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Alternative to Insurance Risk Transfer: Creating a catastrophe bond for Romanian earthquakes

Apostolos Kiohos[12] and Maria Paspati[1]

Abstract

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 limitations of the insurance and reinsurance market capacity led to the development of alternative risk transfer products. These products are designed to alleviate the risk, in whole or partly, by putting into effect securitisation mechanisms that increase liquidity. Among them, catastrophe risk bonds are designed to transfer the financial consequences of natural catastrophic events (e.g. floods, hurricanes, earthquakes etc.) from the issuers to investors. Within this context, this paper investigates the effects of earthquakes in Romania and suggests a catastrophe bond issuance that offers coverage in case of large earthquakes. Through this mechanism, Romanian governmental authorities will attain sufficient and sustainable fund liquidity for covering the financial obligations following a catastrophic earthquake.

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Keywords: Alternative Risk Transfer, Natural Catastrophe, Insurance–Reinsurance, Catastrophe bond, Earthquake, Romania.

1 Introduction

Montz *et al.* (2017) use the term "natural hazard" to describe the interaction between humans and extreme natural events. The exposure of humans and their activities to natural forces constitutes the hazard. The term "natural hazard" represents the likelihood or potential of an event, rather than the event itself, rendering natural hazards a constant threat to society. Although natural hazards are mostly regional, their distractive potential is so strong that generates considerable impact on both economic (monetary damages) and social life (injuries, loss of life), and affects ecological, and/or technical systems.

On the other hand, the term "natural disaster" can only be used after the occurrence of an event that has a large impact on society. Disasters can be considered based on the probability or relative frequency of hazard events and the impacts of events of certain intensity or magnitude.

Climate change and human intervention have increased the magnitude and frequency of natural disasters that affect all aspects of economic activity, raising concern on environmental issues such as sustainability and human-nature symbiosis. Kollias and Papadamou (2016) examine how and to what extent market agents and investors react to catastrophic events, focusing mainly on extreme temperature events, storms, floods, wildfires and industrial accidents. The results indicate that natural and anthropogenic catastrophes have no immediate impact on stock indices. Furthermore, wildfires and industrial accidents act as reduction factors for systematic risk for portfolios that follow sustainability

[1] Department of International and European Studies, University of Macedonia, Greece.
[2] Hellenic Open University, Greece.

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strategies. The impact of industrial accidents on the environment is only temporary, leaving no lasting imprint. Wildfires, on the other hand, leave a long-lasting damage imprint on the environment, as disaster recovery takes considerable time.

Unlike other natural disasters, it is difficult to estimate the exact time of occurrence of an earthquake; scientists can only predict the timeline and magnitude based on the history of earthquakes in a region. South East Europe has a long history of destructive earthquakes: Romania, Greece, Italy, Bulgaria, and Turkey are among the most exposed regions of the continent. Romania is one of the fastest growing economies in the European Union (EU). Yet it is still one of the poorest, therefore its population and economy are more vulnerable and exposed to natural hazards of high impact and lower probability (World Bank, 2018). Also, Romania is heavily urbanised. Its capital, Bucharest, is densely populated and gathers numerous high-risk buildings and significant facilities. In terms of economic activity, Bucharest is the most prosperous city in the country and is ranked among the main industrial centers and transportation hubs of Eastern Europe. Natural disasters hurt the economy's productive competency and cause disproportionate damage to society (Lang *et al.*, 2012).

Romania is vulnerable to various natural hazards, with earthquakes posing one of the greatest risks. Therefore, Romania is a very seismic country, with approximately 500 earthquakes occurring every year. The country is characterised of large earthquakes that have caused severe human, infrastructural and economical losses over the years. According to historical data, it is believed that 17 earthquakes of magnitude 7 and over have occurred, which corresponds to one large earthquake every 58 to 59 years (Armaş, 2006). As recorded by the Emergency Events Database (EM-DAT) 13 large earthquakes have taken place in Romania from 1900 until today, that affected 392,850 people and resulted in 2,630 fatalities. Total damage amounts to about 2 billion dollars (Centre for Research on the Epidemiology of Disasters, 2009). The major seismic risk zone in Romania is located in Vrancea region, at the bending zone between the Eastern and Southern Carpathians, where at least three tectonic plates are in contact: East European plate, Intra-Alpine and Moesian sub-plates. The seismic activity of this area is the main source of hazard on Romanian territory, as well as the neighbouring countries.The intense seismicity of the Vrancea zone results in the most destructive effects for the country, endangering high risk man-made infrastructures such as nuclear power plants (Cernavoda, Kosloduj), chemical plants, large dams, and pipelines that go through Romania to Central Europe and to Moscow (Mărmureanu *et al.*, 2011).

In many instances, government funds cannot fully suffice for covering the damages produced by extreme natural events, which leads to high fiscal exposure. Thus, a better use of insurance, combined with improvements in the legal and institutional framework, is needed to reimburse disaster victims and reduce vulnerability. Up to 2008, financing natural disaster risk in Romania was mainly based on public financial resources from the state and local budgets (in the form of contingency funds), and external aid (European Union's Solidarity Fund). The main disadvantage of such financing is that the volume of funds is not adequate enough to cover the losses suffered. In addition, low percentages of non-life insurance penetration, along with little involvement of insurance companies in preventing and reducing the impacts of natural and technological hazards, were recorded in 2011 (Zelinschi, 2011).

