HOW CATASTROPHE MODELS CAN HELP REDUCE THE PROTECTION GAP AT SCALE.

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The gap between insured and total economic losses from natural catastrophes highlights both the challenges in managing risks in a changing world and the opportunity for public and private sectors to help reduce the gap. Making such initiatives efficient and sustainable requires reliable risk information to support sound decision making, and we argue that this can come from using catastrophe models in new ways. In this short paper, we summarise the challenges faced by public-private partnerships to address climate and disaster risks, and we present a case study to show how sensitivity analysis with a flood catastrophe model can be useful in shaping an efficient risk management strategy.

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THE INSURANCE GAP AND HOW TO CLOSE IT.

An active and impactful first three quarters of 2023 resulted in elevated natural catastrophe losses for the globe. Total economic losses were estimated at USD290 billion, including USD93B insured. This USD197B (68%) insurance protection gap highlights the scale of the opportunity for both the public and private sectors to better prepare citizens for natural catastrophe risks[1].

Without more financial preparedness, this protection gap will grow. Many factors have increased the potential for unprecedented losses and disruptions from systemic or highly correlated catastrophes, such as climate change, the transition to low carbon economies, growth concentration, rapid urbanization, and global supply chain consolidation.

In this context, matching capital with risk is not a small task, and securing insurance cover brings several challenges. Citizens may be insufficiently risk aware; they may be behaviourally biased against purchasing protection; and they may over-rely on post-event assistance – whether from government or others. Insurance affordability is also a challenge, as is a lack of regulatory support or a mature insurance market. There may not be sufficient data available on the risks, and an insurance solution may be costly to implement. For flood risk in particular, addressing the scale of the protection gap requires significant amounts of capital, calling for large-scale measures across both public and private sectors.

These large-scale measures can be supported through well-targeted, multi-stakeholder public-private partnerships (PPP) and flood risk-sharing facilities. These should align incentives between all parties with a stake in improving resilience, from governments to private-sector insurers. International donors can also assist, by subsidising premium payments for example, or providing technical assistance to accelerate insurance penetration. For instance, the Southeast Asia Disaster Risk Insurance Facility (SEADRIF) is a prime example of the potential of these PPPs to offer sustainable risk transfer mechanisms against flood events at regional level.

These partnerships take time to mature and reach the scale required to protect economies and livelihoods efficiently. Understanding the risk from highly volatile perils such as flooding will require careful analysis, as there will be significant implications for both climate adaptation and resilience strategies. Nevertheless, the urgency of the climate crisis, and the scale of the potential disasters it may bring, justifies accelerating the pace of development of our risk information tools so that we can bring all financial protection instruments to bear.

[1] Q3 2023 Gallagher Re Natural Catastrophe Report, Gallagher Re, October 2023

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MAKING DECISIONS: THE ROLE OF CATASTROPHE MODELS.

To minimize the risk from repeated catastrophes, government decision-makers and risk managers will consider a range of adaptation and resilience strategies.

For flooding, they might reduce risk through structural protection, such as flood defences, increasing the resilience of buildings, and nature-based solutions – while at the same time using financial protection (such as insurance) to manage residual risks from unavoidable extreme scenarios. Ideally, deciding between risk reduction and risk financing strategies would depend on hazard intensity, exposure and vulnerability of assets and populations, as well as the effectiveness of each strategy in reducing the overall financial impact. In reality, it largely depends on a government's risk appetite, fiscal space, investments and insurance budgets, and its reliance on international aid.

Given this complexity, identifying the correct mix of policies is a substantial challenge for decision makers. They need sound and reliable information about the likelihood and impact of natural disasters, and about the effects of any mitigating actions they might take. This requires a rethink of the way we use our existing informational tools – such as catastrophe models.

A catastrophe model is a powerful tool that helps decision makers understand and quantify risk under different physical conditions (e.g., climate change) and with different levels of adaptation and resilience. It usually expresses risk in terms of financial loss. Navigating the different climate change, adaptation and resilience scenarios is daunting, not least because the associated uncertainty cannot be constrained based on expert knowledge or historical observations. Therefore, the best use of catastrophe models is not as tools to make predictions, but rather as tools to support exploration of possible futures[2]. In this context, sensitivity analysis can provide insights on the relationship between model input and output that can be relevant for decision-making[3].

