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Earthquake Financial Protection for Greece: A Parametric Insurance Cover Prototype

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ABSTRACT

Greece is among Europe's most exposed countries to seismic activity but it lacks a financial backstop mechanism to protect its population from large economic impacts induced by earthquakes. The government does not have protection for its own assets and expenses either. Financial mechanisms that would address these needs are often perceived as expensive and difficult to put in place. However, recent advancements in the financial and reinsurance markets towards streamlining risk transfer and making it more transparent and affordable offer new possibilities for countries like Greece. Protection mechanisms that work on a "parametric" basis, for instance, can provide cash fast and transparently after an event without the need to sustain lengthy claims adjustment periods. As they are fully customizable, they offer the possibility to be tailored to any budget, large or small. A parametric insurance product bases the recoveries not on a loss adjustment process, as is the case in an indemnity policy, but rather on a series of physical measurements, akin to a derivative. In this paper we construct a prototype parametric cover to showcase how these relatively novel financial techniques can be applied to benefit Greece. The paper briefly revisits the underlying numerical theory for the construction of these risk management solutions. Two different types of covers, one designed to respond with an expected return period of 25 years and another at a return period of 100 years, illustrate the levels of recoveries that can be expected from different earthquakes depending on the budget allowable.

Keywords: Earthquake Risk, Parametric Insurance, Parametric Hedges

INTRODUCTION

Catastrophic seismic events of past years have made evident the relevant role of insurance in complementing other earthquake mitigation strategies (Franco, 2014). Insurance mechanisms are, however, far from perfect and specific circumstances, like the liquefaction damages experienced in New Zealand (King et al., 2014), still pose challenges that the traditional insurance product finds hard to address. Dissatisfaction and distrust with traditional earthquake insurance -despite some successful experiences- have made *ex post* disaster management (i.e. dealing with the consequences of the event only after it has happened) still the prevalent strategy worldwide. A Guy Carpenter (2014) study showed that the worldwide gap between economic and insured losses due to natural disasters remains high at 70%. Among the factors that contribute to this gap,

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Guy Carpenter (2017) lists low insurance penetration, which in turn is attributable to the public perception that existing risk and value of insurance are misaligned. The insurance and reinsurance industry is keen to reduce this insurance gap as it is interpreted as both a commercial opportunity and a social responsibility challenge. New insurance solutions, partly grounded on new technologies and distribution through the Internet, aim to make risk transfer more accessible and affordable.

In this paper, we introduce a parametric insurance cover prototype for Greece, akin to existing mechanisms for Mexico, Peru, Colombia, Chile, and other countries (e.g. Artemis, 2018). This prototype is defined by a set of magnitude thresholds that, if attained or exceeded for events in certain geographic regions, results in a payout. Parametric solutions are perfectly suited for an electronic environment as they rely on remotely-sensed information and contractual payments can be potentially executed via smart contracts (Clack et al., 2016). They can be flexibly sold in the financial markets, depending on user requirements and regulatory framework, as catastrophe (cat) bonds, derivatives (Cummins, 2008), or as (re)insurance. Often due to difficulties to frame these solutions as proper insurance, they are referred to as *hedges*.

Parametric hedges have established themselves as a viable alternative to traditional earthquake indemnity insurance, which typically involves damage surveyors and claims specialists and may take months or even years (if claims are disputed) before providing monetary relief. Not relying on claims settlement processes after the occurrence of damage, parametric solutions are able to ensure fast and transparent earthquake risk protection. However, parametric hedges carry significant *basis risk*, the risk that a certain event may trigger a payment even if the actual loss is small or zero or, conversely, that an event may cause a very large loss without a payment being triggered. Therefore, their proper usage needs to be critically understood and carefully embedded within broader risk management frameworks.