On November 4^{th}, 2008 the Romanian Parliament passed the *Law No. 260/2008 on compulsory home insurance against earthquakes, landslides and floods* (in force as of 10 March 2009), which made insurance against natural disasters compulsory for all types of dwelling, of residential or commercial use (main or holidays residences, social housing, staff accommodation, on-site housing, accommodation for officials), built with all types of materials (reinforced concrete, metal or wood, materials resulting from or no exposed to any heat and/or chemical treatment). The Law also instituted the Insurance Pool against Natural Disasters (Pool-ul de Asigurare Împotriva Dezastrelor Naturale - PAID), a privately owned insurance/reinsurance undertaking formed by the association of insurance companies for the conclusion of compulsory indemnity-based housing insurance, in accordance with the provisions of *Law no. 260/2008*. PAID was established as an insurance company in November 2009, through the joint effort of 12 national and international insurance companies (ABC Asigurări, Astra Asigurări, Carpatica Asig, Certasig, City Insurance, Credit Europe Asigurări, Euroins România, Generali, Grawe România, Groupama România, Platinum Asigurări and Uniqa Asigurări), which are now PAID's shareholders. These private insurers distribute the mandatory stand-alone basic coverage provided by *Law no. 260/2008* through PAID; they also offer their own additional coverage against earthquakes, which is automatically included in residential property insurance policies, but covers commercial property as well. Though it is not legally required, in cases of major earthquakes that may use up the scheme's funds, a loan might be provided to PAID by the government. The mission of PAID is to provide protection to all residents against three natural risks specific to Romania: earthquakes, floods and landslides, so that the effects of a catastrophe are minimized both in the population and the whole economy (Pool-ul de Asigurare Împotriva Dezastrelor Naturale, 2017).

As of now, numerous normative and legislative actions were taken in order to amend and facilitate the enforcement of *Law no. 260/2008*. However, according to data reported by the OECD, only an estimated 19% of households have purchased earthquake coverage through PAID, despite the rather appealing insurance premium charged (which is based on the sum insured – either EUR20 for EUR20,000 in coverage[3] or EUR10 for EUR10,000 in coverage[4] – and the construction particularities of the dwelling) and the monetary penalties imposed in case of failure to comply with the law (of RON 100 - EUR 20 - to RON 500 - EUR 100). Note that a form of co-insurance can be imposed either by limiting the amount insured or by making payments claimable on loss. However, the deductibles are not yet specified. Other OECD findings indicate an underinsurance for earthquake risk in Romania, which can be attributed to an expectation that governments would compensate losses and a limited awareness of such risk (Organisation for Economic Co-operation and Development, 2018).

Geophysical and hydro-meteorological disasters undermine the Romanian government's poverty alleviation efforts and the country's sustainable economic growth. Given that Romania's vulnerability will be amplified by climate change, actions are taken in order to increase the country's physical, social and financial resilience to climate and disaster risks. Since 2017 Romania has resorted to various funding mechanisms provided by the World Bank.

On November 2017, within the second phase of *Developing the South East European Multi-Hazard Early Warning Advisory System*, Romania received through Global Facility for Disaster Reduction and Recovery (GFDRR –a grant-funding mechanism, managed by the World Bank that supports disaster risk management projects worldwide) a grant of USD 1,500,000. The funding source is Jobs Umbrella Multidonor Trust Fund (MDTF – a financing instrument that supports the World Bank Group's actions for poverty reduction and inclusive growth) and the Expected Completion Date is December 2020. A second grant of USD 1,000,000 was funded by the MDTF in December 2017 with Expected Completion Date as of August 2020, so that Romania could reduce its vulnerability and plan measures to mitigate natural disaster risks, within GFDRR's *Strategies and Options for Scaling up Disaster Risk Management in ECA Countries* initiative. The third grant of USD $350,000 was received in January 2018 and aimed to *Accelerate Disaster Risk Management and climate resilience in Romania through policy reform, investment in risk reduction and civil society engagements*, by January 2020 (Global Facility for Disaster Reduction and Recovery, 2019).

Additionally, Romania is also engaged in two projects with the form of loans, directly funded by the World Bank. Through the *Program Development Objective (PDO) of the Building Disaster and Climate Resilience Program Project for Romania* (approved on June 26th 2018), the Romanian Ministry of Public Finance (borrower) will receive a total of USD 493.06 million (principal) as a *Loan with a Catastrophe Deferred Drawdown Option (Cat DDO)*, with 2.25% interest rate and other charges and fees and closing date as of December 31st, 2021. 88% of the loan will be allocated to Public Administration and 12% will be spent on Information and Communications Technology Services. The financier of this project is the International Bank for Reconstruction and Development (IBRD) and the project will be implemented by: the Ministry of Internal Affairs - Department of Emergency Situations; the Ministry of

[3] Type A dwellings: construction with a supporting structure made of reinforced concrete, wood or metal or outside walls made of stone, burnt brick, wood or any other material resulting from heat and/or chemical treatment.
[4] Type B dwellings: construction with outside walls made of unburned brick or any other material which has not undergone heat and/or chemical treatment.

Public Finance; and the Ministry of Regional Development and Public Administration (The World Bank Group, 2019a). A second loan from IBRD, of USD 60.48 million (principal) and 0.22% interest rate and other charges and fees, was approved on July 24th 2018 with closing date December 31st 2024. The project is called *Strengthening Disaster Risk Management Project* and will be put into practice by the Ministry of Internal Affairs - Department of Emergency Situations and General Inspectorate for Emergency Situations; and the Romania's Ministry of Public Finance. Note that in this case there is no borrower specified. The whole amount will be allocated to Public Administration (The World Bank Group, 2019b).

In July 2017 Italian based global insurer Assicurazioni Generali SpA completed its third multi-peril catastrophe bond (CAT Bond) namely "Lion II Re DAC", worth 200 million Euros. It was the first European multi-peril catastrophe bond since 2000, indicating how rare a catastrophe bond exposed to multiple natural perils in Europe can be. Coverage will be across a four-year term, on a per occurrence basis, with indemnity trigger. European windstorm coverage is for all of the countries exposed to that peril, while European flood coverage will be a subset, including the United Kingdom, Germany, Austria, Hungary, Czech Republic, Slovakia, Poland and Switzerland. Italian earthquake coverage is for the entire country (Evans, 2017).

However, earthquake hazard in Romania is excluded from the coverage provided by "Lion II Re DAC". Furthermore, the funding mechanisms (loans) described in previous paragraphs provide only short term financing and therefore repayment might become a financial burden in the long run. The above two limitations and the aforementioned circumstances concerning the Romanian earthquake issues, motivates us to manage, for the first time, the earthquake risk in the country. This is achieved by the creation and pricing of an earthquake catastrophe bond for Romania and estimating the probability of a general type of this bond, based on the magnitude of earthquakes as a parametric trigger. This catastrophe bond will be able not only to transfer the financial consequences of such an extreme event into the financial markets; it will also provide a stable and secure funding mechanism for Romanian authorities, as well as portfolio risk diversification for insurers and reinsurers.

