FINANCIAL RISK MANAGEMENT FOR EARTHQUAKE DISASTER: A CASE STUDY OF RHODES AND GRANADA

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Abstract: *A comprehensive disaster risk management strategy is crucial for mitigating the impact of earthquakes and safeguarding valuable cultural heritage. This study, developed within the EU funded project HYPERION, focuses on the cities of Rhodes and Granada, which possess significant cultural assets subject to seismic hazard. Financial risk management plays a pivotal role in this strategy by enabling resource mobilization for efficient disaster response and minimizing long-term financial consequences. Herein we explore the implementation of ex-ante financing options, which are financial arrangements established before disasters occur, to ensure swift and effective response measures. Ex-ante financing options encompass two main approaches: risk retention and risk transfer mechanisms. Risk retention involves setting aside resources, such as contingency funds or individual/shared reserves, for immediate post-disaster use. On the other hand, risk transfer mechanisms shift financial risk to third parties, such as insurance companies or capital markets. To optimize these financing options, we employ a comprehensive approach known as risk layering, which categorizes risks based on their return periods or probabilities. Risk layering facilitates the strategic deployment of various financial tools for each risk layer, resulting in enhanced efficiency and reduced overall costs of risk financing. The aim is to develop a financial risk management strategy based on risk layering for stakeholders in macro-sectors with shared risk characteristics and synergies. We define three risk layers: (i) low-impact, high-frequency risks, where risk retention measures like contingency or mutual funds are most appropriate; (ii) medium-to-severe risks occurring at lower frequencies, for which risk transfer through parametric insurance is identified as the optimal financial risk management tool; and (iii) very high-impact, highly infrequent risks, requiring risk absorption through financial assistance from the public sector and international donors. To determine the most cost-effective thresholds for each layer and stakeholder macro-sector, we employ an optimization approach. By tailoring risk management options to the specific needs of different stakeholders and considering their capacity to absorb risk, our research contributes to effective disaster financial risk management for earthquake-prone areas.*

1. Introduction

Developing a comprehensive disaster risk management (DRM) strategy is pivotal in minimizing the repercussions of earthquakes and safeguarding invaluable cultural heritage (Jigyasu (2005), Romao et al. (2022)). Such a strategy encompasses various elements, including thorough seismic risk assessment, targeted risk reduction measures, robust disaster preparedness initiatives, swift emergency response mechanisms, effective recovery plans, and sensible financial and contingency planning (Freeman et al. , (2003)). For cultural heritage, this entails activities such as conducting seismic risk assessments for the sites, implementing measures to reinforce structures, and establishing early warning systems. This comprehensive approach spans all phases of a disaster, aligning seamlessly with the country's development goals and priorities. Importantly, it integrates across diverse sectors such as cultural heritage authorities, urban planning, environmental planning, civil protection, and more, to foster a holistic response. Financial risk management plays a crucial role in DRM, as it allows to swiftly mobilize resources during sudden-onset disasters like earthquakes (Linnerooth-Bayer et al. (2015)). This strategic allocation of funds not only enhances rapid response but also minimizes enduring financial repercussions. The significance of this approach is particularly evident in cultural heritage preservation, where financial resilience ensures the safeguarding of historical assets.

In this work, we focus on ex-ante disaster risk financing mechanisms i.e., strategic planning and investment in financial risk management before the onset of a natural disaster. Ex-ante financing options for risk management primarily involve risk retention and risk transfer mechanisms. Risk retention involves allocating resources, such as contingency funds or individual/shared reserves, to be promptly utilized in the aftermath of a disaster. This approach offers the advantage of immediate access to funds without incurring additional costs. However, a significant challenge arises in the need to maintain these reserves indefinitely, which can be politically unsustainable and incurs in the opportunity cost by tying up a certain amount of capital for an unspecified duration. Notably, risk retention finds its optimal application in scenarios characterized by high-frequency, low-severity risks, where the potential short-term losses can be adequately covered by the readily available reserves.