METHODOLOGY

The prototype developed in this paper features payment conditions according to a regular, three-dimensional grid based on the "payment table" concept presented in Franco (2013). This approach allows us to capture risk with higher detail, therefore reducing basis risk while preserving transparency and simplicity in the determination of payments. Incorporating the depth of event hypocenters in the parametric hedge development, we are able to implicitly identify faulting mechanisms such as crustal or subduction. This grid is applied to the region of interest, which in this case covers the area surrounding Greece and contains all seismogenic sources that might cause loss in the national territory.

We apply an optimization procedure to identify a magnitude threshold for each cell in the grid so that it meets certain design constraints. This optimization approach relies on data about the distribution of risk which was obtained from an existing earthquake risk model. In essence, this numerical process aims at balancing two metrics, the expected frequency of payment and the actual transferred risk, as defined in the following sections. Intuitively, a mechanism that provided payment for every event would cost too much money as the premium is approximately proportional to this frequency. However, a cheap mechanism that would not pay even for large destructive events would be useless for the insured.

Problem formulation

Region of interest

The first step in the formulation of the proposed parametric insurance cover prototype consists in the definition of the region of interest, taking into account the exposure (assets at risk) and the regional seismicity. Notice that the definition of the region of interest is not limited to the horizontal directions (longitude and latitude), but includes the vertical direction, using a depth limit as necessary to accurately capture all relevant fault mechanisms. In the attempt to capture the largest number of seismic events causing damage, the region of interest typically extends beyond the considered exposure distribution.

Discretization of the domain

When the region of interest is established, we construct a regular mesh of hexahedra that univocally divide this region into a number $N_{\mathbf{Q}}$ of volumes, or "cubes" $\mathbf{Q}$ (they are actual cubes only in the special case that all dimensions are the same in the appropriate projection). The parametric insurance cover prototype that we propose associates a magnitude threshold to each one of these cubes. The policy pays out if an earthquake happens in the region of interest and its magnitude attains or exceeds the magnitude threshold associated to the cube which contains its hypocenter. Both the information on the magnitude and location of the hypocenter (physical parameters of the parametric hedge) are typically publically available in near-real-time from trusted sources, such as the U.S. Geological Survey (USGS) (Wald & Franco, 2016, 2017). The higher the number of cubes, the higher the ability of the parametric hedge to capture the risk correctly but also the higher the computational burden to determine the optimal magnitude thresholds in each volume.

Definition of variables

We will assume the existence of a catalog $\mathbf{E}$ of $N_{\mathbf{E}}$ seismic events, where an earthquake $E_k \in \boldsymbol{E}, k \in (1, \dots, N_{\mathbf{E}})$, happening in the region of interest results in damage to the considered exposure and is characterized by the following variables: its magnitude (M_k), its hypocenter location (X_k, Y_k, Z_k), its rate of occurrence (R_k), and the exposure's losses, (L_k). These losses may be estimated through available catastrophe models, which will not be covered in depth as part of this paper. Suffice to say that the necessary output can be obtained from commercial models such as those developed by AIR Worldwide[2], Risk Management Solutions (RMS)[3], or CoreLogic[4], or from publicly available models such as the Global Earthquake Model (Crowley et al., 2013). In this paper, the proposed prototype relies on the AIR Worldwide European Earthquake Model (Catrader v19.1) (e.g. Rong et al., 2011; Lai et al., 2012).

If M_k is equal or higher than the magnitude threshold associated to the cube that includes the event hypocenter, the parametric hedge is triggered. In this case, the transferred risk (T_k) associated with the event E_k is given by Eq. (1):

$$T_k = R_k \cdot L_k. \tag{1}$$

For a reference cube $Q_i \in \mathbf{Q}$, $i \in (1, \dots, N_{\mathbf{Q}})$, with magnitude threshold $\widehat{M}_i$, $\mathbf{E}_i$ is the set of events included in the cube (i.e., having hypocenter within the cube Q_i), defined as follows:

$$\begin{aligned}\mathbf{E}_i &= \{E_k \in \mathbf{E}\colon (X_k, Y_k, Z_k) \in Q_i\} = \\ &= \left\{E_k \in \mathbf{E}\colon \left\{X_k \in \left[X_{Q_i}^{min}, X_{Q_i}^{max}\right) \wedge Y_k \in \left[Y_{Q_i}^{min}, Y_{Q_i}^{max}\right) \wedge Z_k \in \left[Z_{Q_i}^{min}, Z_{Q_i}^{max}\right)\right\}\right\},\end{aligned} \tag{2}$$

where $X_{Q_i}^{min}$, $X_{Q_i}^{max}$, $Y_{Q_i}^{min}$, $Y_{Q_i}^{max}$, $Z_{Q_i}^{min}$, and $Z_{Q_i}^{max}$ are the minimum and maximum values along the X, Y, and Z directions for the reference cube Q_i. The set of trigger events $\hat{\mathbf{E}}_i$ is given by

$$\hat{\mathbf{E}}_i = \left\{E_k \in \mathbf{E}_i \colon M_k \geq \widehat{M}_i\right\}. \tag{3}$$

Representing the events in set $\hat{\mathbf{E}}_i$ triggering cube Q_i as Poisson processes, the probability that cube Q_i is triggered (P_{Q_i}) is given by

$$P_{Q_i} = 1 - e^{\left(-\sum_{E_k \in \hat{\mathbf{E}}_i} R_k\right)}. \tag{4}$$

The total trigger probability P_Q, considering the entire set $\mathbf{Q}$ of $N_{\mathbf{Q}}$ cubes, is given by

$$P_Q = 1 - e^{\left(-\sum_{Q_i \in \mathbf{Q}} \sum_{E_k \in \hat{\mathbf{E}}_i} R_k\right)} = 1 - e^{(-R)} \tag{5}$$

where R is the total trigger rate. The total trigger rate drives the cost of the parametric hedge, for example if the parametric hedge triggers (i.e. transfers risk) after every earthquake, the parametric hedge will pay after every earthquake and therefore it will be very expensive for the policyholder.

[2] AIR Worldwide (https://www.air-worldwide.com/)
[3] Risk Management Solutions (https://www.rms.com/)
[4] CoreLogic (https://www.corelogic.com/)

Formulation of the parametric hedge as an optimization problem

Our goal is to find the best combination of cubes Q_i and magnitude thresholds $\widehat{M}_i$ that maximizes risk transfer T at a given rate of occurrence (i.e., at a given budget constraint), with

$$T = \sum_{Q_i \in \mathbf{Q}} \sum_{E_k \in \hat{\mathbf{E}}_i} T_k. \tag{6}$$

We can formulate the optimization problem in the following terms:

$$\begin{gathered} \max T \\ s.t. \ \sum_{Q_i \in \mathbf{Q}} \sum_{E_k \in \hat{\mathbf{E}}_i} R_k \leq R_{max} \end{gathered} . \tag{7}$$

The optimization problem is subject to the budget constraint (expressed in terms of a maximum value of total trigger rate R_{max} that should not be exceeded). The solution of the optimization problem can be expressed as a vector of threshold magnitudes or trigger conditions, each associated to a specific cube within the considered region of interest.

Note that the objective function used here aims to maximize risk transfer, not to explicitly minimize basis risk. Both approaches are feasible and have been used before. The choice largely depends on the desired behavior of the trigger. For instance, in Franco (2010) a parametric trigger for Costa Rica is designed using an evolutionary algorithm that aims to minimize the occurrences in which an event with a loss lower than a threshold would trigger the structure. Conversely, Franco et al. (2018) design a parametric hedge for California that uses a linear programming approach to maximize risk transfer at a given budget, analogously to the path chosen here. As basis risk is often hard to define explicitly, maximization of risk transfer makes sense when the desired trigger is expected to allocate some level of protection to areas of high risk regardless of the specific loss they might cause. In this paper we solve the optimization problem with a linear programming approach; alternative techniques have been explored in de Armas et al. (2016).