The paper is organized as follows. First, we provide a brief literature review, followed by an overview of the Alternative to Insurance Risk Transfer transactions. Next, we provide a description of how catastrophe bonds are structured. On the fourth section of this paper we present the methodology and the analysis of the results in order to introduce the catastrophe bond for earthquakes in Romania. The paper closes with some concluding remarks.

2 Literature review

As losses from natural hazards increased over the years, insurers became more reluctant to provide coverage against disaster risks. This led to the development of alternative funding mechanisms linked to finance markets, such as catastrophe bonds. Despite the rapid expansion of the catastrophe bonds market, their attractiveness may be affected by investor risk aversion conversely correlated with risk default (the lower the risk default the more risk-averse the investors who might consider purchasing the catastrophe bond), myopic loss aversion (the combination of sensitivity to losses than gains and frequent portfolio evaluation even by long-term investors), ambiguity aversion and comparative ignorance (investors' willingness to pay more for more familiar outcomes), worry (anxiety about the possibility of losing face value due to catastrophic event), fixed cost of education (time and money invested in order to become familiar with the technical and legal details of a new market). Taking these into consideration, catastrophe bonds are considered unusual ambiguous assets; therefore higher risk premiums should be charged (Bantwal and Kunreuther, 2000).

Cummins (2008) offers a concise overview of the structure and operation of catastrophe bonds, emphasising their success as risk-linked securities that offer protection against events that have very low probability of occurrence. He also appoints, contrary to prior analyses on offshore issuance of catastrophe bonds, that regulatory and accounting issues do not hinter the growth of the finance market. In the first case, offshore issuance of catastrophe bonds offers higher expertise with lower transaction costs than onshore issuance, providing efficient and effective issuance handling and insurance settlement. In the second case, offshore catastrophe bonds do not create taxation problemσ for underwriters, as no income, corporate, withholding, or other taxes in offshore jurisdictions are imposed on catastrophe bond and the incomes created are not taxable for tax purposes in the onshore financial markets. Finance market development is only being impeded by offshore catastrophe bond issuance in terms of information dissemination, as data on privately placed bonds are not widely available.

Catastrophe bonds are priced at spreads over some widely accepted index (e.g. LIBOR), meaning that investors receive adjustable interest plus a spread or premium over the adjustable rate.as a means to secure insurers and investors from interest rate (mark-to-market) risk and default risk. Still, most catastrophe bond valuing models available in the literature are rather complex.

For example, Lee and Yu (2002) developed a model that incorporates default risk (when the insurer becomes insolvent and fails to pay), moral hazard (when the insurer's incentives to reduce risk overreaches the benefits of cancelling some or all of the outstanding debt), and basis risk (when the actual loses of the insurer are not completely offset by the hedge), under an environment of stochastic interest rates. Estimating the catastrophe bond prices with the use of Monte Carlo method, they record an increase in asset volatility and default risk of the issuer rise with higher values of interest rate elasticity. Additionally, the higher the initial capital position (the ratio of asset to liability) of the issuer, the lower the default risk and the higher the catastrophe bond price. The default risk premium decreases with the asset to liability ratio and increases with occurrence intensity and loss volatility. With the inclusion of moral hazard, default risk rises and the bond price decreases significantly. The effect of moral hazard intensifies the higher the occurrence intensity, loss standard deviation, and interest rate elasticity of asset and it decreases with the asset to liability ratio. Basis risk minimises with the decrease of loss correlation, dragging down the catastrophe bond prices, and increases with loss frequency and loss volatility. The effect of basis risk heightens with the trigger level, loss volatility, and catastrophe occurrence intensity, and lessens with the initial capital position.

Jarrow (2010) on the other hand, proposed a simpler formula for valuing catastrophe bonds. In his approach, he assumes that (i) the issuer is default free, (ii) the markets for Libor rates and Cat bonds are arbitrage free, and (iii) the losses incurred due to the catastrophic event are independent of the Libor rate process. Hence, all interest and principal payments have a probability equal to one. The catastrophe bond valued has the following characteristics: (a) it receives floating payments based on the Δ-Libor rate per year (where Δ the time period between payment dates on the catastrophe bond in years) plus a spread, (b) the face value of the catastrophe bond is paid at maturity date (unless a catastrophe takes place), (c) in the occurrence of a catastrophic event, the holder reimburses the losses and the catastrophe bond is terminated. The catastrophe bond value is, therefore, determined by the floating rate payments (split into the next interest payment and the remaining payments), the fixed spread rate, the face value payment received if no event occurs, and the face value payment received with the occurrence of the catastrophic event (taking into account that residual payoff is independent of the Libor rate process).

The Mexican government was one of the first that realised they can no longer disregard fiscal risk posed by natural disasters. In particular, the two large earthquakes with magnitude of 8.1 and 7.3 that took place in Mexico City on September 19 and, 1985, signaled the shift in disaster risk management for the country. Mexico is located atop three of the Earth's largest tectonic plates (the North American plate, the Cocos Plate, and the Pacific Plate), that produce, very frequently, large magnitude events with high impact on the country's social and economic activity (similarly to the case of Romania). As part of the government's risk management efforts, Fondo de Desastres Naturales (FONDEN - Natural Disasters Fund) was established in 1985. In 2006, FONDEN, with the support of the World Bank, proceeded to the issuance of the world's first parametric catastrophe bond against earthquake risk, with payments based on the magnitude (Mw[5]) of the earthquake. (The International Bank for Reconstruction and Development/The World Bank, 2012)

[5] 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. The moment magnitude (Mw) scale, based on the

In 2010, Härdle and Cabrera, assuming perfect financial market, examined the calibration of the aforementioned catastrophe bond, based on earthquake's intensity, for both reinsurance and capital markets, with the use of historical data. They then proceeded, under the assumptions of non-arbitrage and continuous trading, in examining the pricing of a catastrophe bond for Mexican earthquakes with a modeled-index loss non-indemnity trigger mechanism, which combined modeled loss and index trigger types in an attempt to reduce basis risk born by the sponsor and combine different variables that influence the underlying risk.