In the next section, we demonstrate a way of using a catastrophe model to analyse climate risk with different adaptation scenarios, using a case study of Hanoi, Vietnam. By combining a catastrophe model with sensitivity analysis, we will answer the following questions:

1. Which combinations of adaptation and resilience measures lead to specific risk outcomes of interest, such as crossing a critical threshold?
2. Which of these measures are most important in controlling the risk estimates?

While we concentrate on a scenario sensitivity analysis here, the tool can also be used to explore how uncertainties in the inputs to a catastrophe model can impact its outputs.

[2] Improving the contribution of climate model information to decision making: the value and demands of robust decision frameworks, Christopher P. Weaver et al., WIREs Climate Change, December 2012.

[3] What has Global Sensitivity Analysis ever done for us?, Thorsten Wagener and Francesca Pianosi, Earth-Science Reviews, July 2019.

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A CATASTROPHE MODEL CASE STUDY: EXPLORING CLIMATE CHANGE, ADAPTATION, AND RESILIENCE IN HANOI, VIETNAM.

The case study region and model setup

Vietnam is exposed to different types of floods such as fluvial, pluvial, coastal, and flash floods, and, over the last four decades, the overall flood risk has increased in urban areas due to increases in exposure, i.e., population growth, economic development, and expansion of buildings in flood-prone areas[4]. Indeed, Hanoi, Vietnam's second most populous city and built in the Red River Delta, has experienced several fluvial flood events over the last 50 years, causing severe socio-economic damage[5].

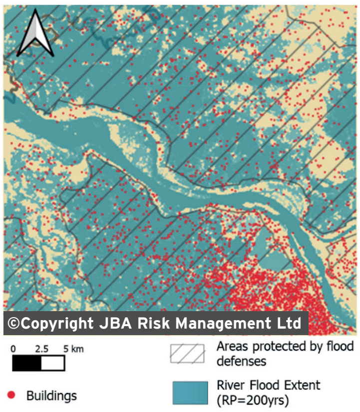

Figure 1: Map of part of the metropolitan area of Hanoi showing the exposed buildings, river flood extent, and flood defences.

For this case study, we used JBA's catastrophe model to quantify the river flood-driven risk in Hanoi in a future climate change scenario, and for different levels of flood defence protection and building resilience. We achieved this by modifying different inputs of the catastrophe model, building a sensitivity analysis as follows:

- **Event set**. To consider the impact of climate change, we created a climate-conditioned event set (a catalogue of plausible observed and simulated flood events) using an intermediate emissions scenario (RCP4.5) for 2050, which was compared against a present day (baseline) event set.
- **Standard of protection**. To consider the impact of future possible investments in flood defences, we considered three options for the standard of protection: unchanged from present-day baseline, increased, and decreased. These respectively represent three scenarios

[4] Understanding and assessing flood risk in Vietnam: Current status, persisting gaps, and future directions, Minh Tu Nguyen et al., Journal of Flood Risk Management, January 2021

[5] An optimal scenario for the emergency solution to protect Hanoi Capital from the Red River floodwater using Van Coc Lake, Hong Anh Sai et al., Journal of Flood Risk Management, September 2020

where the government maintains the status quo, invests heavily in flood defences, or allows the defences to deteriorate.

- **Resilience**. We increased and decreased the damage ratios in the model's vulnerability functions to represent both a scenario where building resilience is improved, and thus damage ratios are reduced, and a scenario where resilience deteriorates due to a lack of investment, meaning damage ratios are increased.

River flood risk is quantified in terms of the average annual loss (AAL), i.e., the expected loss per year (in US dollars) as estimated over a long (multiple thousand-year) time frame.

What can we learn from a sensitivity analysis?

Sensitivity analysis enables decision makers to explore how different combinations of inputs can lead to desirable, or undesirable, risk levels. One way to use sensitivity analysis is to specify an acceptable or unacceptable range for risk (e.g., AAL) and explore the combinations of input uncertainties that lead to each case.

Figures 2, 3 and 4 illustrate this visually through parallel coordinate plots. These plots consist of parallel vertical axes crisscrossed by lines running left to right. The first three vertical axes respectively represent the climate change, defence standard of protection, and building resilience inputs, with the different values they can take indicated on the axes. The right-hand vertical axis shows the risk estimates, as AAL in millions of US dollars. Each crisscrossing line represents one simulation of the catastrophe model, which uses a particular combination of the three inputs, specified on the three left-hand vertical axes, and arrives at the AAL value on the right-hand axis. Each figure shows the same set of simulations (grey lines) but with different simulation runs highlighted (magenta).