APPLICATION TO GREECE

We apply the methodology described in the previous section to develop a parametric insurance cover prototype for Greece. The region of interest covers an area extending from 15E to 30E degree in longitude and from 32N to 45N degree in latitude, including Greece and a large part of the Balkan region, western Turkey, and southern Italy, with a focal depth range extending to 100 km. The region of interest has been discretized with a regular grid of 1560 cubes of size 0.5x0.5 degrees on the horizontal plane and 50 km on the vertical plane. The region of interest includes the location of earthquakes that may potentially damage the considered exposure, the insurable building stock in Greece (see the risk distribution maps in Fig. 1) provided by AIR Worldwide's earthquake model for Europe.

The considered region is the most active in the Mediterranean area with Greece ranking sixth in the worldwide seismic exposure (Tsapanos & Burton, 1991). The earthquake catalogue proposed by Makropoulos et al. (2012) for Greece and adjacent areas (narrower than the region of interest in the present application) between 1900 and 2009 lists more than 1,500 events with magnitude M_W equal or above 5.0 with 8 events attaining or exceeding M_W7.0. According to the Institute of Geodynamics (2006) 40 earthquakes in this time span resulted in considerable casualties. Petseti & Nektarios (2012, 2013) report Greece suffering between 1990 and 2010 a maximum earthquake-induced loss exceeding 2 percent of Greece's 2010 GDP, the greatest loss in the European Union (EU) in that time span. Just 18 kilometers from the highly densely populated Athens metropolis, the M_W5.8 Mount Parnitha (Athens) earthquake of September 7, 1999 was the costliest event that hit the region (Pomonis, 2002), with economic loss approaching 4 billion Euro, (around 3% of Greece 1999 GDP). A probabilistic risk model for Greece has been proposed by Pomonis et al. (2001), and may be of interest to explicitly encompass uncertainties in the different analysis modules at the basis of catastrophe models. Pomonis et al. (2014), for instance, discuss how a reliable assessment of the vulnerability is needed to assess earthquake losses and implement mitigation scenarios considering the large heterogeneity in Greece's residential exposure.

