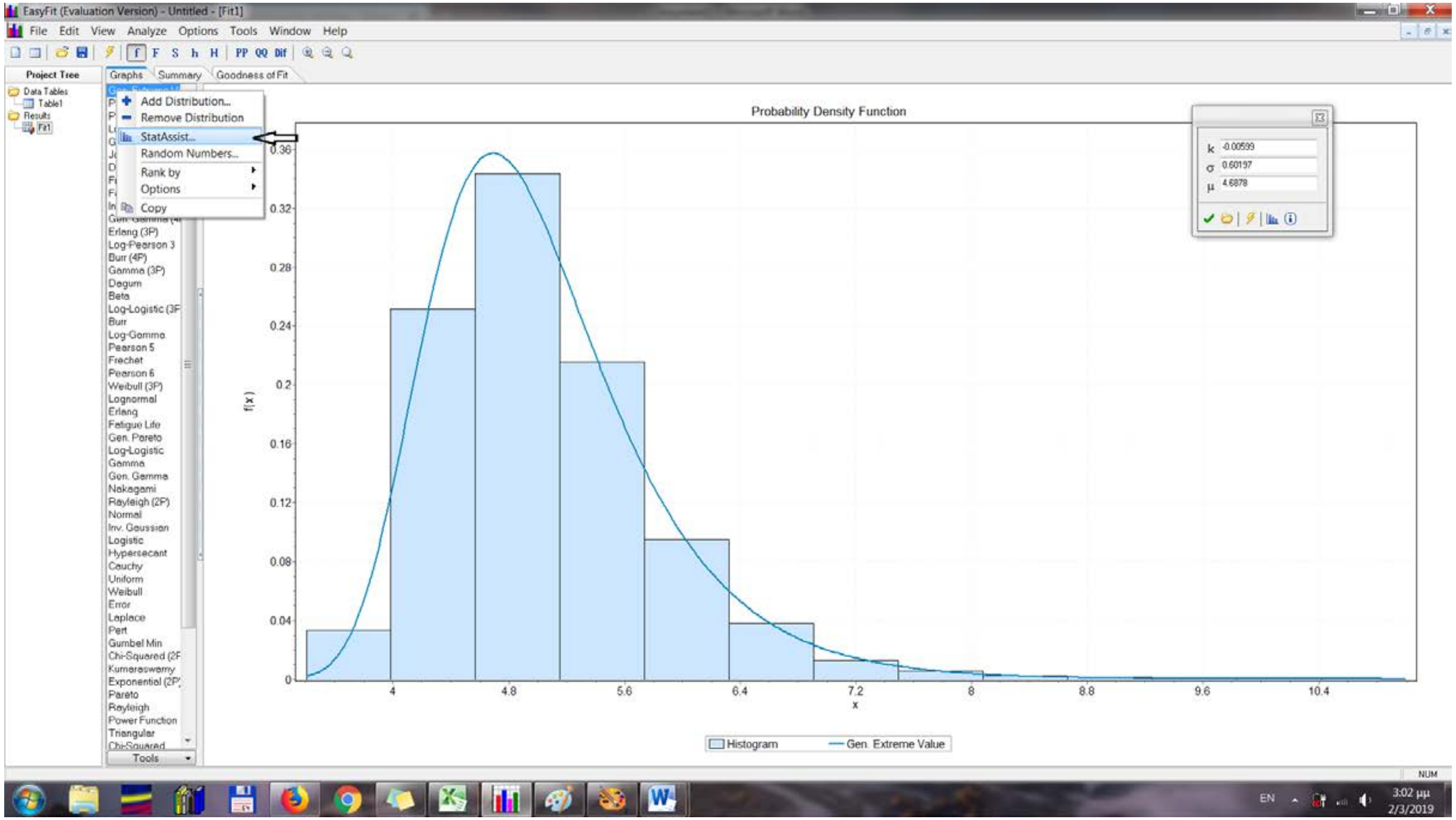


Goodness of Fit - Summary

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
21	Gen. Extreme Value	0.03074	1	4.7126	3	373.66	7
47	Pearson 5 (3P)	0.03213	2	4.6814	1	376.41	13
49	Pearson 6 (4P)	0.03244	3	4.6965	2	376.42	14
41	Lognormal (3P)	0.03267	4	4.8136	6	487.58	25
25	Gumbel Max	0.03274	5	4.8317	7	487.38	24
30	Johnson SU	0.03292	6	4.9841	8	375.95	9
8	Dagum (4P)	0.03292	7	4.7957	5	376.28	11
18	Frechet (3P)	0.03306	8	4.7762	4	376.32	12
16	Fatigue Life (3P)	0.03328	9	5.218	12	427.37	20
29	Inv. Gaussian (3P)	0.03334	10	5.1536	11	427.37	19
23	Gen. Gamma (4P)	0.03373	11	5.3325	13	427.39	21
10	Erlang (3P)	0.03549	12	6.3302	15	361.36	5
38	Log-Pearson 3	0.03627	13	5.102	9	376.5	15
3	Burr (4P)	0.03703	14	5.1528	10	373.74	8
20	Gamma (3P)	0.03734	15	6.513	16	361.36	4
7	Dagum	0.03765	16	6.101	14	376.26	10
1	Beta	0.03953	17	7.0212	17	386.66	17
37	Log-Logistic (3P)	0.04104	18	7.3094	18	346.43	3
2	Burr	0.04442	19	9.5384	19	287.03	1
35	Log-Gamma	0.05525	20	14.584	20	381.55	16
46	Pearson 5	0.05836	21	15.891	21	488.26	26
17	Frechet	0.05892	22	20.812	23	293.2	2
48	Pearson 6	0.06145	23	18.728	22	417.43	18
59	Weibull (3P)	0.06527	24	33.348	27	650.33	33
40	Lognormal	0.06721	25	24.313	24	480.29	23
9	Erlang	0.06765	26	35.951	28	575.72	30
15	Fatigue Life	0.06799	27	24.997	25	479.91	22
24	Gen. Pareto	0.0726	28	1074.0	48	N/A	
36	Log-Logistic	0.07528	29	25.928	26	367.49	6
19	Gamma	0.07609	30	39.832	30	549.64	29
22	Gen. Gamma	0.07729	31	36.221	29	504.62	27
42	Nakagami	0.08334	32	71.088	36	724.02	34
53	Rayleigh (2P)	0.09121	33	57.836	32	530.31	28