The model comprised physical parameters of the earthquakes (magnitude and depth), historical and estimated losses, and impact of the event on main cities. The historical losses were adjusted to inflation, exchange rate and population growth, and were proven to be directly proportional to the parameters of time and magnitude and inversely proportional to depth. Through the examination of the empirical mean excess function of the frequency of Mexican earthquakes (waiting time between events) Härdle and Cabrera (2010) confirm the theory of time independence of earthquakes.

The proposed pricing model resulted in an non-arbitrage price of the zero coupon model equal to the expected discounted value of the principal paid by the catastrophe bond, depending on the time of the event occurrence. As the expiration date increased, the occurrence probability of an extreme vent increased as well, resulting in lower bond prices. However, an increase in the threshold level (in their case set at 6.5 Mw) resulted in higher bond prices, as the probability of a trigger event lowers in this case.

Loss distribution function seems to affect the bond price as well. Still, the expected loss is proven to have a greater impact on the catastrophe bond prices than the entire distribution of losses, due the non-linear character of loss distribution and the dependence of the various variables that define the catastrophe bond prices. For example, an earthquake with strength two Mw higher than the average strength might result in more or less than twice the damage caused by an average event.

3 Alternative to Insurance Risk Transfer and CAT bonds

Traditionally, the main method of risk transfer for insurers was the purchase of reinsurance that provides the mechanisms to share and diversify extreme risks across regions and across market participants. Reinsurance also enables primary insurers to reduce their risk exposure and capital requirements. Insurers transfer risks like natural catastrophe risk (for non-life 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 (Bernard, 2013).

Alternative Risk Transfer (ART) basically uses innovative insurance and capital market solutions toward hedging and transferring risk from one risk bearing party to another, or to capital markets' investors. The products and solutions offered within the ART marketplace manage to exceed the boundaries of traditional-conventional risk management concepts and techniques (e.g. pure insurance, reinsurance, derivatives) through combining a diversity of financial mechanisms from various different sectors, thus attracting capital from a broad range of sources and offering greater customization, flexibility, and cross-sector integration (Banks, 2008).

Cummins and Weiss (2009) categorise the various instruments (carriers and products) that comprise the ART market as follows:

- Risk Pools and Insurers: Self Insurance Plan, Captive Insurance Companies, Risk Retention Groups.
- Hybrid Products: Finite Reinsurance, Multi-year Products, Multi-peril Products, Multiple-trigger Products, Industry Loss Warranties, Sidecars.

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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.

- Financial Instruments: Contingent Capital, Options, Swaps, catastrophe bonds.

Catastrophe bonds 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 (SPR), which is also known as transformer (because it transforms insurance risk into securities). The SPR 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 SPR 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 is paid periodically and the principal is returned at maturity unless the bond is 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. 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 and Zanjani, 2012).

4 Methodology and analysis of results

The goal of this section is to provide a general type of earthquake catastrophe bond and its valuation framework, which are based on magnitude of earthquakes as a parametric trigger.

4.1 Methodology

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 depend on catastrophic events (as confirmed by the analysis of Lee and Yu (2002) - see Section 2). 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 catastrophe bond requires an incomplete market framework (contrary to the suggestion of Härdle and Cabrera (2010)) 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.

Using the aforementioned approach and the theory of equilibrium pricing, in 2007 Zimbidis, Frangos, and Pantelous developed a simple one-period pricing formula, based on historical data, which will be applied to this paper. The valuation requires 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.

4.2 One period model

In this subsection we present the one-period model, where the interest rate dynamics are restricted to constant values of different rates. Following Zimbidis *et al.* (2007), the necessary symbols and the respective notation are defined as below:

- T: maturity date for the catastrophe bond.

- *FV*: is the face amount of the catastrophe bond.
- *r(t)*: is the risk free rate continuously compounding, up to maturity date (e.g. 1-year Romanian Treasury Certificates).
- *k*: 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, measured in moment magnitude (Mw). M is a random variable following the distribution obtained in Table 2.
- P_{CAT}: is the price of the catastrophe bond at the time of issuance.
- *C(R; M)*: is the cash value of the catastrophe bond at the maturity date depending upon the value of M.

We signify *C(R;M)* as pay-off function of the catastrophe bond with piecewise cash flow on maturity. In this case the catastrophe bond cash flows depend only on the catastrophic risk variables and their structure is given in the following expression (Zimbidis *et al.*, 2007).

$$C(R;M) = \begin{cases} \mathrm{FV} * (1+3\mathrm{R}), & \text{if } \mathrm{M} \in (0, 5.4) \\ \mathrm{FV} * (1+2\mathrm{R}), & \text{if } \mathrm{M} \in (5.4, 5.8) \\ \mathrm{FV} * (1+\mathrm{R}), & \text{if } \mathrm{M} \in [5.8, 6.2] \\ \mathrm{FV}, & \text{if } \mathrm{M} \in (6.2, 6.6) \\ \frac{2}{3}\mathrm{FV}, & \text{if } \mathrm{M} \in (6.6, 7.0) \\ \frac{1}{3}\mathrm{FV}, & \text{if } \mathrm{M} \in (7.0, 7.4) \\ 0, & \text{if } \mathrm{M} \in (7.4, \infty) \end{cases} \qquad \text{(Expression 1)}$$

The pre-determined magnitude levels in Expression 1 are the trigger points of the catastrophe bond.

In the one-period case, we assume that *FV*, *r*, *R*, and *k* are constant. Therefore, cash flow is independent of financial risks (risk-free interest rate, and LIBOR rate), and the price of the catastrophe bond can be approximated according to equilibrium pricing theory as follows (Cox and Pedersen, 2000):

$$\mathrm{P}_{\mathrm{CAT}} = \frac{1}{r+k} E_{Q1}[C(R;\ M)] \qquad (1)$$

where E_{Q1} is the probability measure corresponding to the distribution of magnitude M (obtained in Table 2), which affects the payoff value C.

In the case of the Romanian catastrophe bond we run 50,000 simulations in R, to obtain the values of *C(R; M)*, depending on the probability of the earthquake's magnitude (E_{Q1}), as set in the intervals of expression Exp.1. We then multiply the values of *C(R; M)* by the discount $\frac{1}{r+k}$ (P = C * discount). The final price P of the catastrophe bond is the mean price of (C * discount).

