CATASTROPHIC EVENTS MODELING

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Abstract: *This paper presents the emergence and evolution of catastrophe models (cat models). Starting with the present context of extreme weather events and features of catastrophic risk (cat risk) we'll make a chronological illustration from a theoretical point of view of the main steps taken for building such models. In this way the importance of interdisciplinary can be observed. The first cat model considered contains three modules. For each of these indentified modules: hazard, vulnerability and financial losses a detailed overview and also an exemplification of a potential case of an earthquake that measures more than 7 on Richter scale occurring nowadays in Bucharest will be provided. The key areas exposed to earthquake in Romania will be identified. Then, based on past catastrophe data and taking into account present conditions of housing stock, insurance coverage and the population of Bucharest the impact will be quantified by determining potential losses. In order to accomplish this work we consider a scenario with data representing average values for: dwelling's surface, location, finishing works. On each step we'll make a reference to the earthquake on March 4 1977 to see what would happen today if a similar event occurred. The value of Bucharest housing stock will be determined taking firstly the market value, then the replacement value and ultimately the real value to quantify potential damages. Through this approach we can find the insurance coverage of potential losses and also the uncovered gap. A solution that may be taken into account by public authorities, for example by Bucharest City Hall will be offered: in case such an event occurs the impossibility of paying compensations to insured people, rebuilding infrastructure and public buildings and helping the suffering persons should be avoided. An actively public-private partnership should be created between government authorities, the Natural Disaster Insurance Pool, private insurance companies, reinsurers, stock exchanges, institutions specialized in cat events modeling in order to develop and use alongside compulsory and facultative insurance of buildings new alternative risk transfer solutions as catastrophe bonds(also known as cat bonds).*

Keywords: *cat risk; cat model; earthquake; financial losses.*

JEL classification: *G22.*

1. Introduction
Catastrophes are extreme events, characterized by a low frequency but a high severity, currently being observed an upward tendency of both parameters. For example, during 1970-1980 the catastrophes frequency ranged around 150 catastrophes per year, while in the years 2000-2011 the recorded values were nearly 300 events each year, the maximum frequency being reached in 2005 when 397 catastrophic events were registered. In this context, special attention of all

stakeholders is required in order to find the most appropriate methods for managing catastrophic risk (cat risk).
In the past, buying an insurance policy seemed to be a complete solution for managing risk, but nowadays we can't say the same thing. Along with the economic development, the limits of traditional insurance could be observed, since new risks appeared and couldn't be covered by this. Among these are the weather conditions risk, terrorism and certain economic risks. Furthermore, over the last years the consequences of catastrophes were devastating in some areas.
There isn't just one class of stakeholders interested in an appropriate catastrophic risk management, but rather all the parties involved which can undergo losses as a result of the occurrence of such an event: property owners, insurers, reinsurers, mortgage banks as well as capital markets due to the call of traditional insurance market to them and the development of alternative risk transfer solutions offered by the market ART- *Alternative Risk Transfer*. Government's role in managing cat risk shouldn't be ignored, especially through some programs whose purpose is to control the consequences of such events by reducing the probability of occurrence of these risks or by establishing of some funds to be used for assistance immediately after a catastrophe has occurred.
Any risk involves a degree of uncertainty, but in the same extent the presence of some influential factors leading to situations entailing damages, so we can't suppose that these events have random consequences, but rather we should concentrate to have a better understanding of deterministic part of them.

2. Cat Risk and Catastrophes Modeling

At the base of risk assessment is situated the exposure, characterized by several elements: the resource at risk, also known as the object of risk; the random event or peril to which the object is exposed; the consequence, representing the possible impact on resource when the peril occurs.
In the next table we are going to illustrate these three concepts for some catastrophes:

Table 1 Exemplification of the defining elements of cat risk

Exposure	Peril	Consequence
The number of houses	Earthquake	Financial losses Human casualties
The number of houses in the area affected by floods	Flood	
The number of houses in the region affected by storm	Storm	
The coast length	Tsunami	
The number of passengers	Terrorist attack	

Source*:* Authors' processing (Condamin et al., 2006:32)

