A CAT BOND-BASED COVERAGE SCHEME FOR THE ITALIAN RESIDENTIAL BUILDING STOCK

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Introduction. Natural disasters are a source of major concerns worldwide since they can have devastating effects on communities, in terms of costs for repairing damaged structures and infrastructure, human losses, business interruptions, and environmental impacts. For this reason, they are relevant issues for individuals, corporations, and governments. Rainfalls, windstorms, tornadoes, floods, and earthquakes cause billion dollars losses every year (Gardoni et al. 2016). In some countries, catastrophe losses are managed by governments and public authorities. In this “welfarist” context, homeowners are not encouraged to subscribe private insurance contracts, and, biased by a low perception of risk, they are often not willing to invest in retrofit interventions. Such situations can be particularly difficult for governments. Similarly, private reinsurance companies, that usually have large portfolios, need to provide coverage to significant losses by using sophisticated Alternative Risk Transfer products (ART). One ART solution is represented by the insurance-linked securitization, an alternative way for transforming catastrophe risk into securities (i.e., catastrophe bonds) and selling them to financial entities able to absorb such high levels of losses (i.e., the financial market). CAT bonds offer a significant supply for reinsurance surpassing the capacity of traditional providers and are therefore well suited to provide coverage for substantial losses (Grossi and Kunreuther 2005). CAT bonds are usually structured as coupon-paying bonds with a default linked to the occurrence of a trigger event or events during the period of coverage. In case of default, the principal, which has been held in trust, is used to pay the losses of the issuing company; on the contrary if there is no default, the principal is returned to the investor at maturity and coupons are also paid as counterweight to the assumed risk. One key point in issuing an earthquake CAT bond, is the definition of the trigger event. A commonly used trigger event is the exceedance of a loss threshold, that is the one adopted in this study. In some other cases, different triggers can be adopted, as physically based parametric triggers. Recently, Hofer et al. 2019 proposed a risk-based CAT bond pricing procedure able to consider the propagation of parameter uncertainties on the default probability (P_f) of a CAT bond and on the pricing, while in Hofer et al. 2020 a general methodology for addressing the design of a CAT bond-based coverage for a spatially distributed portfolio is proposed. This paper aims to presents the results of Hofer et al. 2020b in which a CAT bond-based coverage scheme against losses induced by seismic events all over the entire national boarders was priced for the residential building stock in Italy. Further details can be found in Hofer et al. 2020.

Framework. As discussed in Hofer et al. 2020, the design of a suitable coverage for a distributed portfolio can be subdivided in four main steps. The proposed procedure can be used for different purposes by issuing companies, considering also different kinds of natural or man-made hazards.

1. *Target losses definition*: the first step deals with the identification of the spatially distributed portfolio that the issuing company wants to cover. Commonly, national governments may be interested in covering the entire national territory, while private insurance or reinsurance companies may want to protect their entire insured portfolio, or part of it, from insolvency risk. The definition of this region has a strong implication on the pricing process, since distribution parameters are calibrated from events occurred or simulated in this specific area. Secondly in this first stage, target losses covered with CAT bonds have to be defined.
2. *CAT bond zonation*: when the portfolio is significantly scattered over a wide region, different risk levels can be observed within the same region. For this reason, a common practice is to tailor CAT bonds associated to different risk levels, in order to meet the needs of different types of investors, via the subdivision of the region of interest in smaller zones. A region with high-impact and frequent events leads to calibrating high-risk CAT bonds with related high gains for risk-seeking investors; on the

contrary, a zone with rare and lowly impacting losses leads to low-risk CAT bonds, more attractive for risk-averse investors.

3. *Calibration of distribution parameters*: the third step consists in the computation of the Poisson process and loss distribution parameters, which are at the base of the mathematical procedure for computing first the default probability and then the CAT bond price. Regarding the loss distribution, rarely enough historical data of extreme events are available, and thus computer simulations are needed to predict potential losses that can arise for the portfolio of interest.