Conversely, risk transfer mechanisms operate by shifting financial risk to external entities, typically involving insurance companies or capital markets. Insurance, as a prominent form of risk transfer, presents the benefit of reduced volatility and alleviates liquidity concerns in the aftermath of a disaster. Yet, this advantage comes at the expense of regular premium payments. The insurance and reinsurance approach prove particularly apt for low-frequency, high-severity losses, where a substantial infusion of liquidity is required. The relatively infrequent occurrence of such events ensures that the premiums charged for these risk transfer mechanisms remain reasonable, aligning cost-effectively with the potential financial impact of these rare but impactful occurrences.

A practical approach to adopting the most cost-efficient management strategy, depending on the type of risk, is referred to as risk layering. The risk layering framework, as explained by Mechler in 2014 and later expanded by Hochrainer-Stigler & Reiter in 2021, is a comprehensive approach to managing risks, particularly those associated with disasters. Originating in the insurance industry, this framework has found applications in disaster risk management and other sectors. Risk layering entails dividing risk into distinct layers based on their probabilities or return periods and associated loss levels. Different combinations of risk management instruments, are then employed to manage each of these risk layers. Figure 1 illustrates the concept of risk layering with losses organized by their return period: from high-frequency, low-impact losses to low-frequency, high-impact losses. This allows to identify different risk layers (low, medium, high) and to implement targeted risk management mechanisms for each one. At the low-risk layer, risk retention is often the most suitable mechanism, in the context of seismic risk, this could mean establishing funds for retrofitting of structural reinforcing to deal with less severe and more frequent earthquakes. For the medium-risk layer, transferring the risk to a third party, such as an insurance company, may be more cost-effective and provide immediate liquidity for reconstruction after infrequent more severe earthquake events. At the high-risk layer, public or international financial assistance may be necessary. While in the most extreme cases, compensation may not be enough to cover all losses. This framework encourages the development of portfolios of options that manage risks at all levels.

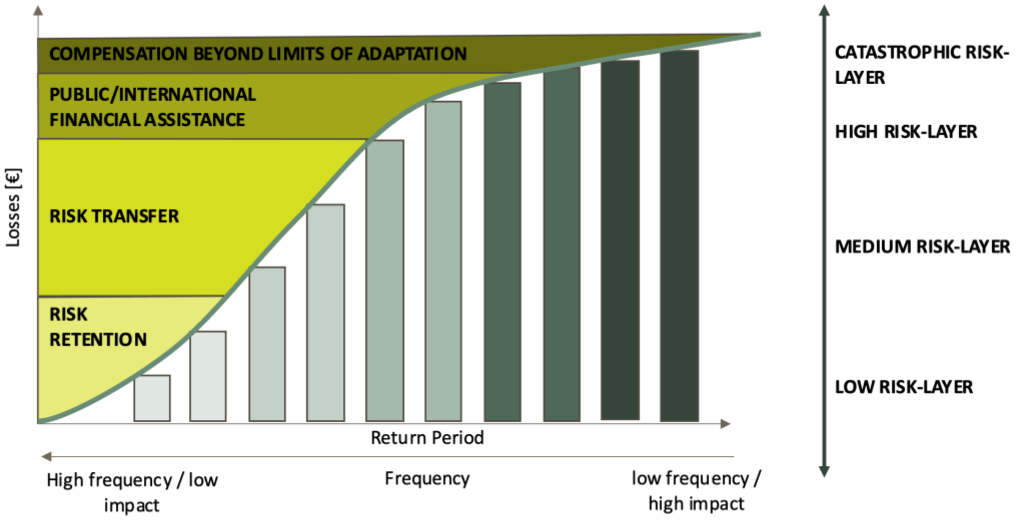

Figure 1. Risk layering framework

This work was developed as part of the the EU-funded project HYPERION (HYPERION (2019)). HYPERION is a collaborative initiative, uniting 26 European organizations, spanning municipal, regional, and national authorities, universities, private entities, and cultural heritage agencies. The project's overarching goal is to harness both existing tools and services alongside innovative technologies, culminating in the development of an integrated resilience risk assessment platform for cultural heritage sites. The primary focus of HYPERION lies in enhancing multi-hazard risk comprehension, fostering improved preparedness, enabling quicker, adapted, and efficient responses, and promoting sustainable reconstruction in historic areas vulnerable to various hazards.

