

General authors' response

We thank the editor and referees for attention and a speedy review process. We read all the comments and carefully revised the manuscript observing the following points:

1. Proofreading grammar and editing.
2. Improving the quality of the figures, tables and captions according to the comments.
3. Improving the discussion of the literature review making sure to deepen the discussion on index selection, loss modeling and risk pricing considering strengths and weaknesses of each method that reflect policy implementation.
4. We clarified the link of crop insurance with hydrologic and sustainable energy insurance. These categories are connected to a broader definition of food security that includes food production, transportation, storage and distribution.
5. We edit the manuscript to make the conceptual framework and the illustrative example (former study case, see answer 1.11 for more details) more clear.
6. The conceptual framework was improved. We modified Figure XX and created a flowchart to demonstrate in a clear way how the readers can use our concept to both design their own index-insurance and interpret the design choices made by other papers. We provided examples from the literature review and a description of each element of the framework, which makes it much more usable.
7. The illustrative example was rendered to be more consistent with the main research problem, which is multi-hazard risk insurance design. Other points that we suggested in the framework, but did not explore in the illustrative example were placed as suggestions for future research. The results were aligned with the research questions and provided insights for future research.
8. Finally we made sure to answer point-by-point all the questions, comments and suggestions made by the referees in the text below.

Response to Referee # 1

General comments

The revised article 'Review article: Design and Evaluation of Weather Index Insurance for Multi-Hazard Resilience and Food Insecurity' still needs improvement. The authors did a lot of work, especially with the case study, but the presentation is still a problem. A basic issue is grammar. There are still many mistakes, grammar issues, incomplete sentences, confusing meanings, wrong figure legends, wrong numbering when citing a figure. The article requires actual professional editing to improve both language and readability. Overall, the result does not reflect the work that has been done.

Response 1.1: Thank you so much for taking your time to read our manuscript and giving us valuable feedback. We corrected the editing mistakes, completed all the sentences, corrected all the figure legends and proofread all the sentences indicated by you as well as other sentences we found necessary. Regarding the editing, we made sure to meet all the requirements and carefully reviewed all the issues you mentioned.

Specific comments

In Methods: 2.2 Case study methodology: includes findings/results that are not appropriate for the methodology section. These should be included in Results. Specifically, as each step obviously builds on the results of the previous one, the authors describe the findings of the previous methodological step to support the next. Or, they rely on the results from the next section 3. This is not appropriate for the Methodology section. It creates confusion in the flow of reading and understanding the methodological steps.

Response 1.2: Thank you for your comment. We've included the steps of the illustrative example (instead of case study) in the results and we adapted the text accordingly. We also improved the text to give more clarity to the conceptual framework and the illustrative example. Regarding our decision to change the name from 'case study' to 'illustrative example', please, check the Response 1.11.

In Results: The results around the case study are not very clear. I could not follow the methodological steps easily. I had to turn back many times to the Methods section. For example, the 2 models should also be explained in the results, to follow the predictors of each one better. Otherwise, the reader must go back to methods to remember which predictors were included in each model. Then, in Discussion (L497), the M1 and M2 models ('M1 for drought and excessive temperature and M2 for heavy rainfall') are not as described in Methods (L159-160: (i) M1: using SPI and TX90p as inputs; and (ii) M2: using SPI, TX090p, and pmax as inputs).

Response 1.3:

We are sorry for that. We named the models in a much more verbose fashion describing each of them in the text and in the figure captions.

Technical comments

Abstract

L6-7, grammar

Response 1..4: Thank you for your comment. We adapted the text as it follows:

"We searched for original research papers in the Scopus database using the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) protocol."

Intro

'Re' for Swiss Re citations and references seem awkward. The entire name Swiss Re should be used.

Response 1.5: Thank you for your commentary and we adapted the text accordingly

The use of /hab for per capita is awkward. Personally I have not seen this before. Please use per cap

Response 1.6: Thank you for your commentary and we adapted the text accordingly

Method

L99: the second step?? Not again the first. Screening looks as the second step in Fig.1

Response 1.7: Thank you for your commentary and we adapted the text accordingly

L125: please correct 'as a reducer of solely the economic sphere of a issue that permeates social, politic and environmental dimensions, this is ultimately a practical approach of widespread use'

Response 1.8: Thank you for your comment. We corrected the sentence as it follows:

Even though this traditional definition has been questioned as a reducer of solely the economic sphere of an issue that permeates social, politic and environmental dimensions, this is ultimately a practical approach of widespread use

L129: Nations? Do you refer to UN? Please correct.