Usually the resource at risk is quantified by values regarding the number of units, the acreage, and the volume. As regards the peril, knowing the probability of occurrence is an important thing. When it comes to the consequences, these can

be: financial or other, but in most of cases the goal is finding a model which results are shown as monetary losses.
Taking into consideration the complexity of catastrophic events the appearance of cat models can't be attributed to one area, but rather is considered that the first models emerged as a result of cumulative effort of insurance experts and those specialized in the science of natural hazard.
The beginning of catastrophe modeling is considered around 1800. Again are different opinions regarding the first steps in models constructing between experts from different fields. Therefore, on one hand, insurers consider that cat modeling lies in the earliest day of property insurance, at that time being used a rudimentary technique that consisted in the use of marks in order to see the concentration of their exposure. On the other hand, seismologists and meteorologists argue for the affiliation of cat modeling to modern science, when the nature and the impact of these extreme events are better understood.
In time there has been observed an evolution of these models, in the 1970's being published some studies theorizing the source and the frequency of events, so that, in the next step, along with the development of information technology systems, models provide estimations of losses in case of catastrophe. The first specialized companies that developed software which estimate the possible losses are: AIR Worldwide, Risk Management Solutions, EQECAT which later changed its name to ABS Consulting.
A positive impulse for the cat models development and also for a better understanding of the need for such models was given in the aftermath of two catastrophes that led to major losses: Hurricane Hugo and Loma Prieta Earthquake, both occurring in 1989. In the next period more and more insurers have turned to specialized companies in catastrophe modeling in order to improve their methods for pricing insurance policies. In addition, a signal to the public sector was given, U.S. Government being the first interested in using such models. So, in 1997 was launched the program Hazards U.S., also known as HAZUS. At first it offered only the possibility of determining potential losses in case of an earthquake, but lately also for losses due to wind or floods.
One of the problems in cat modeling is the lack of historical data. Since catastrophes are rare events large series of data can't be built and this explain the necessity of calls for the use of simulations through which similar results are obtained as in the case of real events occurrence.

3. Cat models components

Models are tools used in order to have a simplified representation of the reality. A feature of catastrophe models is that these are built through the contribution of several disciplines, such as: physics, meteorology, statistics, insurance, engineering and others. Informatics contribution shouldn't be neglected because it offers us the use of simulation and thereby relevant results, even with smaller data series.
For all models there is a certain degree of uncertainty which can't be completely removed. So, it is necessary to distinguish between two different types of uncertainty: random and epistemic. Regarding random uncertainty we should mention that there is no way to reduce it by getting more information, but is associated with the impossibility to predict catastrophes. On the other hand, epistemic uncertainty emerges because of insufficient data or information for a specific catastrophe and in

this situation a better understanding on the phenomenon or additional information may lead to decrease of the uncertainty, which is the purpose when building a catastrophic model.
All cat models have some common components, or modules as these are called, regardless the type, or region where catastrophe occurs. In the following a detailed presentation of each of them will be offered. In addition it will be recorded the defining elements for each of them. (Born and Martin, 2006; Chávez-Lopez and Zolfaghari, 2010; Zimmerli, 2003; Grossi and Kunreuther, 2005)

3.1. Hazard Module

Randomness characterizing natural catastrophes can't be eliminated with the help of certain models, as it is impossible to exactly predict their occurrence moment. If for certain natural catastrophes, for example floods, sometimes there are some warnings a few days before in the great majority of cases even this is impossible.
The ultimate goal of hazard module is identifying the locations most likely to be affected, the frequency of occurrence as well the severity, intensity of catastrophes. In order to do this the specialists performing model follow next steps:

- Getting data from past catastrophes;
- Determining the probability distribution based on historical data;
- Generating, by computer, a large number of events similar with past ones, resulting a large scale of cat events that might actually produce;
- Calculating the intensity for each location considered.

Necessary information on past events include: localization of seismic zones and faults, geological properties of the region to observe the seismic waves propagation, in the case of earthquakes; coast length, barometric pressure, wind speed when it comes to hurricanes.
In order to achieve simulations, one of the most popular and used method is Monte Carlo. This is an iterative technique which consists in generating a number of scenarios based on a set of initial data when seeking more data and real observation is not possible, this being also the case of catastrophes. For achieving a similarity between real and simulated events it is necessary that the latter to follow the probability distribution of initially recorded data.
A very important element is the occurrence frequency of catastrophes, this aspect being characterized by a high level of uncertainty and at the same time by a major influence on the final outcome of model, the determination of possible losses. For determining the occurrence probability of an event should be taken into consideration certain representative parameters of that event. For example, in the case of earthquakes should be considered the pressure on faults.
The final step of this module, once all other requirements have been met consists in intensity quantification for each event resulting from simulations. Thus, for earthquakes, magnitude is the measure of intensity. If we consider a Richter scale we get a measure of intensity depending on the energy released by earthquakes, but in the case of Modified Mercalli scale the intensity is expressed by the potential losses. Another advantage is the fact that if an earthquake is characterized by a single level of magnitude, in case of potential losses, the distance from the epicenter is considered and as we move from the epicenter, the reduced losses will be observed.

