VULNERABILITY MODELLING FOR INSURANCE LOSS ESTIMATION – WHAT ARE THE CHALLENGES?

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Abstract: Natural catastrophes worldwide lead to billions of dollars of economic as well as insured losses annually (Munich Re, Nat Cat Service). Catastrophe models are generally used to produce views of natural catastrophe risk. The insurance and reinsurance industry utilizes catastrophe models to develop risk metrics for insurance premium pricing, reinsurance contracts and capital market instruments. One of the key components of catastrophe models is the vulnerability of the insured risks, i.e. the building stock. This paper will introduce the concept of catastrophe modelling, insurance and reinsurance and the impact vulnerability makes on insurance premium and reinsurance metrics. It will then discuss the common drivers of vulnerability from physical and economic perspective making reference to earthquake and wind perils. The challenges of characterization of vulnerability are then discussed focussing on the drivers of vulnerability with examples from European earthquake and wind events.

Introduction

The insurance premium and re-insurance treaty pricing is done using aggregate exceedance probability (AEP) and occurrence exceedance probability (OEP) risk curves as illustrated in Figure 1 below as a general exceedance probability (EP) curve.

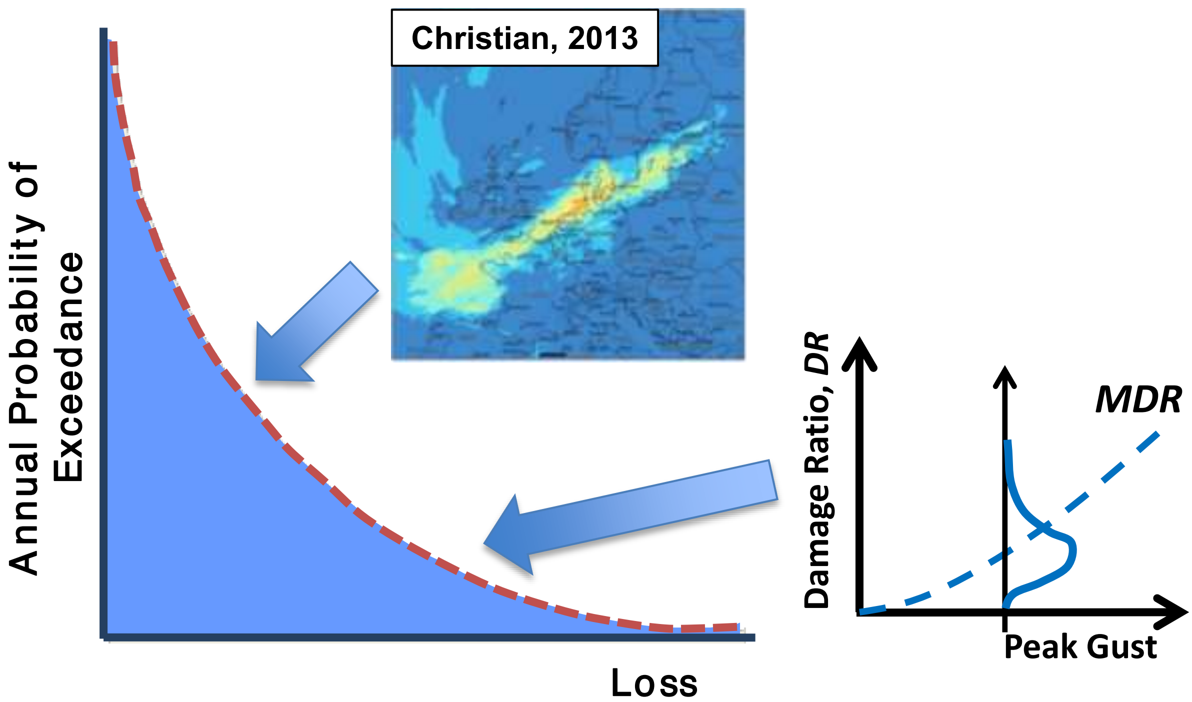

Figure 1: Illustration of exceedance probability (EP) curve together with the constituent components of hazard and vulnerability. Hazard footprint of storm Christian by PERILS

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The area under the AEP curve is the annualized average loss (AAL) that is factored in the calculation of the insurance premiums. The AEP and OEP curve's tail risks (losses at higher return periods) are used to evaluate the reinsurance treaty premiums and cost of reinsurance. Catastrophe models produce OEP and AEP curves, the risk metrics needed for insurance risk evaluation. A catastrophe model consists of three components: hazard, vulnerability and exposure. Hazard component represents the estimation of the likelihood of a catastrophic event of a particular intensity such as rate and intensity of an extra-tropical cyclone or magnitude of an earthquake. The hazard component also models the event footprint resulting from the hazard event, an example illustrated in Figure 1 for an extra-tropical cyclone in Europe. Vulnerability quantifies the expected loss ratio or mean damage ratio (MDR) and the aleatory uncertainty around the MDR as a function of hazard e.g. peak gust, as illustrated in Figure 1. The vulnerability is commonly evaluated as a function of the physical properties of the building or subject at risk, e.g. occupancy, construction type, height and year of construction. The damage ratio distribution described by the vulnerability function represents the ground up loss ratio distribution where no impact of insurance policy terms is considered. Exposure component consists of the location of risks, physical properties of the subjects at risk as well as the value of the coverages such as building, content and business interruption or additional living expenses. The physical as well as monetary values are for a particular client's book of business or for the industry as a whole.