Response 1.9: Thank you for your commentary and we adapted accordingly

Figure 1. corrections are required (eg identified instead of dentified). There is no numbering of the 4 steps in the image. Consequently, in the text below (L135), the reader cannot understand which are the 'steps 2-4'.

Response 1.10: Thank you for your commentary. We adapted Figure 1 including the numbering and then we adapted it to the text.

Correct as Case study instead of study case

Response 1.11: After carefully analyzing the commentaries from the reviewers and the opinion of the co-authors we decided to change the name of this section as "Illustrative example". We understand that the term "case study" implies a more indepth treatment of the methods and results, such as what is found in Chang et al (2019) and Sursur et al (2019). Our idea was to provide an illustrative example to demonstrate how the design of multi-hazard index insurance could be done according to our conceptual framework as it was provided in section 2.4 in Arosio et al (2020). However, instead of using a hypothetical example, we used observed climate and crop yield data.

References:

Chang, Y., Hou, K., Wu, Y., Li, X., & Zhang, J. (2019). A conceptual framework for establishing the index system of ecological environment evaluation—A case study of the upper Hanjiang River, China. *Ecological indicators*, 107, 105568.

Susur, E., Hidalgo, A., & Chiaroni, D. (2019). The emergence of regional industrial ecosystem niches: A conceptual framework and a case study. *Journal of cleaner production*, 208, 1642-1657.

Arosio, M., Martina, M. L., & Figueiredo, R. (2020). The whole is greater than the sum of its parts: a holistic graph-based assessment approach for natural hazard risk of complex systems. *Natural Hazards and Earth System Sciences*, 20(2), 521-547.

L166-169: please correct and complete the phrases

Response 1.11:

Thank you for your comment we corrected the sentence accordingly as follows:
“The expectation of loss $E[\text{Loss}]$ was determined using the generation of 50 synthetic scenarios of weather data. The synthetic weather data was simulated using a multi-site multi-variable (daily precipitation and temperature) weather generator method. The method applies a wavelet-based algorithm for multiple sites and requires and was applied using the R-package PRSim”

Table 2: the correct name for the 3rd topic is ‘Sustainable energy’.

Response 1.12:

Thank you for your comment. We corrected this in the text and Table 2 accordingly.

L299-301: the phrase : ‘Temperature variation....hazard’ is mentioned 3 times..

Response 1.13: Thank you for your commentary. We edited the text "Other types of hazards encompass temperature variation, fire, storm, wind, and cloud hazard issues. These represented 12% of the reviewed studies, and the temperature variation is half of that."

L310: chose forest fires or wildfires

Response 1.14: Thank you for your commentary. We choose to use the term wildfires after carefully reading the text of Hardy (2006).

Reference

Hardy, C. C. (2005). Wildland fire hazard and risk: Problems, definitions, and context. *Forest ecology and management*, 211(1-2), 73-82.

L358: needs correction. Mean loss is not the method but the parameter used

Response 1.15:

Thank you for your comment, we corrected this point in the text:

“The loss expectation can be determined using the historical burn rate method (HBR), which is based on the observation of historical losses“

L366-367: needs grammar correction

Response 1.16:

Thank you for your comment, we corrected this sentence in the text:

“The transformation method proposed by Wang (2002), also referred as Wang Transform, takes into consideration the impact of nontraded assets in premium rates and the method was applied by Boyle et al. (2021) and Denaro et al. (2018).”

L406: not Figure 6

Response 1.17:

We are very sorry for that, we corrected all the captions and figures in the text.

L414, evaluated

Response 1.18: Thank you for your commentary and we adapted the text accordingly

The legend of Figure 6 must be wrong.

Response 1.19: Thank you for your comment, we made significant changes in the figures and made sure to proofread to our best knowledge.

L441: (v) I assume that spi exhibited the highest, not the lowest, number of occurrences.

Response 1.20: Thank you for your comment. We carefully examined the figure and the text and decided to remove this part in order to deliver a clearer message. We believe that the illustrative example is much more clear and easy to follow now.

L444: this increase is not clear, perhaps it should not be mentioned

Response 1.21: Thank you for your comment. We carefully examined the illustrative example and decided to remove this part as well, since we did not intend to analyze trends. Our focus was to analyze multi-hazard events and we think we made it very clear in the illustrative example after adopting all the suggestions and comments from the referees.

L500, the phrase 'The study case we presented helped to assess the and model the impact of different multi-hazard risks.' is incomplete.