In this work, our focus is on the cities of Rhodes and Granada, both rich in cultural assets that are vulnerable to seismic hazards. This research hones in on practical applications of ex-ante financing options within the risk layering framework. Specifically, we aim to optimize financial risk management strategies for seismic risks in these representative case studies. To inform our approach, we leverage the earthquake risk assessment produced within the project, encompassing both direct and indirect financial loss estimates (Tsarpalis et al. (2023), Karaferi et al. (2023)). By delving into the unique challenges presented by each city's cultural heritage sites, we seek to identify the most cost-effective approaches to mitigate seismic risks. Our goal is to tailor financial risk management strategies that not only enhance resilience but also ensure the preservation of these invaluable cultural assets. Through this endeavour conducted within the broader context of the HYPERION project, we aim to contribute valuable insights into optimizing seismic risk management for cities with similar characteristics and challenges.

2. Methodology

In this section, we delve into the specifics of the tools that make up our financial risk management strategy and discuss how we are going to optimize a layered approach.

2.1 Reserve Funds

A reserve fund, a straightforward form of risk retention, involves setting aside cash reserves in anticipation of an earthquake. This approach offers immediate and complete access to funds without incurring premiums or surcharges on the saved amount. However, there are notable considerations. Firstly, the reserve needs to be established initially and replenished after each event and subsequent drawdown, making it vulnerable to potential shortfalls if multiple events occur consecutively or if the reserve is insufficient. In such cases, losses may remain uncovered, necessitating borrowing which may be very expensive or not available entirely. The indefinite maintenance of reserve funds, until an event occurs, poses political challenges as it can be difficult to justify, especially when prevention measures may not yield immediate political dividends. Additionally, there is an opportunity cost associated with tying up a certain amount of money indefinitely. Figure 2 illustrates this dynamic: as events of variable severity produce damages, the reserve fund (green line) may or may not be able to cover the losses (uncovered losses, in blue), subsequent events (e.g., event 2 and event 3) may leave even relatively small losses uncovered, conversely, reserves may grow very large and become unsustainable between events (e.g., event 4 to event 5). Consequently, this type of tool proves efficient and sustainable primarily for high-frequency, low-severity risks where a relatively small reserve is sufficient.

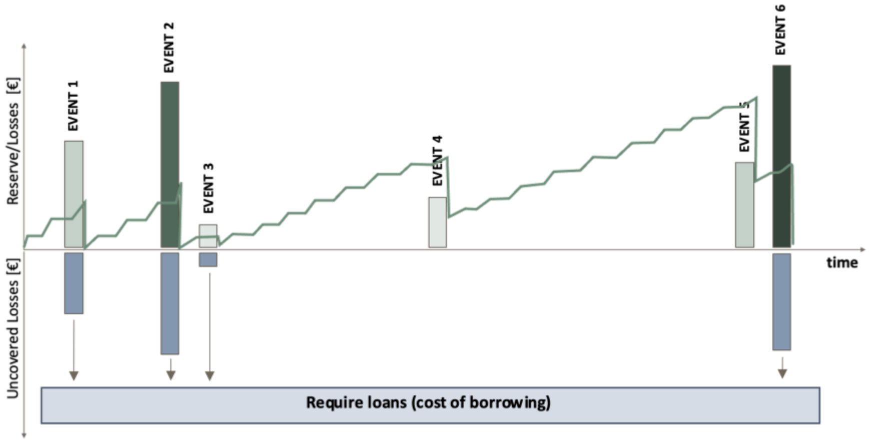

Figure 2. Example of a reserve fund over time

2.2 Parametric Insurance

Insurance serves as a risk transfer mechanism to a third party, typically an insurance company, and is well-suited for scenarios involving low-frequency but high-severity losses that demand substantial liquidity. It operates by alleviating the uncertainty associated with disaster event losses, ensuring a fixed level of coverage predetermined by the insurance contract. Typically, an insurance product provides a payout for losses that surpass the deductible (or attachment point AP) yet fall below the policy limit (or exhaustion point EP). The adjustment of these parameters, namely the deductible and policy limit, plays a pivotal role in determining the cost of the policy, commonly known as the premium. Employing insurance for risks characterized by high severity but low frequency ensures that premiums remain reasonable, striking a balance between coverage and affordability. This approach, coupled with a small manageable reserve fund tailored on the deductible (see Figure 3), not only provides financial security for substantial losses but also mitigates the financial burden on policyholders, making insurance a practical and effective tool in managing specific risk profiles.