A vulnerability function has a direct impact on the AEP and OEP curves. For instance the shape of the vulnerability function defines the shape of the EP curves as this represents the distribution of the hazard interaction with the vulnerability. Adjusting the vulnerability function's MDR therefore has a direct impact on the AAL as well as the return period loss affecting the reinsurance treaty cost calculations. As an example, doubling the vulnerability at all peak gusts will result in doubling AAL and approximately similar change in the EP curves. The aleatory variability has no impact on AAL. However, this could have a significant impact on the tail of the EP curves where an increase in variability will "fatten" the tail risk. Given the impact a vulnerability function has on the EP curves and the resulting risk metrics, it is important to understand the drivers of vulnerability. This allows a better insight into what forms a vulnerability function and hence the sensitive drivers of vulnerability that ultimately impacts the EP curves.

Figure 2: Damage to RC commercial and industrial facilities observed by the Author in Bologna after the Emilia-Romagna Earthquake of May 2012

Drivers of vulnerability

Drivers of vulnerability in a loss modelling context are principally two fold; physical and economic. The physical drivers of vulnerability are generally associated with the resistance of various components within a subject at risk to loading imposed by a particular form of hazard e.g. ground motion, peak gust, flood depth, etc. This is appreciated by studying the damage modes of buildings as illustrated in Figures 2 and 3 citing examples of earthquake and wind storm damage from European events of Emilia-Romagna Earthquake of May 2012 and windstorm Klaus in January 2009 respectively. What determines the resistance of a subject at risk to a particular hazard is adaptability to local hazard, legislation, architectural practice and deterioration.

Figure 3: Typical damage modes observed in Europe extra-tropical cyclones from damage surveys by the Author in France after windstorm Klaus, Jan 2009

In earthquake zones, buildings requiring seismic design follow provisions in building codes with special structures following site specific studies to determine the seismic loading requirements. It can be generally envisioned that the design requirements as well as construction practice that evolves with time follows the seismic hazard identification of a particular location. Legislation however plays a crucial role in determining the actual practice adopted despite the presence of seismic design codes and provisions at a national level. Some jurisdictions may choose stringent requirements over and above the national codes, while others may stipulate regional variability with special provisions for certain class of buildings. Usually legislation at local level determines the enforcement of design approach ultimately determining the local construction practice, e.g. building control legislation and enforcement. Hence the reason why one often finds little or no seismic considerations among buildings in seismic zones that should consider the hazard in the basic structure design. Architectural practice is a characteristic of the history of a particular region. Older historical structures that may have survived past events hence have an inherent resistance to seismic loading above the requirements as determined based on codes or our current understanding. The opposite is also true where the older buildings may not survive an earthquake without any form of retrofitting based on current seismic provisions. Deterioration results in reduction of resistance to loading. For seismic loading, this may be due to deterioration of cover for reinforcement and subsequent weakening of reinforcement. Deterioration is unlikely to be a major factor in altering seismic resistance of the main structural system, given the safety margins adopted at design stage. However it could affect the resistance of non-structural components such as cladding, roofing, partition walls etc.

In earthquakes the resistance of the main structural frame is a key determinant of building vulnerability. In the case of windstorms, particularly the extra-tropical events, damage starts from the non-structural components such as roofing, cladding, windows etc. As illustrated in Figure 3. The physical vulnerability of a subject at risk to wind is therefore largely driven by the damageability of the roofing elements and to some extent the building structure, based on the resistance to wind loading. Climatological adaptation is probably the most influencing factor for wind resistance where stringent design criteria are expected in high wind design areas. The 50year wind hazard map as used in wind codes is an illustration of the spatial variability of hazard. Wind codes also stipulate minimum requirements, for example, the need to nail every 5th tile in the general area of a roof in accordance with BS5534. However, design requirements may vary somewhat differentially where local legislation such as building regulations in local jurisdictions may impose certain requirements. In Scotland the use of sarking boards is recommended in the Scottish building regulations. While codes and regulations lay down the minimum requirements, the actual wind resistance may vary and could be above or below the required or intended level. For instance, roofing is not generally legislated to the same extent as structure design for wind loading. Most of the homes or residential properties are not engineered in that they follow a generally accepted best practice approach possibly adopted from local practice going back many years of construction history and experience. Some regions may have architectural restrictions or historically adopted certain architectural styles. Deterioration also affects wind resistance as roofs are constantly exposed to wind loading since the date of installation or repair possibly following a storm. On this note, roofs that are not well maintained are more likely to have a lower wind resistance than intended. Above discussed factors of wind resistance are therefore the physical drivers of wind vulnerability. It should be noted that these physical drivers vary by type of building occupancy as well as by location.