An extension of this model, with the addition of a catastrophic risk variable (depth of the earthquake at time *t*) and a financial market variable (inflation rate at time *t*) can be found in *Shao et al.*, 2015.

4.2.1 Extreme Value Theory for defining extremes in Earthquake Magnitude

Extreme events are of low-probability in terms of occurrence, yet of high-loss in terms of impact.

Risk management problems related to insurance and reinsurance are often resolved by statistically analysing extremes.

Extreme Value Theory (EVT) provides the methodology for quantifying such extreme events and their consequences by modelling a set of random observations to the extreme event data rather than all the data, thereby focusing on the statistical behaviour of maxima and fitting the tail of the distribution. EVT is also used to extrapolate the probability of out-of-sample, more extreme, events. Finally, it helps to estimate diversification factors when managing bond portfolios. Nevertheless, EVT is based on an asymptotic argument and is applied to small sized sampled, therefore one has to utilise it with caution (Embrechts *et al.*, 1999). In this paper we use the Generalised Extreme Value (GEV) Distribution as a tool for the application of the EVT theory as follows.

Mises (1954) and Jenkinson (1955) independently derived the Generalised Extreme Value distribution (GEV), often denoted G(μ, σ, ξ), in order to describe the distribution of the maxima of a set of observations. The cumulative distribution function (CDF) is given by:

$$G(x;\mu,\sigma,\xi) = \exp\left\{-\left[1+\xi\left(\frac{x-\mu}{\sigma}\right)\right]_{+}^{-\frac{1}{\xi}}\right\} \qquad (2)$$

By differentiating (Eq. 3) with respect to x, we could get the probability density function for GEV as:

$$g(x;\mu,\sigma,\xi) = \frac{1}{\sigma}\left(1+\xi\left(\frac{x-\mu}{\sigma}\right)^{-1-\frac{1}{\xi}}\right)\exp\left[-\left(1+\xi\left(\frac{x-\mu}{\sigma}\right)\right)^{-\frac{1}{\xi}}\right] \qquad (3)$$

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. 2as $\xi \to 0$, the model corresponds to the Gumbel distribution. For the cases $\xi > 0$ and $\xi < 0$, Eq. 2 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 and Joseph, 2016).

4.3 Data Analysis

In the case of the Romanian catastrophe bond, the analysis is based on the series of annual maximum magnitude of earthquakes in the country, over the period 1969-2018 (see Table 1). Data were obtained from Institutul National de Cercetare Dezvoltarepentru Fizica Pamantului, Romania, available athttps://web.infp.ro/#/romplus.

Table 1: Annual Maximum Magnitude of Earthquakes in Romania.

Year	Magnitude (Mw)	Year	Magnitude (Mw)
1970	4.7	1995	4.1
1971	3.8	1996	4.6
1972	3.8	1997	4.7
1973	6.0	1998	4.7
1974	4.9	1999	5.3

1975	5.3	2000	5.0
1976	3.9	2001	4.9
1977	7.4	2002	4.7
1978	5.2	2003	4.7
1979	5.3	2004	6.0
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
1994	4.3	2019	4.1

Spatially these earthquakes are depicted in Figure 1. Note that the majority of the events originated from the Eastern Carpathians – Vrancea region, as mentioned above regarding the seismicity of Romania.

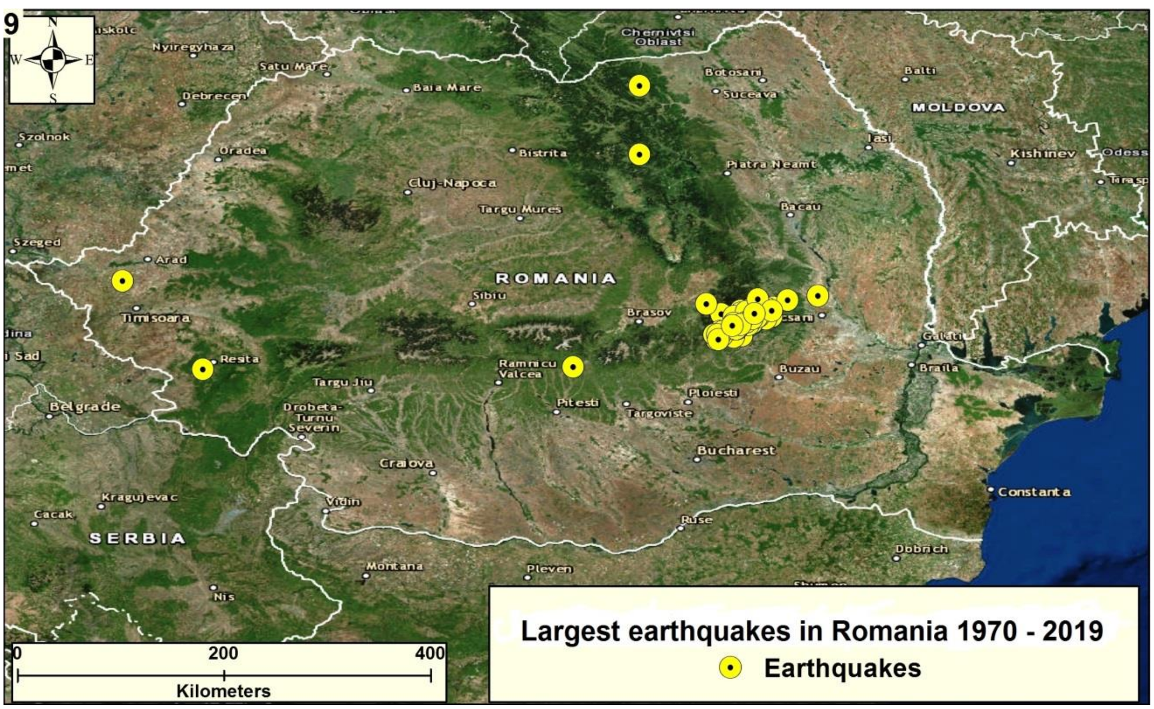

Figure 1: Largest earthquakes in Romania, 1970-2019.