Response 1.22: Thank you for your comment, we corrected this phrase:

"The study case conducted in this subsection illustrates one possible application of the framework, considering several analyses and visualizations that a stakeholder could use to better understand the impacts of extreme weather events over time on agricultural productivity, considering both the historical values and the crop loss probability."

Response to Referee #3

The article proposes a literature review of multi-hazard weather-index insurance for agriculture, specifically for crops. The paper would like to identify which indices are used to assess and monitor extreme weather events, what functions and methods are used to determine the vulnerability of food production to multihazard events and how to compute risk premiums. The authors applied the PRISMA protocol to identify 34 studies on the selected topic. In addition, they propose a conceptual framework to solve the problem of multi-hazard risk and minimizing the premiums (lines 404-406). The conceptual framework is applied to the production of soybean in Brazil.

Response 3.1: Thank you for taking the time to review our manuscript. Your suggestions and commentaries were carefully considered and discussed among the co-authors.

The topic of multi-hazard index insurance deserves for sure further attention, as underlined by the authors, thus a review of studies addressing multi-hazard parametric insurance for crops is a valuable contribution for the scientific community. However, my feeling is that the paper in its current form is a little bit confusing for the reader.

Response 3.2: Thank you for your comment. We took into consideration all the comments from Reviewer #1 and Reviewer #3 in order to make sure to improve the readability of the

manuscript, correct editing and grammar mistakes and present the results in a clear and concise manner.

First of all, the authors state in the abstract and in the introduction that their “primary focus is considering a multi-hazard approach and selecting studies in food security” (line 5) and they would like to answer the question “What functions and methods are used to assess the vulnerability of food production to extreme weather events?” (lines 74-75). However, inside the paper there are continuous reminder to insurance for renewable energy production and hydrological risk and it is not clear if the two aspects are related with food security or not. If this is the case, the authors should explain the connection better.

Response 3.3: Thank you for making this point. In fact, we clarified the definition of food security we are using in the text:

“Food security ‘exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life. Household food security is the application of this concept to the family level, with individuals within households as the focus of concern.’”

This means that the concept is rooted in the pillars of availability, access and utilization. From this perspective we connect the importance of linking the insurance for food production (agricultural) to other types of insurance that contribute to access to energy (sustainable energy) and water (hydrological) that are important for storage, transportation and hygiene of food.

Secondly, the paper seems to be divided into two distinct parts: a first one dealing with the literature review and a second one explaining the conceptual framework used to solve the problem of multi-hazard risk and minimizing the premiums. Proposing a conceptual framework and applying it to a specific case study inside a literature review article sounds strange since usually a literature review explores the studies on a specific topic and provides information on gaps, shortcomings and future research areas for that specific topic. In addition, both the parts, the literature review and the proposed conceptual framework, are not deepened enough.

Response 3.4:

Thank you for your comment. We carefully reviewed the manuscript so we could improve the discussion of the literature review while making a stronger connection between these two parts. As we further explain in the next answers, we tried to make sure to demonstrate and prove the importance of the manuscript having these two parts to the readers.

In the sections 3.2.1, 3.2.2 and 3.2.3 (Hazard assessment, vulnerability analysis and financial methods and risk pricing) the discussion is too simple. In section 3.2.1 I would have expected a discussion on the advantages and disadvantages of the application of the described indices in parametric insurance and an insight on the indices adopted for multi-hazard risk assessment.

Response 3.5: We are deeply sorry that we had not addressed the discussion properly. This is an important point, and we are thankful for your comment. We have included a discussion about the advantages and disadvantages of the application of the rainfall-based, remote

sensing, and more complex indices in the index insurance. Furthermore, we improve the discussion about the multi-hazard interaction.

In section 3.2.2 there is no discussion on the pros and cons of the described methodologies used to determine crop vulnerability to multi-hazard events.

Response 3.6: Thank you for your comment. We carefully reviewed

Finally, in section 3.2.3 again a discussion on the strengths and weaknesses of the methods proposed in the literature to determine fair premiums is lacking. Therefore, I suggest to improve the sections.