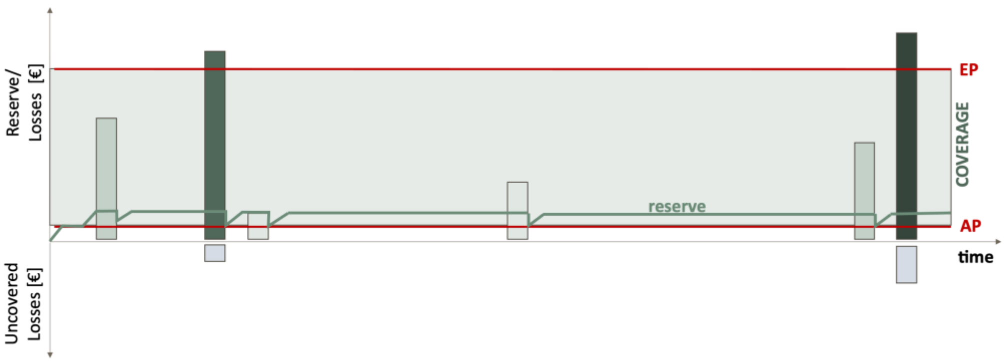

Figure 3. Example of a strategy combining insurance and a small reserve fund over time

Parametric insurance, a distinct insurance variant, diverges from indemnity insurance in its payout mechanism (Shah et al. (2018)). While indemnity insurance bases payouts on actual damage assessed by an expert, parametric insurance triggers payouts through a measurable index acting as a proxy for real losses. This approach offers several advantages. Firstly, it incurs lower transaction and administrative costs, resulting in more affordable premiums. Secondly, parametric insurance mitigates concerns related to moral hazard and adverse selection. Thirdly, it ensures swift claims resolution and payouts, a crucial factor in the aftermath of natural disasters such as earthquakes (Goda et al. (2015)). Despite these benefits, a potential downside exists in the form of basis risk—a disparity between the index (and consequent payout) and actual losses. Despite this drawback, parametric insurance stands as a compelling option, particularly in scenarios where quick claims resolution and cost-effectiveness are paramount considerations.

In this work we use parametric insurance and leverage on the modelled losses (ML) estimated within the HYPERION project (Tsarpalis et al. (2023), Karaferi et al. (2023)).

Payout Function

We define the payout function (Equation 1 and Figure 4) using the following features:

- Attachment Point (AP): This represents the threshold above which the policy contract is triggered, and a payout becomes due. It essentially acts as the starting point for financial coverage.
- Exhaustion Point (EP): This marks the threshold or policy limit beyond which the maximum payout is triggered. It sets the upper limit for the coverage offered by the policy.
- Retention of Losses: Losses falling below the Attachment Point (deductible) and above the Exhaustion Point are retained by the policyholder. This ensures that the policyholder bears some of the financial burden.
- Constant Payout Beyond EP: As the modelled loss surpasses the Exhaustion Point, the corresponding payout remains constant and is equal to the Coverage Limit (CL). This means that once the losses exceed the maximum payout threshold, the policy provides a consistent level of financial coverage.

$$payout = \begin{cases} 0 & if\ ML < AP \\ ML & if\ AP < ML < EP \\ CL & if\ ML > EP \end{cases} \tag{1}$$

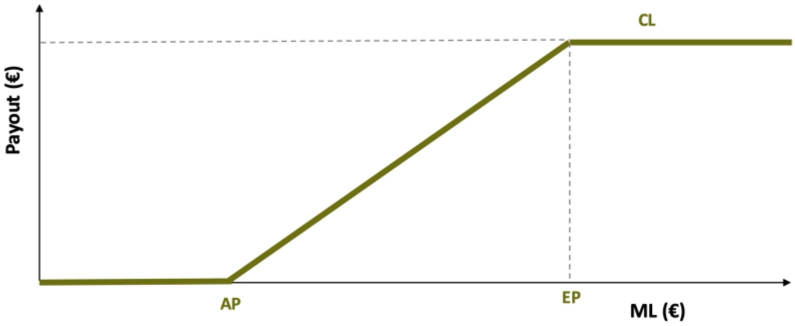

Figure 4. Payout function

Fine-tuning these parameters not only influences the policy's cost (premium) but empowers policyholders to balance coverage and affordability, making informed decisions aligned with their unique risk preferences.