Figures 2 and 3 depict a time series plot and a histogram of the 50 annual maxima respectively. 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.

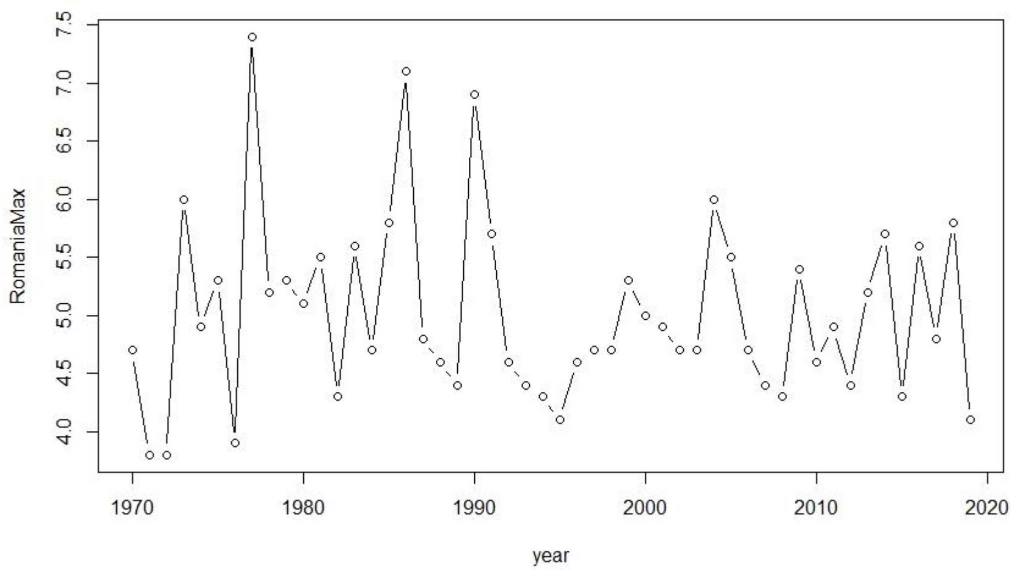

Figure 2: Times series scatter plot of the Annual Maximum Magnitude of Earthquakes in Romania.

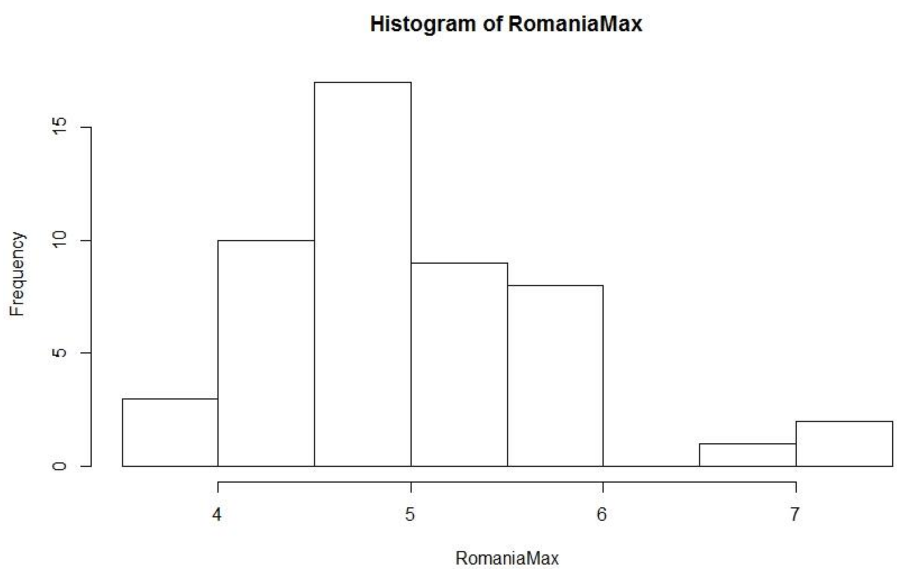

Figure 3: Histogram of the Annual Maximum Magnitude of Earthquakes in Romania.

4.4 Analysis of the Results

Given that the maximum likelihood has an asymptotic Gaussian distribution, we have an approximated confidence interval. We use numerical optimization routine to maximise the log-likelihood function for the data presented in Table 1. This leads to the following estimates:

$$\hat{\mu}\text{(location estimate)} = 4.6560311,\ \hat{\sigma}\text{(scale estimate)} = 0.5991244,$$
$$\hat{\xi}\text{(shape estimate)} = 0.0121248,$$

for which the log-likelihood is 53.67408. The approximate variance-covariance matrix of the parameter estimates at each data point is:

$$V = \begin{bmatrix} 0.009104012 & 0.002611989 & -0.003508108 \\ 0.002611989 & 0.004819119 & -0.001977507 \\ -0.003508108 & 0.001977507 & 0.0109617051 \end{bmatrix}$$

* 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 (μ, σ, ξ). Computing square roots, the standard errors are 0.09541495,0.06941988, and 0.10469816, for μ, σ, and ξ respectively. Combining estimates and standard errors, approximate 95 % confidence intervals for each parameter are:

$$\hat{\mu} \in (4.56061615,\ 4.75144605),$$
$$\hat{\sigma} \in (0.52970452,\ 0.66854428),$$
$$\text{and } \hat{\xi} \in (-0.09257336,\ 0.11682296)$$

Greater accuracy of confidence intervals can usually be achieved by the use of profile likelihood. Figure 4 shows the profile log-likelihood for ξ, from which a 95% confidence interval is obtained. The horizontal blue line represents the profile confidence interval with confidence coefficient *conf*.