Figure 2 highlights the risks when the climate is fixed under baseline conditions, showing the AAL values for the various adaptation scenarios. Here, the resulting AAL estimates range from USD3M to nearly USD10M, across the full range of combined standard of protection and building resilience levels.

Now, imagine that a decision maker wants their future climate risk to remain within this baseline range – that is, not exceed USD10M. They can then interrogate the parallel coordinate plot again, as shown in Figure 3, this time highlighting the simulations corresponding to an AAL below USD10M. With the assumptions made in this experiment, Figure 3 shows that the only

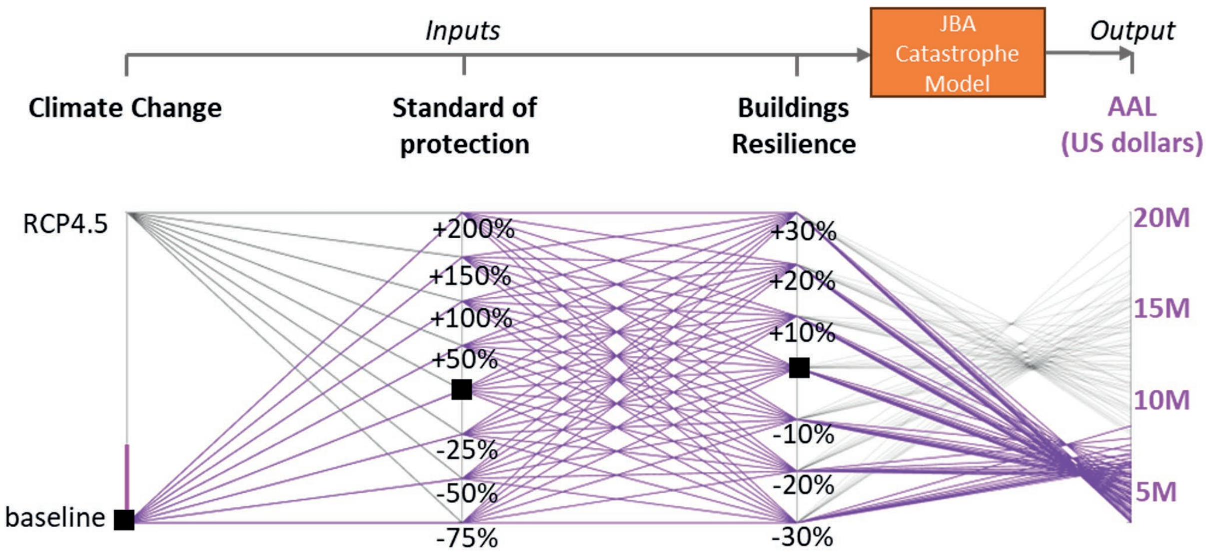

Figure 2: A parallel coordinates plot highlighting (in purple) the resulting risk (AAL estimates) under the baseline event set for different combinations of catastrophe model inputs. The black boxes on the first three axes indicate baseline values for the inputs.