4. *CAT bond price computation*: lastly, CAT bond price is computed. Among the most common techniques, stochastic processes are adopted for CAT bond pricing; in this case, one common method is to model the credit default probability which follows the way of pricing credit derivatives in finance, and to assume the time to be continuous. The catastrophe process is thus modelled as a compound doubly stochastic Poisson process, where the potentially catastrophic events follow a doubly stochastic Poisson process, and the associated losses are assumed independent and generated from a common probability distribution. The CAT bond's default occurs when the accumulated losses $L(t)$ exceed the money threshold level D before the expiration time T. Under these assumptions, the price for *zero-coupon* V^{ZC} (i.e. debt security that does not pay interest but renders profit only at maturity) and *coupon* V^{C} CAT bond (i.e. debt security that includes attached coupons and pays periodic interest payments during its lifetime and its nominal value at maturity), can be computed as discounted expected value of the future payoff. The general mathematical formulation is detailed in Hofer et al. 2019.

Case study. The exposed framework is applied to design a coverage scheme for the entire residential building asset of Italy considering seismic events as relevant natural hazard. In this application, the Italian Government is taken as the issuing entity, which adopts CAT bonds for a full risk-transfer, considering as lower bound seismic events with magnitude $M \geq 4.5$. The region of interest is represented by the Italian peninsula, and the target losses are represented by the potential direct costs to be sustained for repairing seismic damage to the Italian residential building stock. First, Italy is divided in three zones based on the seismic risk maps developed by Zanini et al. 2019. This zonation (Fig. 1a), based on the seismic risk map and adopting administrative borders, assures an almost constant combination of events frequencies and amount of losses within each zone, and the exact attribution of each event to the corresponding zone.

The calibration of the Poisson process and loss distribution parameters is based on the numerical simulation of 100'000 years of seismicity within the national territory, because of the limited number of real losses and claim data. For the generation of 100'000 years of seismic events, the seismogenic source zone model ZS9 of Meletti et al. 2008 is adopted, together with the seismogenic zone parameters of Barani et al. 2009. The shaking scenario associated to each generated event, is computed in terms of peak ground acceleration with the ground motion prediction equation proposed by Bindi et al. 2011. According to Zanini et al 2019, the seismic vulnerability of the Italian residential building stock is characterized by setting a building taxonomy consisting in 8 taxonomy classes (TCs): (*i*) masonry structures built before 1919, (*ii*) masonry structures built post 1919, (*iii*) gravity load designed reinforced concrete (RC) structures with 1-2 storeis, (*iv*) gravity load designed RC structures with 3+ storeis, (*v*) seismic load designed RC structures with 1-2 storeis, (*vi*) seismic load designed RC structures with 3+ storeis, (*vii*) gravity load designed masonry-RC structures, (*viii*) seismic load designed masonry-RC structures.

The exposure model of the national residential building stock is defined at municipality-level granularity and data are retrieved from the 15th census database of the National Institute of Statistics. Fig. 1b and 1c illustrates 100'000 years of simulated seismicity for the seismogenic zone 905. For the calibration of the three sets of distributions parameters, earthquakes occurred inside of each CAT bond zone border were then selected. Fig. 1d shows the selected events for each zone, resulting in 126'414 in Zone 1, 151'245 in Zone 2 and 38'380 in Zone 3. Among the three, Zone 2 has the highest intensity since more events occur in it, in the same time window. Lognormal CDFs were fitted on the cumulative losses to obtain the loss distribution parameters for each zone (Fig. 1e).