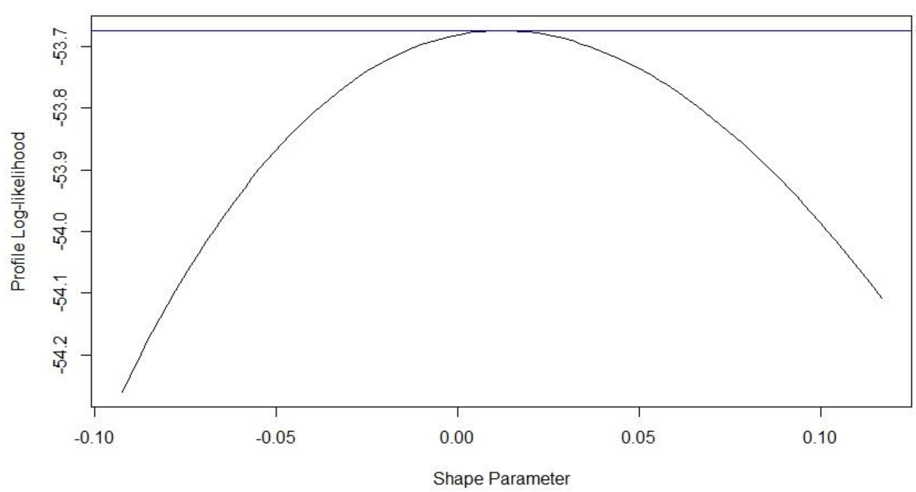

Figure 4: Profile log-likelihood of ξ for the Annual Maximum Magnitude of Earthquakes in Romania.

The various diagnostic plots for assessing the accuracy of the GEV model fitted to the Annual Maximum Earthquakes in Romania data are presented in Figure 5.

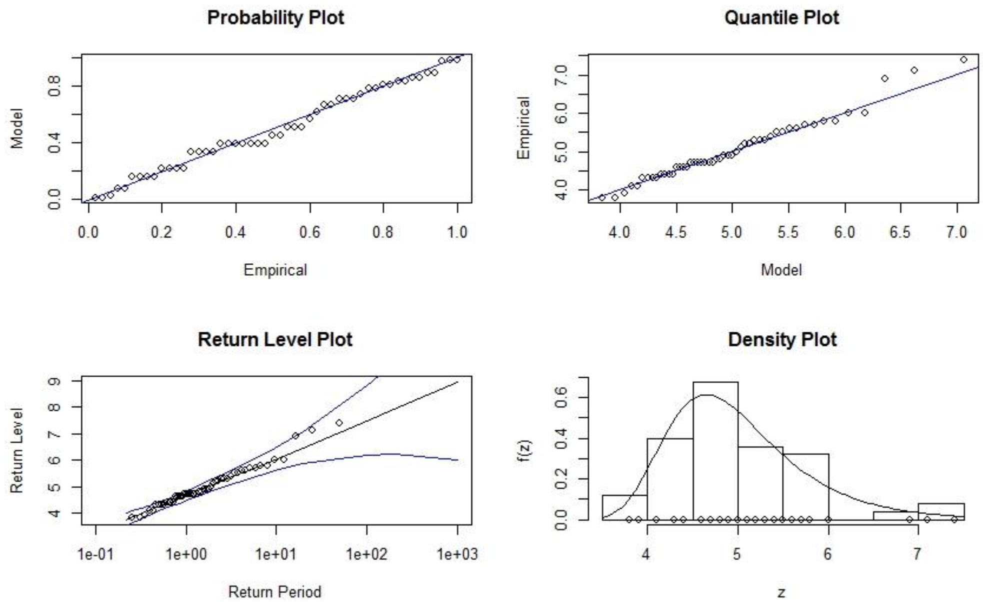

Figure 5: Diagnostic plots for GEV fit to the Annual Maximum Magnitude of Earthquakes in Romania.

The probability plot displays the cumulative distribution function of the model, versus the empirical cumulative distribution function.

The quantile plot compares the model quantiles against the data (empirical) quantiles, i.e. it displays the cumulative distribution function of the model, versus the empirical cumulative distribution function.

The fact that both the probability and quantile plots do not deviate from a straight line (each set of plotted points is near-linear), suggests that the model assumptions are valid for the data plotted.

The return level plot shows the return period against the return level, as well as an estimated 95% confidence interval (the blue curved lines represent the upper and lower bound of the confidence interval). It tests the suitability of our fitted model beyond the range of our observed data. The return level is the level (in this case magnitude) that is expected to be exceeded, on average, once every m time points (e.g. 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 (plotted points close to the black line). The curve also provides a satisfactory representation of the empirical estimates, especially once sampling variability is taken into account.

Finally, the density plot depicts the histogram of our data against the fitted density (a plot of the fitted GEV density superimposed onto a histogram of the actual data). The corresponding density estimate seems consistent with the histogram of the data presented in Figure 3. Consequently, all four diagnostic plots provide support to the fitted GEV model.

The sample mean excess function $\hat{e}(u)$ is an empirical estimate of the mean excess function which is defined as $\hat{e}(u) = E(X - u \mid X > u)$, 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 tail behaviour of the distribution displayed in Figure 6 reflects the sample mean excess, and the downward trend suggests very short tail behaviour for the Annual Maximum Magnitude Earthquakes in Romania. The dashed lines above and below the continuous one represent the upper and lower bounds of the confidence interval.

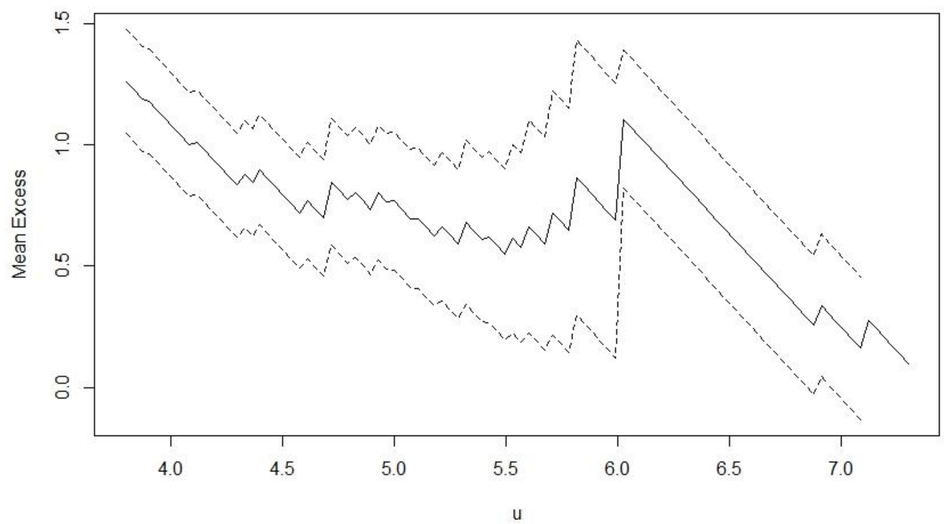

Figure 6: Sample mean excess for Annual Maximum Magnitude of Earthquakes in Romania M(t), with 95% confidence interval.