Apart from physical drivers, the economic factors that drive vulnerability are the relativity of repair cost (driving the cost of an insurance claim) to the rebuilt cost (determines the sums insured). The cost of repair and rebuilt are affected by the cost of labour and material and in the case of repair, the availability of resources after an event. Despite the low level of physical damage in Europe winter windstorms, it is widely believed based on observations that a wind event at national scale could drive up the cost of repair in the short term after the event. This is due to lack of material and labour to conduct the repairs over a reasonable time period driven by the supply and demand balance in the market. The uneven distribution of economic development in a country could also affect the availability of resources post event and affect the repair vs rebuilt cost relativity. Another important aspect is the state of the insurance market and client's processes to handle claims. Where clients have a greater understanding of claims pricing to detect fraud as well as correct pricing, the volatility of the claim value is low as well as the expected claim value for a particular extent of physical damage. Given the size of the event and number of claims to handle, clients generally adopt a multi-tier approach to processing where claims below a threshold are processed internally while those above are examined based on internal checks and external visits by loss adjusters. Such practices affect the relativity of the claim value and the rebuilt cost.

Challenges of vulnerability characterization - Earthquakes

The vulnerability function describes the expected or mean loss or damage ratio as well as the variability around this for a particular hazard level. What is defined as a vulnerability function in a catastrophe model is a function that describes the population mean and the variability of vulnerability of single subject at risk and not the vulnerability of a specific building. For example, when we say vulnerability of a 5-story RC commercial building constructed in 1980, we expect the mean damage ratio of that building for a particular ground motion or wind speed to be representative of all similar buildings belonging this risk class defined by height, construction, occupancy and year built. This population mean could also vary by region or remain the same within national borders. An individual building may have an MDR that differs from the population mean. Catastrophe models adopt a hybrid component based approach and empirical approach to develop the population mean damage ratio as a function hazard. The advantage of this hybrid approach is that the component approach allows detailed insights into the component behaviour that govern the overall building mean damage ratio while the empirical approach brings in the understanding of inter-event, inter-client and inter-location variability. The latter empirical approach defines an empirical vulnerability function that is used to calibrate the component based functions. The challenges in defining this empirical view for a particular type of risk arise from the difficulties in establishing the precise state of the drivers of vulnerability i.e. the precise physical as well as economic state of the subject at risk belonging to a particular building class population.

The earlier section discussed that the physical drivers are adaptability to local hazard, legislation, architectural practice and deterioration, which determines the level of resistance to external hazard and hence the vulnerability. The following discussion with examples should hopefully shed some insight into the challenges of vulnerability characterization.

In earthquake vulnerability determination, the challenges are generally associated with the characterization of the vulnerability of the main structural system. If we look at the hazard adaptability issue, determining the precise level of seismic design adopted for a particular class of risk is difficult unless one has access to information on the way buildings are constructed for the population concerned and how regulations are enforced. Seismic hazard maps and building code provisions provides a first insight into how the vulnerability varies regionally and how it varies by class of building. However one needs to also understand the regulations applied locally and an understanding of the level of enforcement. It was discussed earlier that the reason why one often finds little or no seismic considerations among buildings in seismic zones is due to difference in enforcement practices. The author and his colleagues conducted site surveys of damaged buildings after the May 2012 Emilia-Romagna Earthquake in northern Italy. It became quickly apparent during the survey that there was a substantial amount of commercial and industrial property damage attributed to the failure of the RC frame system at the connections. Figure 3 illustrates damage seen widely in the surveyed region outside of Bologna. Closer examination of some of the sites revealed that there is a practice of simply supported beams spanning vast open spaces supported by columns with limited lateral bracing. Looking at the seismic design map, the region of Emilia-Romagna is in seismic Zone II/III of the Italian seismic design code. For commercial and industrial structures of high importance, one should consider moment frames to transfer the loads to the connections and allow sufficient capacity to absorb the cyclic loading and plastic deformations without compromising structural integrity and life safety. The point to note here is that seismic design codes alone do not provide an insight into the vulnerability of the population of the building class. Hence the challenge is to identify such characteristics of constructions practice and hence amend the view of vulnerability applied to certain regions. Even if one has access to documents pertaining to the local legislation, enforcement remains another matter, which could well be subjective.