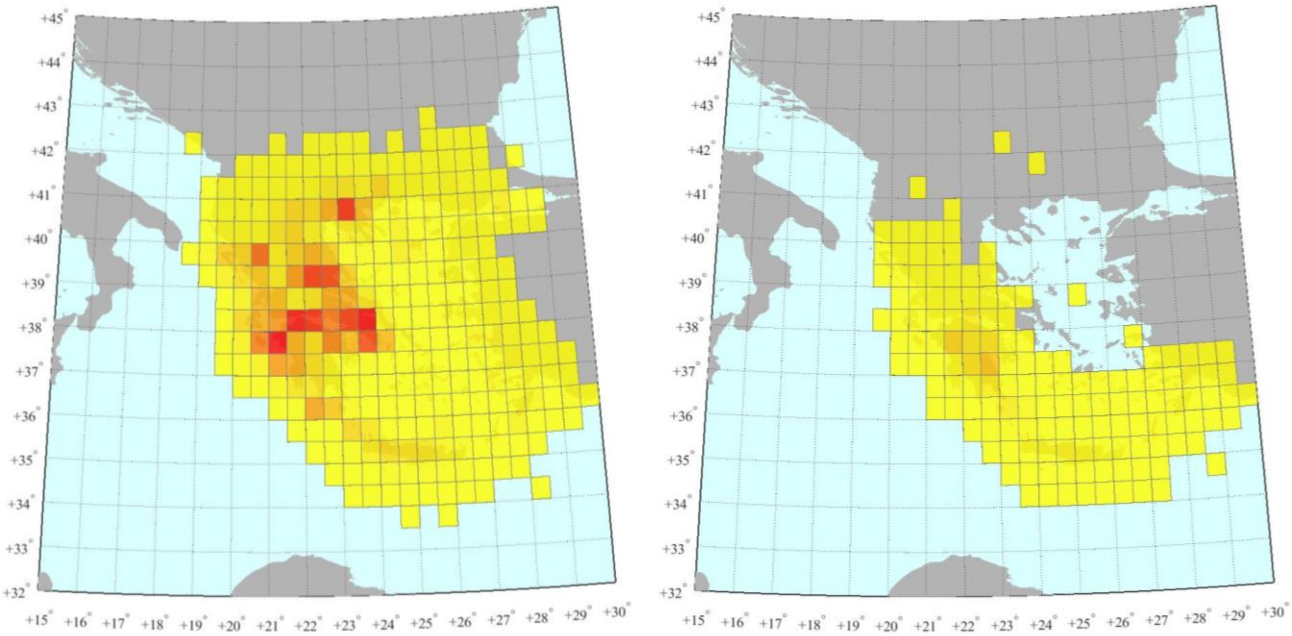

Figure 1. Risk by cube based on original exposure. Left hand side: depth Layer 1 [0km - 50km); Right hand side: depth Layer 2 [50km - 100km). Earthquakes occurring in volumes shaded with darker red colors carry more risk, either due to their higher frequency, higher damage potential, or both.

Despite Greece experiencing in the past a large number of damaging earthquakes, insurance penetration is lower than 10% according to the 2012 report of the European Commission (Maccaferri et al., 2012). Furthermore, as per the residential assets at risk, only the overdue value of a mortgage is actually covered. In general, the recovery in the aftermath of a damaging event is based on ex post financing (Petseti & Nektarios, 2012, 2013), resulting in a high, possibly unbearable, burden on already stretched public finances.

RESULTS

We compute two solutions to optimize risk transfer via a parametric mechanism, one that is calibrated to produce a payment with an expected frequency of a 25-year return period and another at a 100-year return period. These solutions are illustrated in Figure 2, where the plots show the trigger conditions in each grid cell for the two depth layers considered in the design. The 25-year return period solution naturally produces trigger thresholds that are lower than those for the 100-year return period solution. This means that more earthquakes are expected to trigger the lower return period mechanism. Naturally, this comes at a cost. As the frequency of payment is higher, the premium will also grow, loosely in proportion to the frequency.

The optimization process, as described above, aims to create trigger conditions such that events with higher frequency and higher potential loss produce a payment of the mechanism. We would therefore expect that, in general, more frequent and more damaging events cause a trigger condition. This is illustrated in Figure 3, where the histograms show (in black) the percentage of events that produce a payment. Events are classified by their relative loss potential. An event in the upper bin produces a loss that is between 90% and 100% of the maximum loss produced by any event in the region. Conversely, events in the lower bin produce a loss that is lower or equal to 10% of the maximum loss. We would expect that the optimization process captures mostly events towards the right end of the distribution, the higher loss causing events, but this will not always hold strictly as the frequency also plays a role. In addition, the geometry of the grid and the events may hinder certain events being captured, for instance in a situation where the same grid cell contains one large loss producing event in the environment of many low magnitude events that would break the frequency budget if all were captured in the mechanism. As before, the 25-year return period solution captures more events in lower loss bins than the 100-year return period solution. This makes sense as the higher frequency budget allows us to consider triggering events at lower magnitudes.