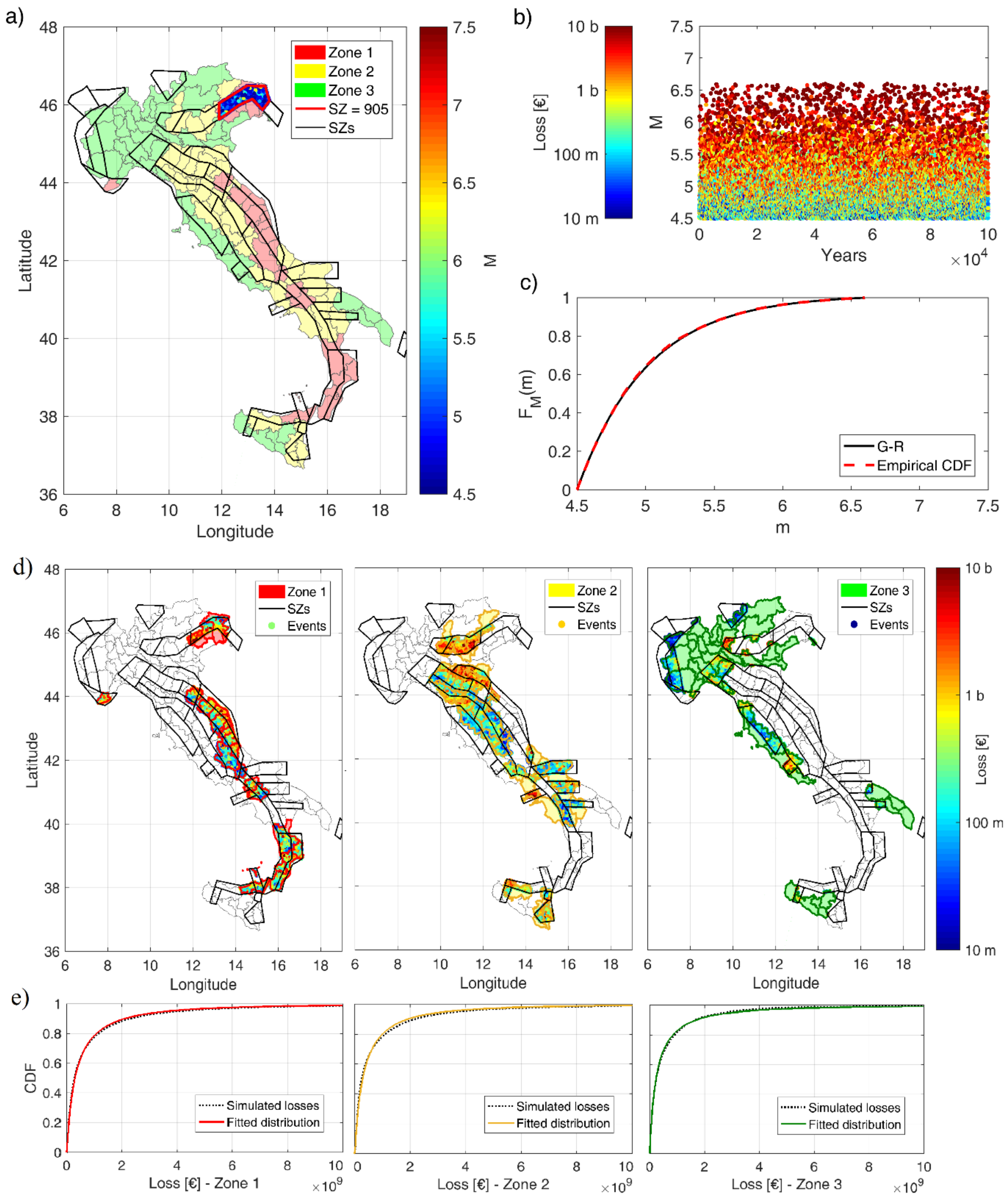

Fig. 1 - Proposed CAT bond zonation for the Italian territory (a), 100’000-years simulated seismicity for SZ #905 (b-c), selected events for each Zone (d) and loss data fitting with lognormal distributions (e).

In the present work, CAT bond price is evaluated at time $t = 0$, assuming a principal equal to 1 €. Two different products were considered for the pricing, a *zero-coupon* and a *coupon* CAT bond, both with a full loss of the principal in case of bond triggering. In the first case, the *zero-coupon* CAT bond is assumed to be priced at 3.5% over LIBOR so that if no trigger event occurs, the total yield is 6%, and consequently $Z = 1.06$ €. For the *coupon* CAT bond, the yearly coupon payments $C(s) = 0.06$ € and $Z = 1.00$ € are considered. A continuous discount rate r equivalent to LIBOR = 2.5% is assumed constant and equal to ln (1.025) (Burnecki et al. 2005). Expiration time and threshold level are considered respectively ranging between [0.25, 5] years and [0.1, 10] *bn* €, guaranteeing in this way a sufficiently broad *T*-*D* domain for showing the variation of CAT bond price for a wide range of possible combinations. The bond for a zone is triggered when the accumulated losses caused by earthquakes occurred within the zone are greater than the set threshold before the set expiration time. Fig. 2 shows the probability of failure P_f surfaces for Zones 1, 2 and 3, together with the bounds deriving from considering the parameters uncertainties and containing the 80% of the probability. Two cross sections of the surface are also shown, corresponding to planes with $T = 2$, and $D = 3$ *bn* €. As a general behaviour common for all the three zones, for a given expiration time *T*, P_f decreases as the threshold level *D* increases, whereas for a given threshold level *D*, P_f increases from 0 to 1 over time. P_f of Zone 1 and Zone 2 are comparable since despite a slightly lower expected loss, Zone 2 has a higher Poisson intensity due to a wider zone area and consequently more events inside. Zone 3 has the lowest P_f due to a combination of lower expected losses and less expected events.