3.2 Vulnerability module

This component of cat models is also known as engineering because the construction of damage functions, which is one of the main objectives of this module, lies with the engineers.

To notice the vulnerability, an analysis of the extent of one specific event is required. For this purpose, once the intensity is determined, for each simulated event resulting from the first module we move forward to apply these values on a portfolio of buildings. A database containing information about buildings and their contents is required, and through mathematical relationships the damages level is computed. The main features of buildings included in databases are: type of construction, building materials used quality of work taking into consideration also the labor force, building destination, occupancy, height, maintenance, age.

Numerical illustration of vulnerability module is realized through damage ratio. This should not be confused with compensation ratio determined as a ratio between the amount of compensation and the insurance premiums collected.

For different insured objects MDR (mean damage ratio) is determined:

$$\text{Mean damage ratio} = \frac{\text{Total losses}}{\text{Total value of insured objects}} * 100$$

One last step after determination of damage functions, through which we can have an image about expected damage ratio for different levels of intensity, is generation of vulnerability curves. These are built depending on the type of risk and also on classes of insured objects.

3.3 Financial losses module

Within this component the last step for finalizing the cat model is realized. It is to establish a relationship between the initial data, characteristic to each catastrophe, and the level of financial losses. At this stage a special attention is given to experts opinions about damage rate for different types of building. This is necessary because it is difficult to update too often damage functions to include all changes when new techniques of construction appear or other codes regulate constructing new buildings.

Then, having estimated the level of losses we can determine the value of insured losses, these being the share of entire damage after a catastrophe covered by the insurer. In this case, policy conditions have a major importance, being considered: existing deductibles, coverage limits, co-insurance, etc.

4. Illustration of the 3 modules of cat models for an earthquake in Bucharest

Hazard module

In Romania, the counties are classified into three zones, A, B and C based on earthquake risk exposure. Those from C zone are the most vulnerable, Bucharest being part of this class. According to the Natural Disaster Insurance Pool the three zones include:

- Zone A: Alba, Arad, Bihor, Cluj, Hunedoara, Maramureș, Sălaj;
- Zone B: Argeș, Bistrița, Botoșani, Călărași, Caraș Severin, Constanța, Dolj, Giurgiu, Gorj, Hargita, Iași, Mehedinți, Mureș, Neamț, Olt, Satu Mare, Sibiu, Suceava, Tulcea, Timiș, Vâlcea;

- Zone C: București, Bacău, Brăila, Brașov, Buzău, Covasna, Dâmbovița, Galați, Ialomița, Prahova, Vaslui, Vrancea, Ilfov

Vrancea is the most important seismogenic zone in Romania. Also, National Institute for Earth Physics defines all epicentral zones: Făgăraș-Câmpulung, Banat, Crișana, Maramureș and Dobrogea. Once identified, these are the locations most likely to be affected in case an earthquake occurs.
Regarding past earthquakes that occurred in Romania in Figure 1 can be observed the most important ones, with a magnitude greater than 6 on Richter scale.

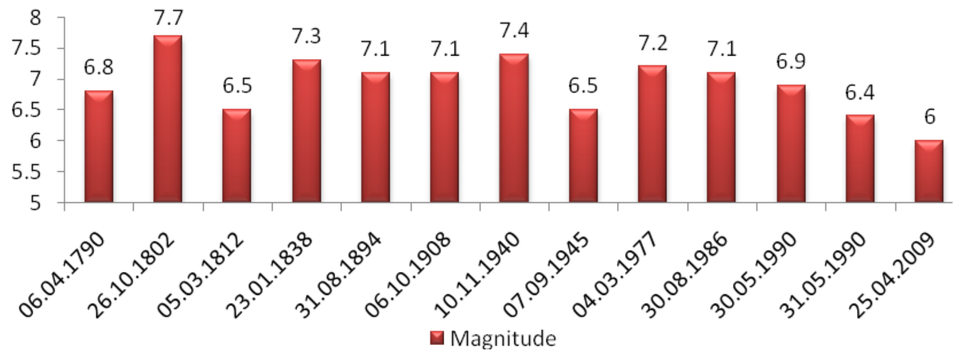


Figure 1: History of Romania earthquakes with magnitude over 6 on Richter scale
Source: Authors' processing based on data provided by www.snas.ro