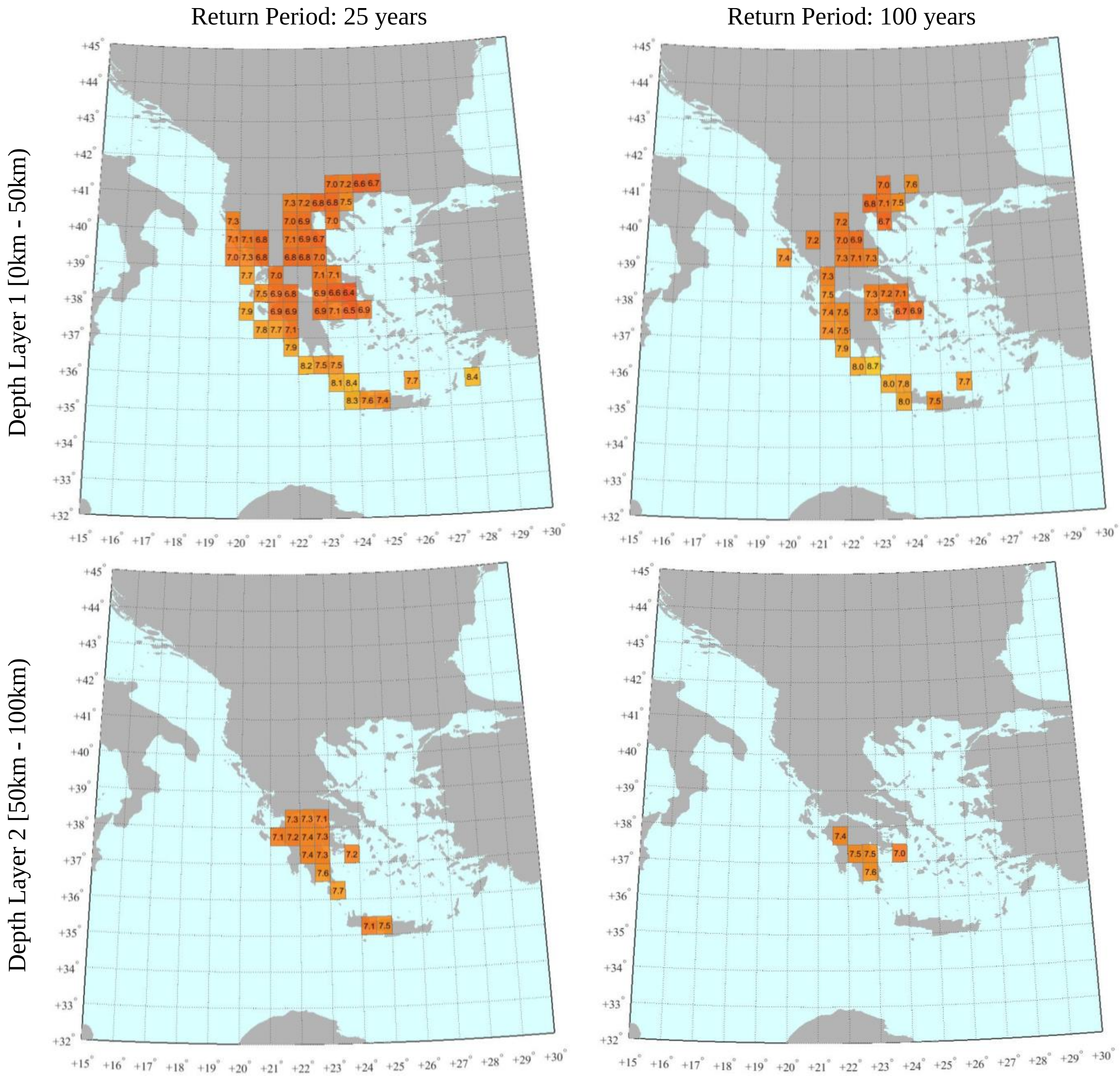

Figure 2. Trigger definition for different return periods and depth layers. Darker colors correspond to cells with lower magnitude thresholds. These should somewhat align with higher risk volumes in Fig. 1.