Pricing

The insurance premium consists of two components: the expected value of payouts, representing what the insurance is statistically expected to pay back, and the loading, which is the actual cost of insurance. The loading is typically determined based on payout variability, reflecting the risk taken by the insurer. In pricing, the Wang transform is a commonly used approach (Denaro et al. (2018)). This method distorts the payout distribution, giving greater weight to the right tail (Wang et al. (2000)). This means that large payouts with low probability, which entail higher capital and liquidity requirements and, consequently, a greater opportunity cost for the insurer, are more heavily emphasized in the pricing model.

We applied the Wang transform to determine the loading and adopted a Sharpe ratio (or the market price of risk) of 2.5 (Wang et al. (2002)).

2.3 Application

Data

Within the framework of the HYPERION project, we employ a robust 10,000-year stochastic catalogue of yearly direct and indirect losses for the cities of Granada and Rhodes estimates (Tsarpalis et al. (2023), Karaferi et al. (2023)). For each city, this catalogue considers a diverse array of macro and micro sectors, encompassing three macro sectors—Residential, Tourism (including Food & Beverage, Arts & Entertainments, and Accommodation), and Commercial (covering Retail Stores, Offices, Real Estate, Technical activities, Wholesale Trade, Retail trade, Finance & Insurance, Trade & repair of vehicles, Warehousing, and Other Services).

To gauge the financial landscape, we leverage the long-term interest rates for Spain and Greece (specifically, Government bonds with a 10-year maturity) and the bank interest rates on loans for Spain and Greece, as sourced from the European Central Bank (ECB (2023)) This comprehensive approach allows us to derive both the opportunity cost and the cost of borrowin, providing a nuanced understanding of the financial dynamics in play.

Strategy Optimization

In order to optimize a layered risk management strategy, our objective is to identify the optimal insurance attachment point (AP) and the corresponding reserve fund level, aiming to minimiz the total costs of the strategy. This optimization process involves a practical approach: employing a 10,000-year Monte Carlo simulation. The total cost, defined in Equation 2, encompasses various components such as the opportunity cost of the reserve fund (OC_{RF}), the opportunity cost of the expected payout ($OC_{E(p)}$), the loading, and the cost of borrowing in the event of a reserve shortfall (CB).

$$min \sum OC_{RF} + OC_{E(p)} + \ loading + \ CB \tag{2}$$

To guide our optimization efforts, we operate under specific constraints. The exhaustion point (EP) is predetermined, set at the loss value corresponding to a 200-year return period. Additionally, a critical constraint dictates that reserve shortfalls can only occur 5% of the time. This constraint ensures the ability to borrow at a reasonable cost, enhancing the overall financial viability of the strategy. By navigating these constraints within the Monte Carlo simulation, we aim to derive an insurance strategy that minimizes costs while maintaining financial resilience against potential shortfalls.

3. Results

3.1 Granada

Table 1 shows the optimization results summary for the city of Granada. While the values for each macro-sector differ based on their respective gross values, the loss exceedance probability curve, which maps return periods (in years) to losses (in € amount), exhibits a shape similarity across sectors (see Figure 5). Due to this consistency, the optimal attachment point (AP) remains relatively uniform across these diverse sectors sitting at about 23 years.