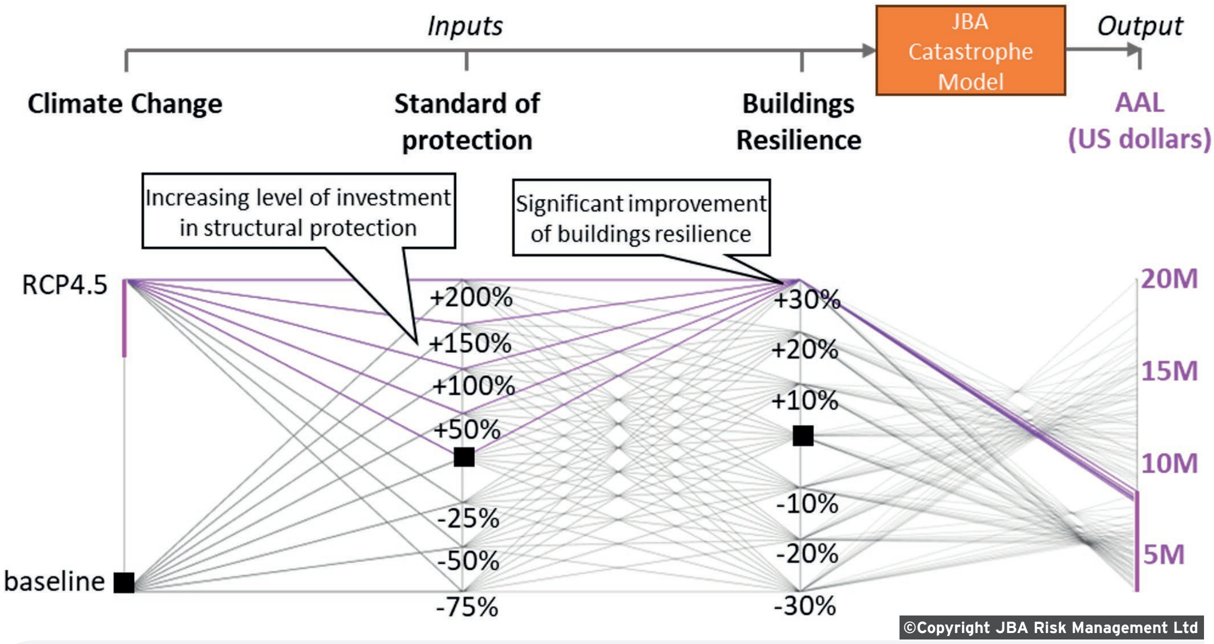

Figure 3: As Figure 2 but highlighting the combination of adaptation strategies required under a 2050 RCP4.5 climate that lead to the same range of possible AAL values under baseline (i.e., as in Figure 2).

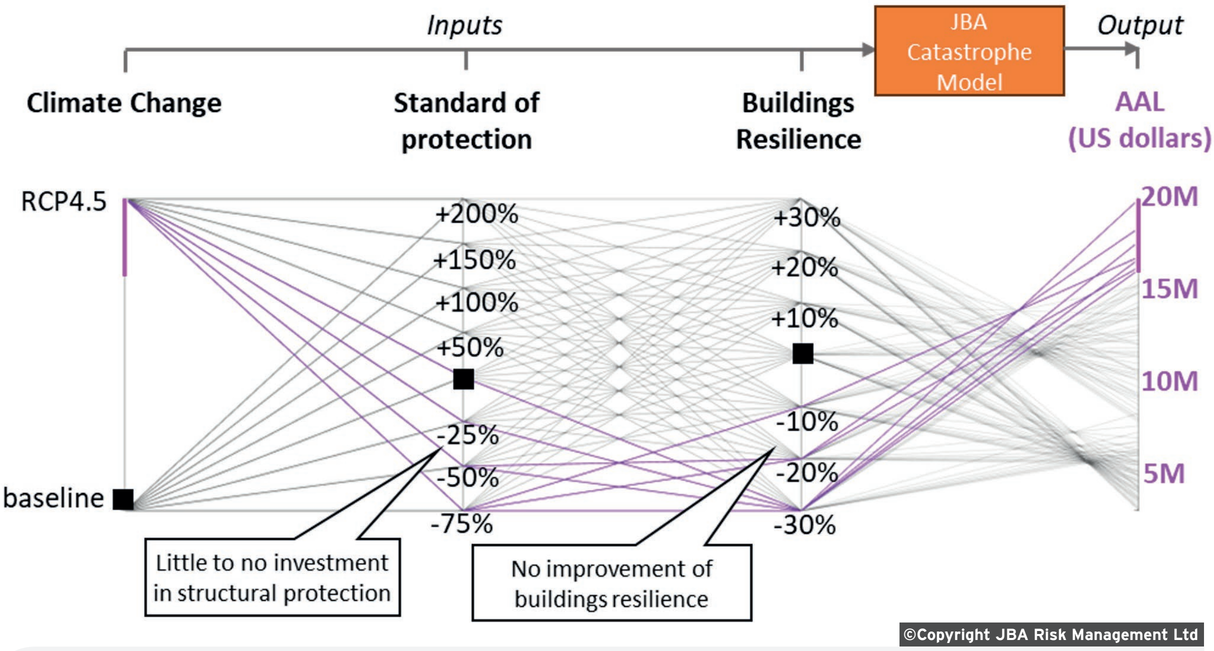

Figure 4: As Figure 2 but highlighting the combination of adaptation scenarios that lead to an unacceptable (>95th percentile) level of risk.

possible ways to keep the AAL within that range are to maintain and/or increase the standard of protection while increasing the building resilience by 30%.

With the same logic as in Figure 3, they can also explore which combinations of inputs lead to an unacceptable level of risk, for example above the 95th percentile of the loss distribution. Figure 4 highlights that this "unacceptable risk" is possible under a future climate RCP4.5 scenario if little to no investment is made in standard of protection or building resilience.