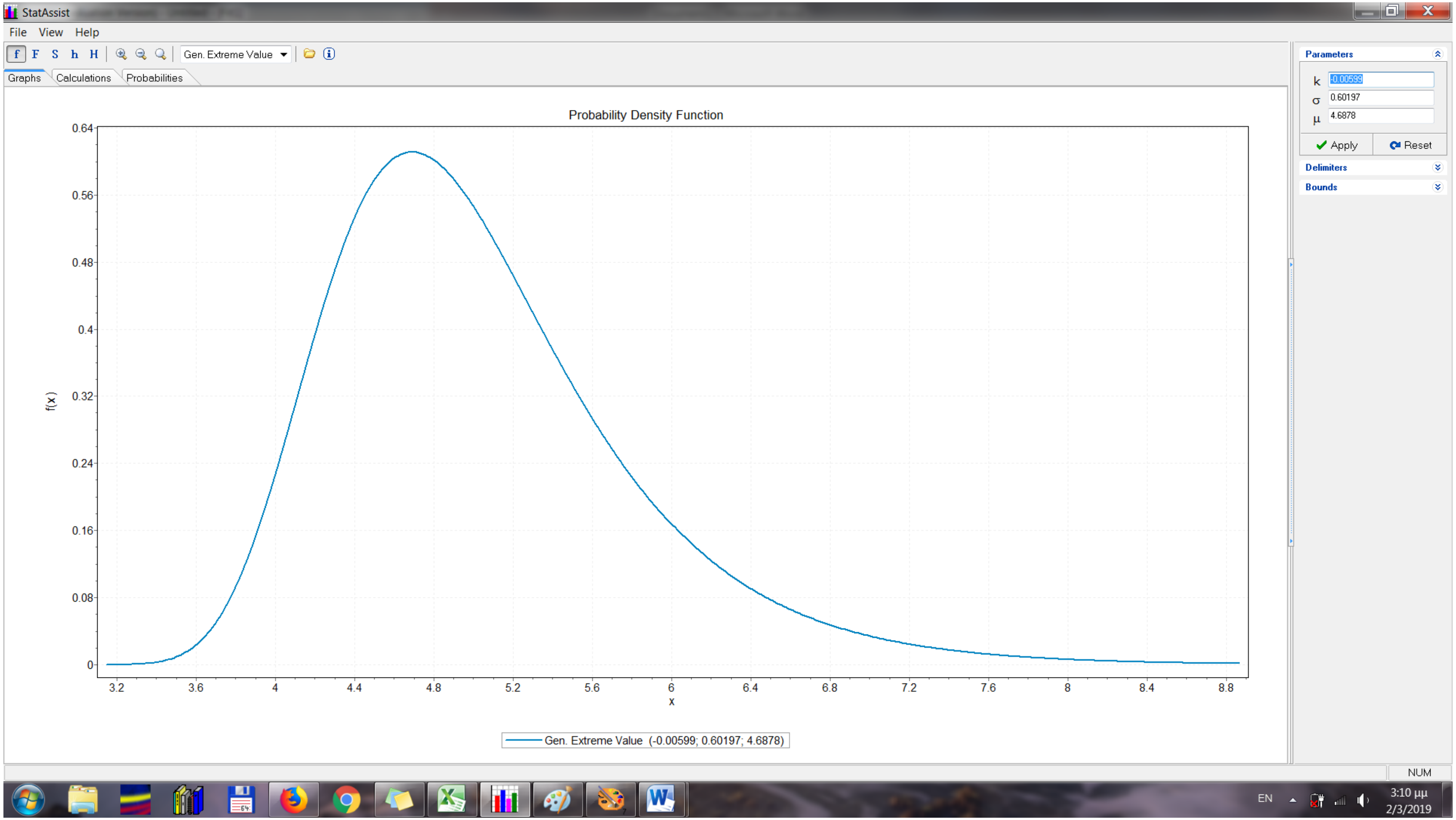
Above the tabs area, and next to the “bolt” button, one can check the Probability Distribution Function (“f” button), Cumulative Distribution Function (“F” button), Survival Function (“S” button), Hazard Function (“h” button), Cumulative Hazard Function (“H” button), P-P Plot (button “PP”), Quality Plot (“QQ” button), and Probability Difference (“Dif” button) for any chosen distribution. Each plot can be saved as an image by right-clicking in the plot area.

Once we set our $\hat{\mu}$, $\hat{\sigma}$ and $\hat{\xi}$ parameters, we return on the “Graphs” tab, right-click on the “Gen. Extreme Value” on the left hand-side column and then click on StatAssist in the drop-down menu.