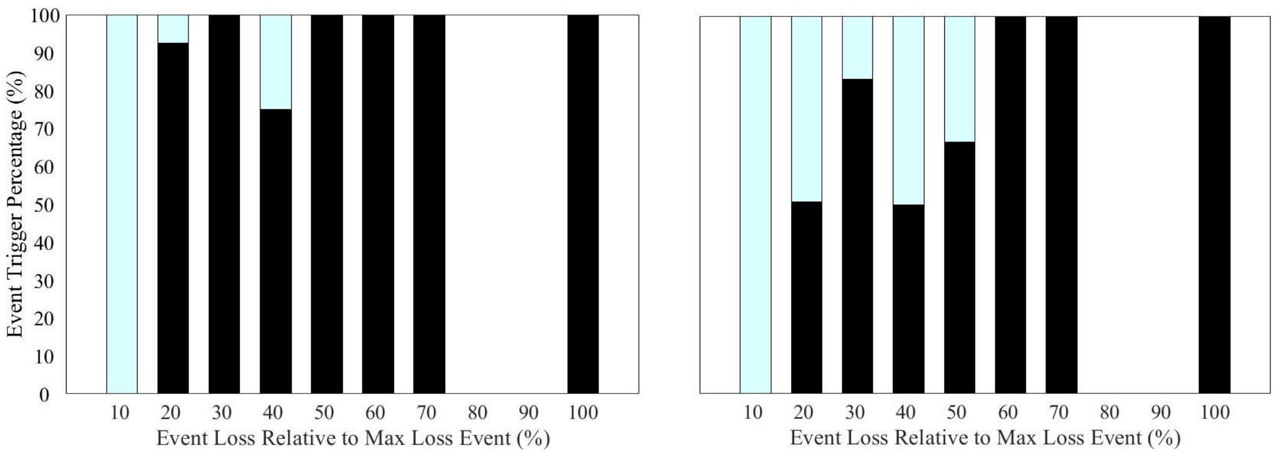

Figure 3. Trigger performance by event loss bin for the 25-year (left) and 100-year (right) return period solutions. More events are covered for the 25-year return period solution, as expected.

Note that the histograms show a gap of events in bins at 80% and 90% of the maximum loss. This is not uncommon as losses do not grow linearly with magnitudes. The catalog of stochastic events contains in the order of 200,000 events within the domain considered towards the lower end of the loss distribution while it only contains about 20 events across all bins with losses larger than 50% of the maximum loss.

Comparing across depth layers in Figure 2, one can observe an effect that deserves attention. A number of cubes show a greater magnitude threshold on the surface 0-50km layer than in the deeper 50-100km layer (e.g., cubes at 24E longitude and 35N latitude for the 25-year return period solution, or cubes at 21.5E longitude and 37.5N latitude in the 100 year return period solution). The solution, constructed thus, requires a larger earthquake on surface than at depth in order to trigger a payment. This may seem counterintuitive, as an earthquake on surface will typically produce more damage than a deeper event. However, from an optimization point of view, this makes sense if, once taking into account the frequency of the events, their losses, and the available total probability budget, the solution reached accomplishes an overall greater risk transfer than having the thresholds reversed. Although this is numerically justifiable, for practical applications we may impose the geometric vertical constraint that deeper magnitude thresholds should always be larger or equal than the ones on surface for any one latitude and longitude pair. Similarly, there are other geometric horizontal constraints that might make sense in certain scenarios to accomplish other objectives, such as for example having smooth transitions between neighboring cells. This more sophisticated analysis is not covered in this prototype exercise; the increasing complexity may be addressed relying on high-performance optimization algorithms, as for example metaheuristic approaches.

CONCLUSIONS

The paper proposes a prototype of a parametric earthquake financial protection mechanism for Greece. The design, while simplistic, has the purpose of illustrating that national governments can seek financial mitigation strategies tailored to their risks and their budgets through modern risk transfer vehicles. The parametric nature circumvents lengthy adjustment processes or disputes in court, thus making the mechanism more attractive to governments for whom transparency is paramount. These tools can be deployed either as catastrophe (cat) bonds or as a (re)insurance contract, which means the capital necessary to provide coverage can be sourced from the investor market as well as from the more traditional reinsurance space. Although existing solutions are often designed to cover entire countries, there is progressively greater comfort applying them to smaller sub-national domains as illustrated by Franco et al. (2018) for California and its major cities. This is useful in risk management schemes in which the government desires to transfer responsibility to smaller regional administrations, while keeping an overall control over recoveries across the territory. In sum, we observe these advanced parametric insurance solutions as the ideal conduit for highly seismic countries like Greece to help avert the detrimental financial impact of large earthquakes.

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