Both Emilia-Romagna event and the 2009 L'Aquila event surveyed by the author (Rosetto, et al., 2011) showed us that historic structures experienced substantial damage during these earthquakes. One would therefore consider that historical buildings in general would be of a higher inherent seismic vulnerability than buildings of similar occupancy designed for seismic hazard. However among the historical residential buildings, there were some who escaped the substantial damage or collapse, only to suffer minor cracking on the masonry walls. Closer examination revealed that these structures have been retrofitted to withstand the lateral loading from an earthquake. The retrofitting was in the form of insertion of RC beams connected as a ring and connected to RC columns. The system therefore provides lateral stability on both vertical as well as horizontal planes (diaphragm action). The retrofitting was done in such a way to minimize the impact on the appearance of the building. Although the post-event surveys revealed such details, it is not generally practical to capture such details of retrofitting for every building of a particular class at a national scale.

Challenges of vulnerability characterization - Windstorms

For wind vulnerability determination particularly for Europe winter windstorms, the challenges of vulnerability characterization are associated with the non-structural elements such as roofing and cladding. In defining the empirical vulnerability one often uses historical wind loss data and their relationship with the corresponding reconstructed events. However, past is not necessarily a guide to predicting future wind losses from a similar event due to changes of the state of the subjects at risk as well as the market conditions. A good example is windstorm Christian that passed over United Kingdom in October 2013 and ended up recording the highest ever gust of 121mph in Kegnaes in southern Denmark. Despite recording the highest ever gust, larger than the gusts experienced in 1999 storm Anatol, the resulting damage in comparison was about a tenth of Anatol on today's monetary values according to PERILS. Field survey carried out by the Author and his colleagues revealed very little occurrences of roof tile uplift throughout Denmark, which had a wide damage frequency range of around 1/1000 to 1/10. Part of the reason is that the storm despite recording a highest ever gust was not widespread and intense as Anatol. Danish have improved the way their roofs are secured and maintain them well, which was evident from the quality of the roof covers examined during the field survey. This highlights the need to factor such changes in an empirical claims analysis to derive vulnerability functions that are applicable to the current conditions.

It is important to understand the state of the insurance market at the time of an event in addition to the physical state or changes to them post an event, if these events are considered in an empirical vulnerability estimation. Christian in the UK known as St Jude was dubbed the next 87J storm given the extent of tree fall resulting from the gusts that impacted southern England. Despite the expectations, the resulting losses were a modest fraction of the 87J event. Although trees are likely to fall during windstorms, the damage would result if they are at close proximity to the buildings. Widespread media reports of tree fall after St Jude, does not necessarily translate to widespread damage to the built environment. The lesson for empirical vulnerability development is that large insured loss in 87J was also attributed to the loss amplifications effects such as larger frequency of claims and claims being paid with little scrutiny. Insurance companies have improved their systems of handling claims via loss adjusters and pre-contract arrangements with approved contractor networks to control the cost of claims and handling costs. Such factors should be accounted for in an attempt to predict the vulnerability for a recurrence of 87J.

Lothar storm in 1999 was famous for its impact in northern France, while windstorm Klaus occurred in 2009 in the southwest of France, an area less prone to damaging extra-tropical cyclones. An empirical claims analysis revealed that a single national vulnerability function could not be used to predict residential wind damage in the whole of France. Author and his colleagues conducted a vulnerability study of residential properties by examining wind design codes in France as well as roofing and cladding guidelines such as DTU (Peiris and Hill, 2012). According to the above sources, southwest of France do not stand out as having a substantially higher vulnerability than the rest of France. In characterizing residential vulnerability for insurance risk modelling, one has to consider the vulnerability implied by the claims data as Klaus is a benchmark event. This example suggests that adaptability to local climate and architectural practices that drives the regional differences in physical vulnerability of roofing alone is not sufficient to determine the vulnerability variability across France. Economic factors that drive differences in repair costs vs rebuilt cost also contribute to defining the mean damage ratio.

Conclusions

The importance of vulnerability determination in catastrophe modelling was discussed by highlighting the impact the vulnerability functions have on the risk metrics used for calculating AAL as well as reinsurance structures. The physical and economic drivers of vulnerability were discussed making reference to earthquake and wind hazard. The challenges of vulnerability characterization were discussed citing examples from Author's experience in surveying damage after European earthquake and windstorm events. It is apparent that understanding the physical state of a population of a class of buildings modelled, is key to determining the mean damage ratio. This requires extensive research to determine the extent of the seismic or wind resistance of the structure through understanding of design, construction practice to enforcement and any changes through time when historical data are used. In addition, understanding local architectural practices and the resulting inherent resistance to external loading is important as well as considering effects of deterioration. From an economic perspective, one needs to be aware of the valuation practices adopted in various regions as well as practices of processing claims particularly changes over time if historical data are used as a gauge.

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