Maximisation of the GEV returned a rather small $\hat{\xi}$= 0.0121248, which can be considered equal to zero (0), therefore the limiting distribution for Annual Maximum Earthquakes in Romania is a type of Gumbel. However, in our case we use the Standard Extreme Value distribution, which groups the three forms of *G* (namely Gumbel, Fréchet, Weibull) and has the following cumulative distribution function:

$$G(z) = P(M_k \leq m_k) = \exp\left\{-\left[1+\xi\left(\frac{z-\mu}{\sigma}\right)\right]^{-\frac{1}{\xi}}\right\} \quad \text{(Eq. 4)}$$

where parameters are $\hat{\mu}$= 4.6560311, $\hat{\sigma}$= 0.5991244, $\hat{\xi}$= 0.0121248.

Equation 4 gives the probability that the annual maximum magnitude earthquake M_k will be less than or equal to a magnitude m_k.

The probabilities intervals for the standard extreme value distribution are shown in Table 2:

Table 2: Probabilities of an earthquake of magnitude M occurring within intervals set by Expression 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)
0.17835	0.11238	0.06451	0.03538	0.019	0.01011	0.01152

Note that, according to Expression 1 our capital may decrease only if the magnitude of the earthquake exceeds 6.6 Mw. According to Table 2, the probability of an earthquake of magnitude greater than 6.6 Mw (i.e. 6.7 →∞) occurring in Romania is around 4%, so we can introduce a catastrophe bond with 96% capital guarantee which makes it rather attractive for conservative investors.

As in the case of Härdle and Cabrera, the trigger event of our proposed model depends on the severity of earthquakes. Nevertheless, while in their case the simulations showed an increase of the price as the set threshold of 6.5 Mw increased (since one would expect a trigger event with low probability), in this paper the simulations run to obtain the values of the catastrophe bond depending on the probability of the earthquake's magnitude resulted in lower prices as the magnitude increased, despite the very low probabilities of occurrence. This could be attributed to the structure of the proposed pricing model that includes fewer catastrophic risk and financial market variables than that of Härdle and Cabrera. Still, our results consistent with the Härdle and Cabrera approach that even the slightest shift in the Mw strength, might result in greater losses than an average event (i.e. the 0.1 difference between n the magnitude set as threshold in the two models).

4.5 Numerical example for the one-period model

Consider a one-period model for a CAT Bond with Face Value FV = RON 4,870 (the equivalent of 1,000€ in Romanian leu - RON, as of 08/11/2020[6]), interest rate r = 3.16% (yield of 1-year Romanian Treasury Certificate, issued on January 13th 2020, with maturity date January11th 2021[7]), Libor rate R = 0.33338% (as of 06/11/2020[8]), and extra risk premium k = 5%, we obtain (according to Expression 1 and Equation 1) a mean price P = RON 3,647.275.

This equilibrium price depends on the financial and catastrophic risk variables described above. As the payoff of the catastrophe bond depends on the earthquake magnitude, the catastrophe bond price decreases as the threshold level (i.e. earthquake magnitude) increases. The range of magnitude has an impact on the securitisation level of the bond, which a (re)insurance company should balance between yield and commerciality through the analysis of historical earthquake loss data.

However, the proposed financial market rate (r+k) is a shift of the interest rate, which, combined with the high expected rates of returns, result in higher yields. Additionally, after almost 25 years of operation, the catastrophe bond market is considered established, minimising the cost of educating oneself about its function and future bond issuances. Consequently, our catastrophe bond is more attractive to single investors than normal return bonds and may also attract highly risk-averse investors.

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 mechanisms.

Romania’s vulnerability to natural risks like earthquakes, floods, and droughts is further nurtured by climate change. Since 1990, natural disasters have resulted in more than USD 3.5 billion of direct damages (which corresponds to 3.5 percent of average GDP). The overall impact of climate-related hazards in the country varies within its regions and is estimated to reach 6 times higher figures by 2080, for damages to infrastructure alone, not only halting economic growth, but also jeopardising fiscal sustainability and undermining the well-being of Romania’s population.

[6] Information obtained from Net Notion - euro-currency.eu, available at https://www.euro-currency.eu/EUR_RON, accessed on 8 November 2020.

[7] Information obtained from National Bank of Romania, available at https://www.bnr.ro/Government-Securities-5676-Mobile.aspx, accessed on 8 November 2020.

[8] Information obtained from HomeFinance.nl, available at https://www.homefinance.nl/english/international-interest-rates/libor/usdollar/libor-rates-12-months-usd.asp, accessed on 8 November 2020.

According to the data available in Insurance Pool against Natural Disasters of Romania website, in the first quarter of 2019 the scheme paid about RON 1.24 million as indemnities for natural catastrophe events to those insured by PAID. Still, 10 years after the project's launch, penetration is low with only 19% of Romanians having their houses insured.

Given the lack of predictability of earthquakes, this natural hazard poses a constant threat for Romania. In addition, the country's needs in disaster relief and reconstruction reserve usually exceed the government's capacity to respond in the event of a catastrophic earthquake, hence the turn for financial help to the international mechanisms described in this paper. However, these mechanisms offer only provisional aid and under certain preconditions (period of years the coverage is valid, total amount the country can claim, interest rates). What is required is a long-term coverage, under terms set by the fiscal capability of Romania.

This can be achieved with the issuance of the proposed catastrophe bond in cases of large earthquakes. With its rather attractive 96% capital guarantee it would be very well received by the market and it could generate sufficient funds for insurance claims indemnification and post-disaster reconstruction costs coverage.

A larger pool for financing disaster risk reduction and recovery will lift the financial burden of hazard mitigation from the Romanian government and also create a safer and more stable environment that may attract other investments and further facilitate economic activities such as industry, trade and commerce, tourism. Yet, Romania has to gain more experience in disaster risk management and global risk diversification.

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