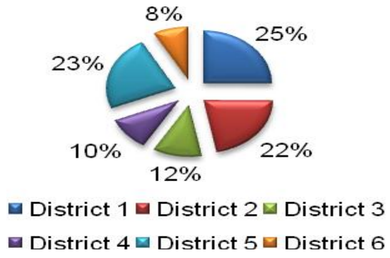
Although the highest magnitude was recorded in case of 1940 earthquake, however in the classification of top 10 disasters in Romania in the period 1900-2012 conducted by Centre for Research and Epidemiology of Disasters (CRED) and made available through the database EM-DAT, the strongest effects were felt in the case of 1977 earthquake. The consequences were:

- 1641 deaths: rank 1 of 10
- 2000 million USD ,economic damage costs: rank 1 of 10
- 396300 affected people, rank 2 of 10

The frequency of Vrancea earthquakes with magnitude over 6 on Richter scale is estimated so: (Wenzel et al.: 2002)

- If $M_w \geq 6.5$, 10 years
- If $M_w \geq 7.0$, 25 years
- If $M_w \geq 7.4$, 50 years

If we consider that an earthquake over 7 occurs every 25 years, the annual probability of occurrence is estimated to 4%.
Vulnerability module
Within this module we propose to notice the extent of an earthquake whose intensity is greater than 7. This requires an assessment of Bucharest housing stock. In 2011 in Bucharest were recorded 113863 buildings mainly concentrated in 3 of the 6 districts, as follows: District 1, District 4 and District 2 together comprising 70% of total buildings in Bucharest.



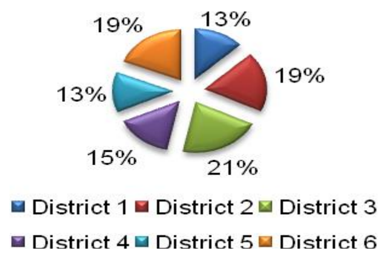


Figure 2: The structure of Bucharest buildings portfolio

Figure 3: Distribution by district of Bucharest conentional dwellings in 2011

Source: Authors' processing based on data provided by www.insse.ro

For a detailed image we considered relevant to assess the number of conventional dwellings, a total of 803794 in 2011. These are evenly distributed in the 6 districts of the capital. Even if the lowest number of buildings can be noticed in District 3 here we can find the greatest number of dwellings, 170205. 98.4% of the total number of conventional dwellings from Bucharest is private property, 1.4% state property and 0.2% private group property.
Also, to observe an earthquake's impact, in addition to housing stock, we should take into account the population exposed to such an event:

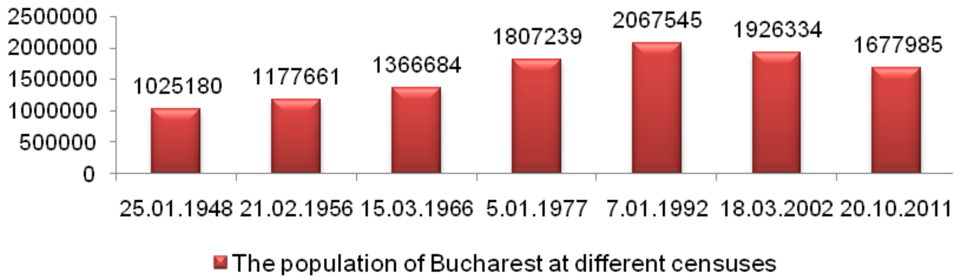


Figure 4: The population of Bucharest at various censuses
Source: Authors' processing based on data provided by www.insse.com

Considering the fact that in comparison with 1977 the population decrease was around 7% we expect in case that an earthquake with the same intensity occurs to face similar consequences in terms of number of people affected. Using Holt Winters forecasting method the next value for the Bucharest population is 1.429.636 people. It is also useful to notice the share of casualties in the total population recorded in Bucharest after the 1977 earthquake. There were registered 1424 deaths and 7598 casualties. By reporting to the total population we obtain the value 0.5%. If a similar event occurs at present this share will be greater, respectively 0.54%. This increase is explained by the decrease of the population, tendency that seems to continue in the future.

We first have to do some clarification on structure of Bucharest housing stock. Thus, 60% of the buildings have been built before 1977, the remaining 40% after 1977. (Lungu, 2002:12)
We use average values for the area where the dwelling is situated, finishing work and surface. The average surface of living rooms in Bucharest is 21.1 square metre (sqm)/room and considering the structure of dwellings depending on the number of rooms we obtain a average surface of a dwelling of 50 sqm.