Table 1. Granada optimization results summary

	Residential	**Tourism**	**Commercial**
Attachment Point (€)	35,193,753 €	2,443,247 €	1,036,155 €
Attachment Point (return period in years)	23	22	24
Coverage Limit (€)	821,595,139 €	122,601,768 €	284,119,293 €

Loading (€)	6,969,113 €	945,488 €	1,940,693 €
Strategy Total Cost (€)	7,832,527 €	1,020,446 €	2,013,426 €

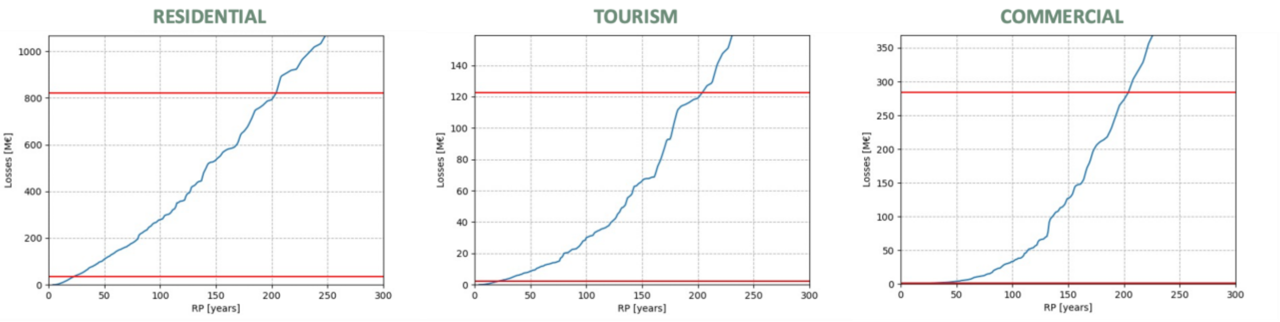

Figure 5. Loss exceedance probability curves for the residential, tourism and commercial macro-sectors in Granada

3.2 Rhodes

The optimization results summary and the loss exceedance probability curves for the city of Rhodes are shown in Table 2 and Figure 6 respectively. Similarly to Granada, the optimal attachment point (AP) is the same across sectors. However, is interesting to note how this value (7 years) is significantly lower for the city of Rhodes with respect to Granada. This is partly due to the Greek city's higher seismicity which determines more severe events to occur at a lower return time and therefore a steeper loss exceedance probability curve. For this reason, buying insurance is more cost-effective for Rhodes at lower return periods.

Table 2. Rhodes optimization results summary

	Residential	**Tourism**	**Commercial**
Attachment Point (€)	13,096,219 €	851,368 €	3,220,520 €
Attachment Point (return period in years)	7	7	7
Coverage Limit (€)	492,554,044 €	60,400,541 €	191,284,816 €
Loading (€)	5,913,118 €	618,930 €	2,060,062 €
Strategy Total Cost (€)	6,926,623 €	695,185 €	2,336,749 €

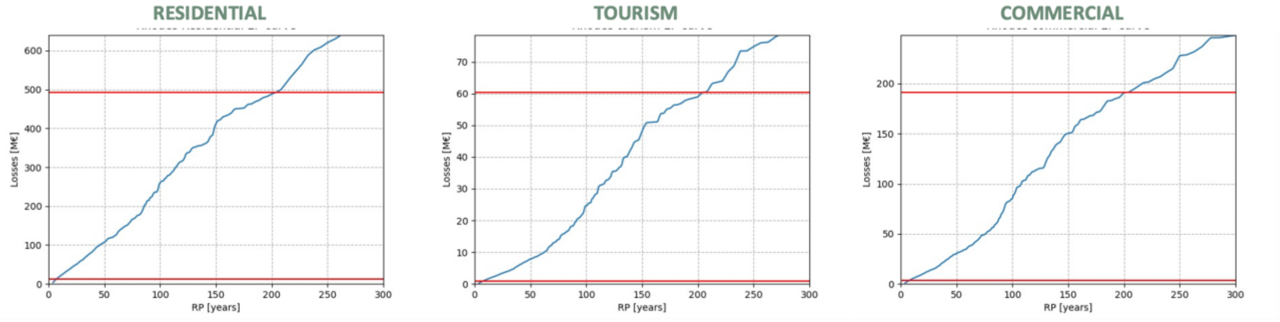

Figure 6. Loss exceedance probability curves for the residential, tourism and commercial macro-sectors in Rhodes

4. Conclusion

In conclusion, financial tools emerge as crucial instruments for effectively managing the financial risks associated with earthquakes, providing adaptable and tailored strategies. The implementation of the risk layer approach, as demonstrated in our study within the context of the HYPERION project, further enhances the strategic allocation of resources for disaster response and recovery. This approach proves particularly instrumental in safeguarding cultural heritage sites, allowing for efficient mobilization of funds when required and mitigating the enduring costs associated with preservation efforts.