Response 3.7:

Thank you again for your comment. We added the following paragraphs to discuss strengths and weaknesses of the methods as follows:

“It is worth mentioning that either the method employed to estimate fair premium values, and to tackle future risk increase due to climate change (CC) scenarios, the insurance market should consider some of the following points in order to reduce their weaknesses or uncertainty sources. First, as mentioned before to calculate the premium value, it converges in a multi-objective problem, then, the premium should be variable within the contract depending on if it is long-term (Aerts et al., 2011). The insured could contract a long-term insurance policy with an established premium, however, due to the CC uncertainty some extreme events could not happen, and the insured paid too much for unnecessary coverage, resulting in more profit for the insurer. Nevertheless, the opposite case could happen where the insured pay less and extreme events happens, and the insurer does not have liquidity to pay losses; Second, a layered insurance scheme including private and public sectors (PP) (Keskitalo et al., 2014, Paudel et al., 2015) to cope with extreme losses. This means that when a certain threshold of loss is reached, the difference of the indemnities will be paid by a second partner, although, the definition of that threshold is another gap in literature, similarly with the strike value K .

Third, according to the spatial scale, a scheme of pool risk is preferable to substantially reduce premium values which requires cooperation among the stakeholders, however, the main issue is to reach full diversification of the portfolio (Porth et al., 2016); Fourth, induce risk reduction proposals in order to increase resilience and promote adaptation within the sector. The latter could be reached through financial incentives such as premium discounts offered to stakeholders when they adopt some mitigation measure, as shown in Hudson et al. (2016). Finally, for a multi-hazard scheme, the above-mentioned schemes should be calculated for each hazard. Nonetheless, premiums values will be different, and a weighted procedure will be required, such as done with the hazard frequency by Salgueiro (2019) and Guo et al. (2019) and mentioned in section 3.2.2.”

Basis risk, which is a crucial point for the effectiveness of index-based insurance is often mentioned, but details on the basis risk of the insurance programs designed in the reviewed studies are not proposed to the reader. This point should be better investigated by the

authors, including in the text some considerations on basis risk proposed in the reviewed studies.

Response 3.8:

Thank you for your comment. We considered this point in the following paragraphs:

“The cluster model demonstrated that historic crop losses were divided into three groups, the first was precipitation deficit dominated, the second was precipitation deficit and high temperatures, and the third was excessive rainfall and high temperatures. Two different loss prediction models were trained with historic data separated according to the cluster analysis. This example suggests that the problem of mismatch between actual losses and losses predicted from the index insurance contract, also called basis risk, does not depend only on having enough data, but also on analyzing the right data for right the hazard or multi-hazard selection. Future work must explore this effect and compare with actual yield.

Our paper demonstrates that, despite index insurance for food security has gained attention in the past years, there is still weaknesses and limitations that must be addressed in future work, e.g, a clear definition and analysis of multiple hazards instead of assuming single hazard risk; Testing different hypotheses of the interaction between hazards, specially for coupled moisture-thermal events; evaluating how the multi-hazard risk selection affects basis risk; analyzing the trade-offs between loss model accuracy and the policyholders willingness to pay.”

Finally, in the conclusion section I would expect to find the answers to the three questions raised in the introduction: 1) What indices are used to assess and monitor extreme weather events? 2) What functions and methods are used to assess the vulnerability of food production to extreme weather events? 3) How to determine risk premiums? Instead, the first part of the conclusions underlines the lack of studies on index insurance tailored to Latin America, while the second part describes the results obtained by applying the conceptual framework to the case study area. I recommend the authors to include in the conclusions the answers to the three research questions they raised in the introduction.

Response 3.9:

Thank you for your comment. After carefully examining the suggestions and comments made by Reviewer #1 and Reviewer #3 We revised and rewrote the conclusion section making sure to answer the research questions.

As a final comment, I suggest to carefully consider if the conceptual framework and the case study should remain a part of the literature review or become a separate article. In fact, the description of the conceptual framework is very simple and does not allow the reader to understand properly what the author did and the results they obtained. A work fully dedicated to it would allow readers to properly appreciate the work done by the authors understanding all the necessary details.

Response 3.10:

Thank you for your comment. We carefully considered your suggestion and we understand that we need to improve the description of our framework as well as the result and discussion of the systematic review. We adapted section 3.3 and changed the name from

"Conceptual framework and study case" to "Conceptual framework and illustrative example". The justification for this change was given in response 1.11. We decided to keep our manuscript with this format and make all the corrections and editing requested by the reviewers accordingly. We believe that the paper benefits from a conceptual framework since the topic 'weather index insurance and food security' is emerging and requires systematization. We have found in the literature a great variability in terms of how the design process is done and interpreted, therefore, a conceptual framework should contribute to future research in the field. We believe that, after carefully reviewing the manuscript according to your commentaries, we made sure to clarify this in the text.