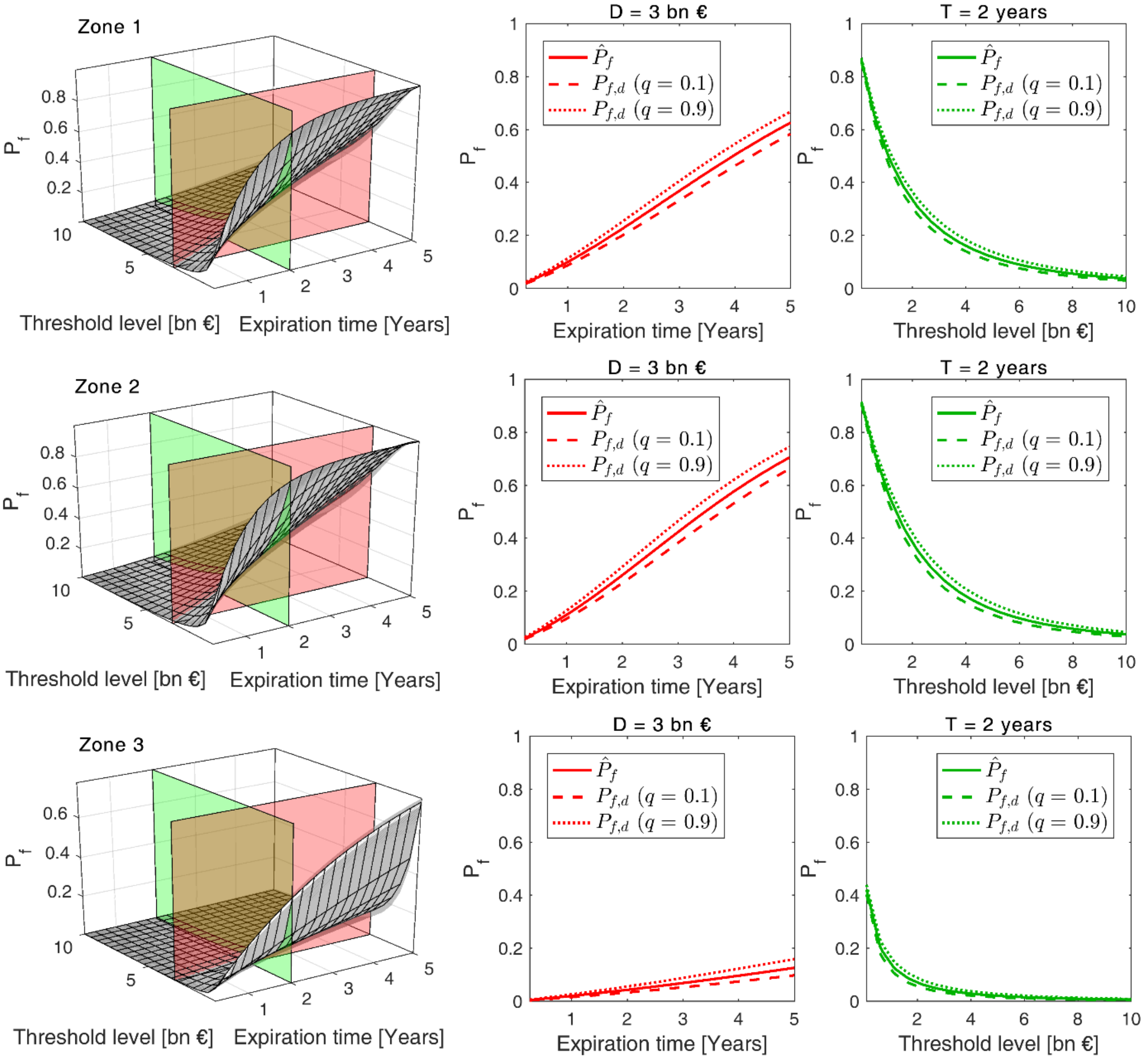

Fig. 2 - Failure probability P_f surface for the three Zones.