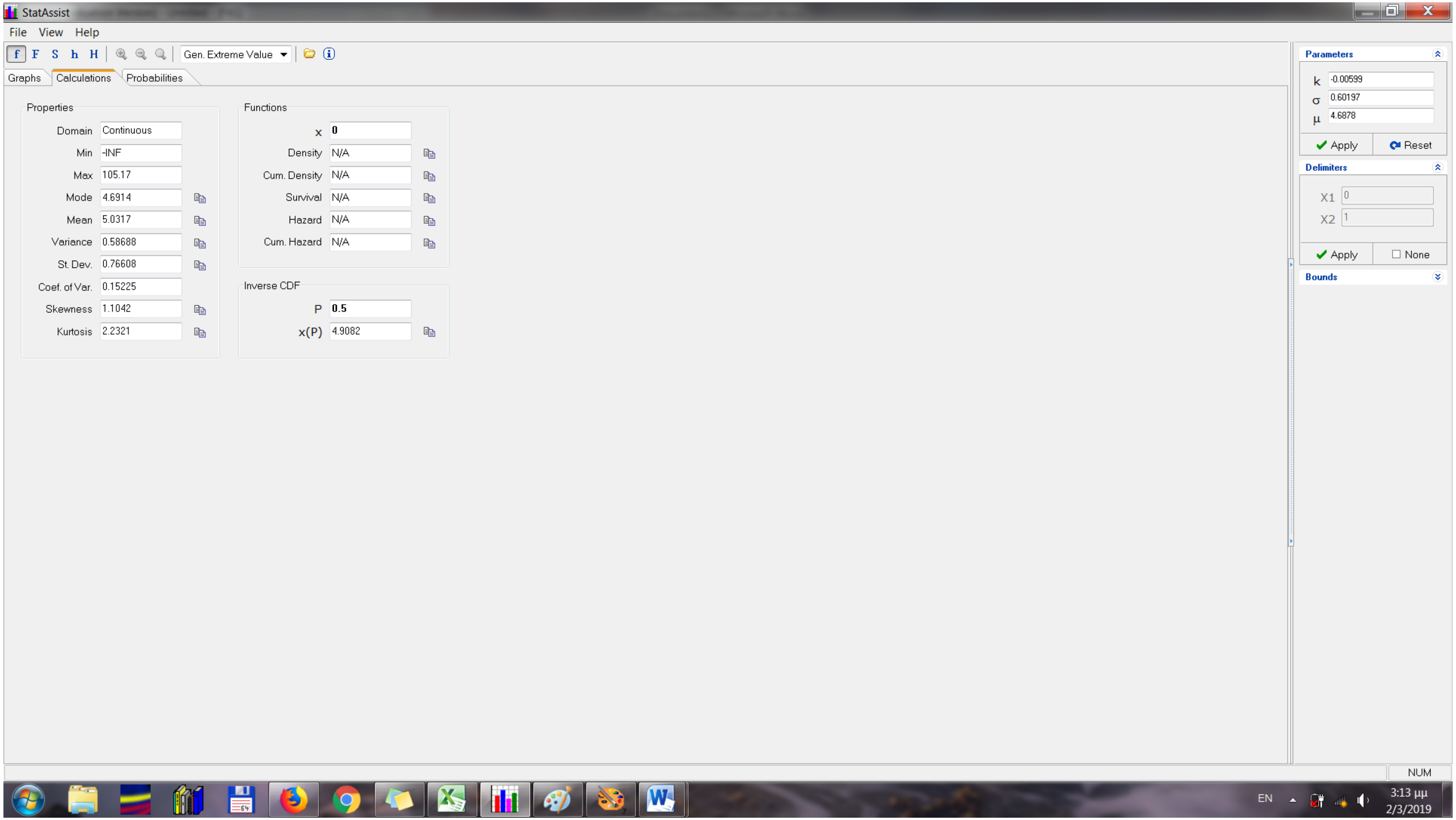


The three tabs in the new window are:

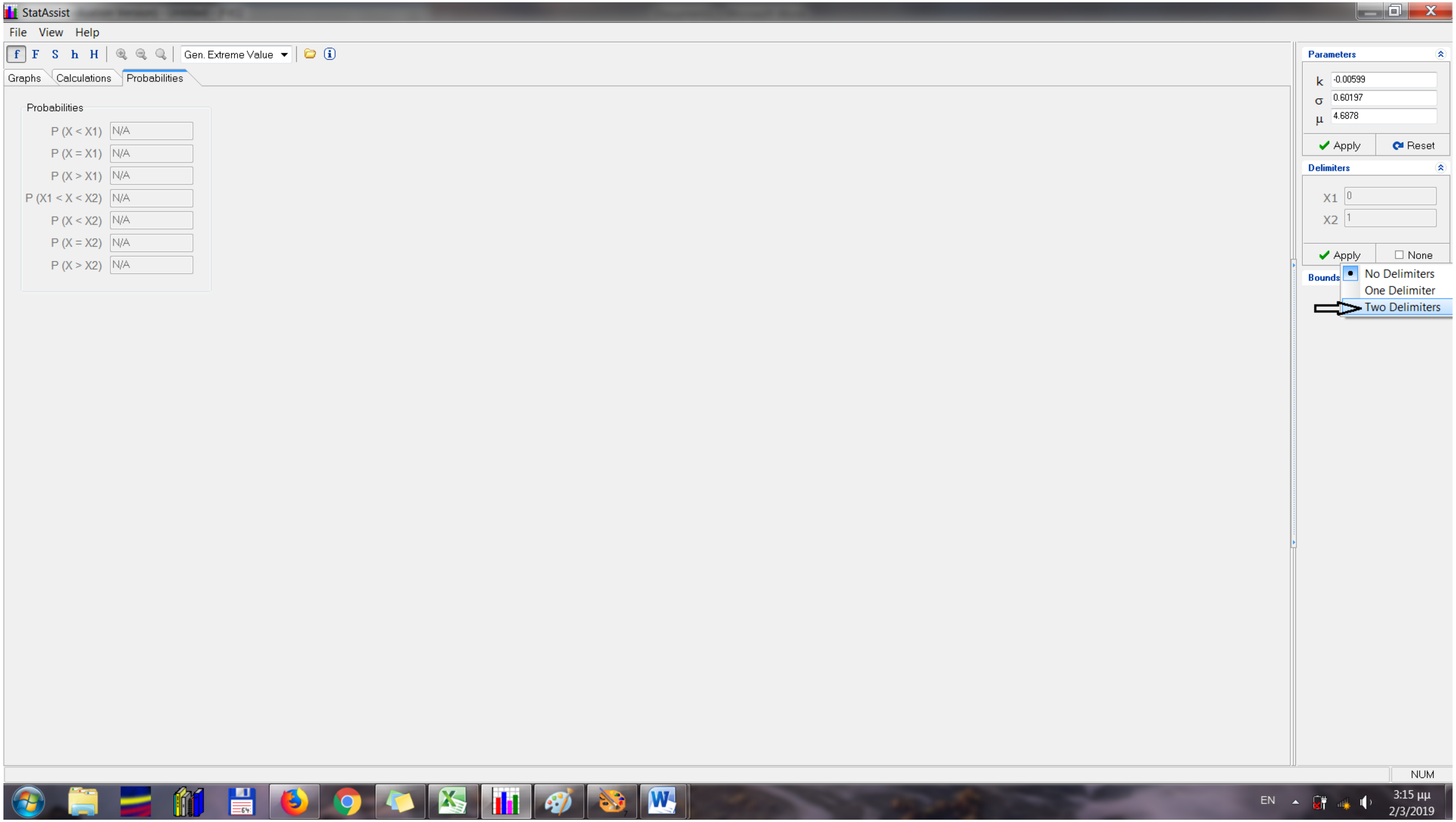
- “Graphs”: the Probability Density Function curve.



- “Calculations”: the properties and functions of the distribution.



- “Probabilities” the probabilities of the distributions, according to an input of our choice. We click “Delimiters” on the right, then the “None” button and the “Two Delimiters” options.



The X1 and X2 fields, under "Delimiters", are now active and we can write the lower (X1) and upper (X2) limits of our magnitudes interval. We then press the "Apply" button and get the probabilities for each interval. We follow the same procedure until we obtain the "X1<X<X2" probabilities for all the intervals set in expression 4.3.1, page 43.