Table 2: The structure of housing stock depending on the number of rooms

	Share in total
1 room	15.5%
2 rooms	40.7%
3 rooms	32.9%
4 rooms	9.2%
5 rooms and more	1.7%

Source: Authors' processing based on data provided by www.insse.ro

To determine an average market value we consider the two moments of the construction year: before and after 1977, so we get:

Table 3: Determination of market value taking into account the year of construction

Year of construction	Market value	Market value of a 50 sqm dwelling
Before 1977	1250 Euro/sqm	62.500 Euro
After 1977	1600 Euro/sqm	80.000 Euro

Source: Authors' processing

Average market value of Bucharest housing stock =60% * 803.794 * 62.500 + 40% * 803.794 * 80.000=55.8 billion Euro.
The average replacement value is 875 Euro/sqm in case of an average level of finishing works, so for the same 50 sqm dwelling results a replacement value of 43.750 Euro.
Once determined this value we can notice that in case of a compulsory insurance policy the amount received as compensation is insufficient to bring the dwelling to the situations before the event. The next step is to determine real value. This value results by applying the remaining value coefficient to the replacement value.

Table 4: Determination of real value taking into account the year of construction

Year of construction	Remaining value coefficient	Replacement value	Real value of a 50 sqm dwelling
Before 1977	55%	43.750 Euro	24.063 Euro
After 1977	76%		33.250 Euro

Source: Authors' processing

Real value of Bucharest Housing stock=60% * 803.794 * 24.063 + 40% * 803.794 * 33.250=22.3 billion Euro
Level of potential damages in Bucharest in case of a Vrancea earthquake with a 8 intensity:

Table 5: Damages distribution depending on the degree of destruction

Damages	Share in the total number of dwellings	Destruction degree
D0-no damage	11%	0%
D1-slight damage	22.7%	0%-30%
D2- moderate damage	28.5%	30%-60%
D3-heavy damage	23.6%	60%-80%
D4-very heavy damage	12.1%	80%-100%
D5-destruction	2.1%	100%

Source: Authors' processing (Trendafiloski et al.,2008:13)

Average potential damages=22.3 billion Euro * (11% * 0% + 22.75 * 15% + 28.5 * 45% + 23.6 * 70% + 12.1% * 90% + 2.1% *100%)= 10.2 billion Euro
To determine the level of potential insured losses we have to know the insurance coverage in Bucharest:

Table 6: Insurance coverage of dwellings in Bucharest

	Bucharest
Number of optional insurance policies	377.976
Number of compulsory insurance policies	129.411
Total insurance policies	517.687
Number of dwellings	792.391
Insurance coverage of dwellings	64%
By optional insurance	47.7%
By compulsory insurance	16.3%

Source: Authors' processing based on www.csa-isc.ro/MediaCentre/Press Release

Total amount insured through compulsory policies= 2.588.220.000 Euro
Total amount insured through optional policies = 60% * 377.976 * 24.063 + 40% * 377.976 * 33.250= 10.484.222.693 Euro
Total amount insured= 13 billion. Euro
Mean Damage Ratio=10.2 billion Euro/13 billion Euro*100=78.46%
Financial losses module
Based on data considered above we can determine the Average Annual Loss:
AAL=p_i*L_i, where p_i is the annual probability of occurrence and L_i, the loss generated by the event i.
AAL=4%* 10.2 billion Euro=408 million Euro

5. Conclusions

Cat models development should become a priority for insurers especially nowadays when cat risks are considered a real problem. Due to high compensations payable in a short period of time, an objective risk assessment is essential for the insurance company for its financial situation in order not to be affected.
In this study we used three different measurements: market value, replacement value and real value. Insurers recommend using the real value, or sometimes the

replacement value when an insurance policy is bought but never the market value because it is questionable. Therefore, although insurers would receive higher premiums because of higher amount insured this fact wouldn't imply also compensations over the damage value. In addition, potential insured persons often are not willing to pay high amounts of money in order to ensure their dwellings. Given the fact an insurance established at market value would avert potential clients more, a compulsory insurance of dwellings is considered to be in fact a "compromise".
In our vision the main coordinates of public-private partnership are the compulsory insurance of buildings with an insured amount chosen by the policyholder and taking as reference the real value of buildings but also subsidizing insurance premiums for those people who can't afford it. In addition alternative risk transfer solutions should be considered for natural catastrophe: earthquakes or floods.

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