Fig. 3a shows the *zero-coupon* CAT bond pricing surfaces V^{ZC} associated with the threshold *D* paying $Z = 1.06$ € at maturity, for each Zone. In this case, for a given threshold level *D*, the CAT bond value decreases over time, whereas for a set expiration time *T*, the CAT bond value increases as the threshold level *D* increases. The prices reflect the related failure probabilities: price of Zone 3 is the highest since it is associated with the lowest probability of exceed the money threshold of 3 *bn* €. Higher gains provided by the bonds are associated to higher failure probabilities. Finally, Fig. 3b illustrates the case of the *coupon* CAT bond, evidencing how the overall trend is similar to the *zero-coupon* one due to the high ratio intercurrent between the principal and the entity of coupons. Numerical results are the combination of two contributions: as time passes, the chance of receiving more coupon payments is bigger, but at the same time, the possibility of losing the principal increases. Both the *zero-coupon* CAT bond and the *coupon* CAT bond price reflect the different seismic risk-levels of the three zones. For a given T-D combination, the price for a bond in Zone 1 and Zone 2 is the lowest while the price in Zone 3 is the highest. This work can be considered the first original attempt currently retrievable in scientific literature aimed at a rational management of significant losses induced to the Italian residential building stock by seismic events. Italian authorities can directly use results, reducing in this way the burden of reconstruction processes on the public finances.

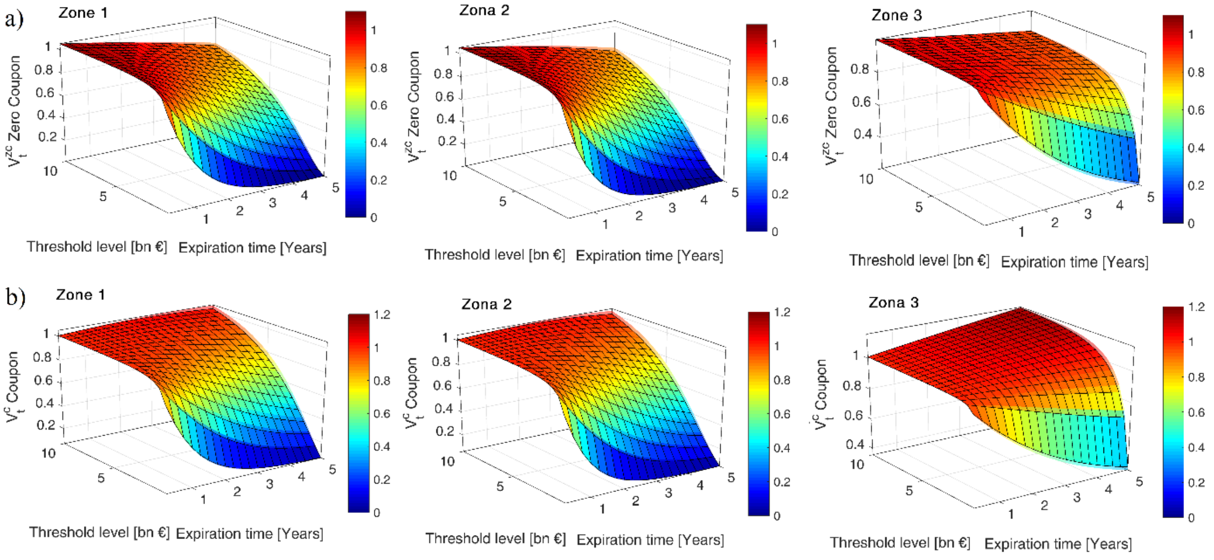

Fig. 3 - *Zero-coupon* (a) and *coupon* (b) CAT bond price for the three Zones.

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