Moreover, it is notable how the application-specific risk profile, characterized by the loss exceedance probability curve, plays a pivotal role in determining the suitability of different financial strategies. Our findings emphasize that the choice between various tools, such as insurance or reserve funds, hinges on the unique risk landscape of a given region. Notably, the risk layer approach facilitates a nuanced understanding of these specific risk profiles, aiding in the identification of optimal strategies for minimizing costs and ensuring financial resilience. In navigating the intricate interplay between risk management tools and seismic risks, our study underscores the importance of tailoring financial strategies to the distinct needs and characteristics of vulnerable areas, particularly those rich in cultural heritage.

5. References

Denaro, S., Castelletti, A., Giuliani, M., & Characklis, G. W. (2018). Fostering cooperation in power asymmetrical water systems by the use of direct release rules and index-based insurance schemes. Advances in Water Resources, 115, 301-314.

European Central Bank (ECB), Bank interest rates on loans for corporations. Url: https://data.ecb.europa.eu/main-figures/bank-interest-rates/loans

European Central Bank (ECB), Long-term interest rate statistics for EU Member States. Url: https://www.ecb.europa.eu/stats/financial_markets_and_interest_rates/long_term_interest_rates/html/index.bg.html

Freeman, P., Martin, L., Linnerooth-Bayer, J., Mechler, R., Pflug, G., & Warner, K. (2003). Disaster risk management: national systems for the comprehensive management of disaster risk financial strategies for natural disaster reconstruction. Inter-American Development Bank.

Goda, K., Wenzel, F., Daniell, J., Beer, M., Kougioumtzoglou, I. A., & Patelli, E. (2015). Insurance and reinsurance models for earthquake. Encyclopedia of earthquake engineering, 1184-1206.

Hochrainer-Stigler, S., & Reiter, K. (2021). Risk-layering for indirect effects. International Journal of Disaster Risk Science, 12, 770-778.

HYPERION (2019). Development of a decision support system for improved resilience and sustainable reconstruction of historic areas to cope with climate change and extreme events based on novel sensors and advanced modelling tools. The HYPERION Consortium, Athens, Greece. URL: https://www.hyperion-project.eu/

Jigyasu, R. (2005). Towards developing methodology for integrated risk management of cultural heritage sites and their settings.

Karaferi, E., Vamvatsikos, D., Kohrangi, M., & Spillatura, A. Exposure, Vulnerabilities, And Scenario Seismic Risk Assessment For The City Of Granada. In Proceedings of SECED 2023 Conference

Linnerooth-Bayer, J., & Hochrainer-Stigler, S. (2015). Financial instruments for disaster risk management and climate change adaptation. Climatic Change, 133, 85-100.

Mechler, R., Bouwer, L. M., Linnerooth-Bayer, J., Hochrainer-Stigler, S., Aerts, J. C., Surminski, S., & Williges, K. (2014). Managing unnatural disaster risk from climate extremes. Nature Climate Change, 4(4), 235-237.

Romao, X., & Bertolin, C. (2022). Risk protection for cultural heritage and historic centres: Current knowledge and further research needs. International Journal of Disaster Risk Reduction, 67, 102652.

Shah, H. C., Dong, W., Stojanovski, P., & Chen, A. (2018). Evolution of seismic risk management for insurance over the past 30 years. Earthquake Engineering and Engineering Vibration, 17, 11-18.

Tsarpalis, D., Karaferi, E., Vamvatsikos, D., Kohrangi, M., & Zeppos, J. (2023) A socioeconomic model for estimating indirect consequences of earthquake hazards to cultural heritage communities. In Proceedings of SECED 2023 Conference

Wang, S. S., 2000. A class of distortion operators for pricing financial and insurance risks. Journal of risk and insurance, 15–36.

Wang, S. S., 2002. A universal framework for pricing financial and insurance risks. Astin Bulletin 32 (02), 213–234.