Finally, we can use the sensitivity analysis to quantify the relative contribution of each of the model inputs to the AAL estimates, using sensitivity indices. Figure 5 shows the sensitivity index for the three inputs explored here, indicating that climate change (as the climate change-conditioned event set) is the dominant factor in driving the AALs, followed by buildings resilience, and then the standard of protection of the flood defences. For this study, we can interpret this result as meaning that mitigation of climate change would have the largest impact on reducing future losses. If that was not possible, there is a slight benefit in investing a limited resource into improving building resilience over flood defence standard of protection.

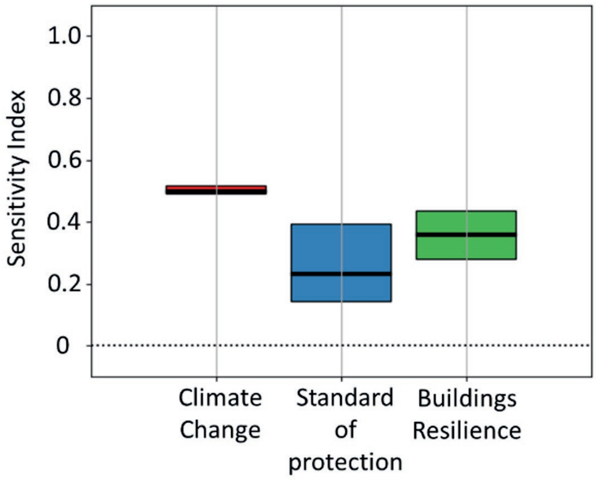

Figure 5: Sensitivity index boxplots for the three different scenarios. Sensitivity indices typically vary from 0 to 1 and the higher the value of the sensitivity index, the higher its relative contribution to the risk estimates. Sensitivity indices were calculated using the PAWN method[6]. The calculation of sensitivity indices was repeated several times using random resamples of the original dataset, creating a statistical distribution of the sensitivity indices.

[6] Distribution-based sensitivity analysis from a generic input-output sample, Francesca Pianosi and Thorsten Wagener, Environmental Modelling & Software, October 2018

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SUMMARY AND CONCLUSIONS.

Climate change is exacerbating the impact of natural catastrophes, and unless public and private sectors rise to the challenge, the gap between insured and total economic losses will continue to grow. PPPs provide an efficient mechanism to close the protection gap, if they are well-targeted, involve all stakeholders, and where all parties and partners can align interests and benefit from mutual contributions.

While there are many examples of successful PPPs, their formation may be hindered by incomplete knowledge of the risks and by a lack of tools to explore different resilience and adaptation options. Here, we proposed using a catastrophe model as a tool to explore possible futures. Using a case study of fluvial flooding in Hanoi, we showed that bolstering catastrophe models with sensitivity analysis functionality can be a powerful tool for decision makers to explore risk outcomes from different resilience and adaptation scenarios. Such tools facilitate a storytelling approach, where the outcomes from these different plausible futures can be investigated through combinations of different catastrophe model inputs, which can then be further used to quantify trade-offs and inform decision making and policy.

Sensitivity analysis is also a powerful tool to explore scientific uncertainties in catastrophe modelling, such as those arising from uncertain or incomplete input datasets, incomplete scientific understanding of processes, and necessary assumptions and simplifications to make the modelling tractable[7]. Used this way, it can inform users about the confidence in outputs while guiding developers to where effort is best spent improving the model.

[7] Uncertainty quantification and attribution in flood risk modelling, Georgios Sarailidis, June 2023

ABOUT.

JBA is the global leader in flood risk science. Our flood maps, catastrophe models and analytics are used by some of the world's largest insurers, reinsurers, financial institutions, property companies and governments. We're part of one of the biggest and best global flood consultancies, employing over 500 experts who work with clients around the world. Our team is a collaboration of scientists who use their expertise to help keep us at the forefront of technical innovation.

Gallagher Re's Public Sector & Climate Resilience Solutions global practice is supporting governments and public institutions to expand the range of available sovereign disaster risk financing tools. A key focus also lies on scaling up market-based solutions through an optimal risk-layered approach that ensures timely and predictable access to funds, ultimately improving the resilience of households, businesses, and the country. We have extensive experience in climate risk assessment and stress testing, enabling clients to navigate through the data and modeling environment. Leveraging climate stress outputs can help identify opportunities for climate adaptation finance and support well-informed decision-making and risk financing strategy development for a broader client base.

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