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Measuring climate change from an actuarial perspective: a survey of insurance applications

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Abstract

Climate change refers to persistent alterations to global Earth's climate, such as a rise in global temperatures, reaching unprecedented peaks in recent years. At the same time, global mean sea levels are on an upward trajectory, with a rate of increase that has accelerated in recent years. These climatic shifts significantly influence the frequency, intensity, and duration of extreme weather events, such as heatwaves, heavy precipitations, droughts, floods, and tropical cyclones, that represent substantial risks and challenges for the insurance industry. This paper delves into the profound impact of climate change on the insurance sector, with a particular focus on the agriculture, property, health, and life insurance industries.

Our scientific approach consists in measuring climate change through an index composed of a basket of climate and weather-related extremes, such as the Actuarial Climate Index™ (ACI) in North America and its European counterparts, the Iberian (IACI) and French (FACI) climate indexes. We discuss how these indexes help quantify the impact of climate change on the balance sheets of insurance companies and, therefore, its impact on the sustainability of the insurance business. The paper underscores the pressing need for the insurance industry to adapt and strategically plan for the increasing risks associated with climate change.

1. Introduction

According to (UN, 2023), climate change refers to long-term changes in temperature, precipitation patterns, sea levels, and other aspects of Earth's system. Changes in climate can occur naturally due to phenomena such as volcanism or solar activity. However, since the early 19th century, the addition of human activities involving the combustion of fossil fuels, which releases greenhouse gases, have contributed to the warming of the globe at a pace unprecedented in at least the last two thousand years. Since the 1980s, every decade has been warmer than the previous one. According to the Intergovernmental Panel on Climate Change (IPCC, 2023b), 2011–2020 was the warmest decade on record. The observed global surface temperature¹ from 2011 to 2020 was 1.1 degrees Celsius higher than the average in the last half of the 19th century. The global surface temperature has increased faster since 1970 than in any other 50-year period over at least the last 2,000 years. Moreover, the World Meteorological Organization (see WMO, 2024) has confirmed that 2023 has been the warmest year on record by a huge margin, and the global average annual temperature² is nearly 1.45 degrees Celsius above pre-industrial levels.

The emission of greenhouse gases plays a pivotal role in influencing and exacerbating extreme climatic events, such as heatwaves, intense precipitations,

¹ In earth science, global surface temperature (GST; sometimes referred to as global mean surface temperature, GMST, or global average surface temperature) is calculated by averaging the temperatures over sea (sea surface temperature) and land (surface air temperature).

² To calculate the global mean annual temperature average, scientists collect temperature data from various locations around the world, including land and ocean surfaces. They then compute the average temperature for each year, providing an indication of the Earth's overall temperature for that particular time frame. This metric is essential to understand climate patterns, detect climate change trends, and assess the impact of various factors on the planet's temperature.

droughts, and tropical cyclones. The warming trend accelerates a heightened frequency, intensity, and duration of heat waves across most terrestrial regions since the 1950s, whereas cold extremes have witnessed a decline in both frequency and severity. Furthermore, certain regions have experienced an escalation in the frequency and intensity of droughts. The occurrence and severity of heavy precipitation events show a discernible increase since the 1950s, over a substantial portion of terrestrial areas. There has been a global uptrend in the occurrence of major tropical cyclones over the past four decades, and marine heatwaves have experienced an approximately twofold increase in frequency. These findings underscore the profound influence of anthropogenic activities on the evolving dynamics of extreme climatic events, as explained in (IPCC,2019; IPCC, 2023a,b).

Climate change presents substantial challenges for human societies, endangering food, and water security, impacting human health, and threatening transportation infrastructures (Dundon et al., 2016) as well as properties (Warren-Myers et al., 2018; Miljkovic et al. 2018). This shift in the environment triggers widespread adverse effects on the economy and society (Pryor, 2017). It is anticipated that the consequences of this environmental transformation will be far-reaching and profound, particularly affecting critical sectors such as agriculture, property, health and life sectors within the insurance industry.

Climate change has the potential to negatively impact the sustainability of insurance in several ways. Firstly, the rise in total losses may necessitate expensive increases in premiums and solvency capital. While the quantitative evaluation of this point is yet to be fully explored (as discussed later in this paper), it becomes more obvious that both past and future costs are a serious menace. Regarding the former, according to (Munich Re, 2024), the losses caused by natural disasters in the year 2023 reached US\$ 250 bn, of which only US\$ 95 bn were insured. Although no mega-disasters such as Hurricane Ian³ occurred in the previous year, a large proportion of the losses in 2023 were associated with several severe storms in the US and Europe. These events are related and can be considered as evidence of the global warming tendency, with important consequences for the insurance business in general, and property insurance in particular (Gupta and Venkataraman, 2024; The Geneva Association, 2021). We can illustrate future expected losses for this last branch of insurance, where (Swiss Re, 2021) forecasts that the rise in the frequency and severity of events due to climate change will add 30%-63% to insured catastrophe losses in advanced markets by 2040. The rise could reach 90%-120% in key markets such as China, the UK, France and Germany.

Secondly, fundamental principles of insurance theory and practice, such as risk insurability, pooling, diversification, and risk transfer, might come into question, a crucial aspect that is still being discussed in the literature. The outcome could have profound implications for the foundations, or even the survival of the insurance industry in this evolving environment, as explained by (Charpentier, 2008; Thistlethwaite and Wood, 2018; Courbage and Golnaraghi, 2022). Despite these concerns, some more optimistic perspectives suggest that the insurance business may not be a victim of climate change

³ See https://en.wikipedia.org/wiki/Hurricane_Ian

but rather a remedy, proposing the development of new technical solutions as highlighted by (Rao and Li, 2023; Savitz and Dan Gavriletea, 2019; Wagner, 2022).

Meanwhile, climate change has already begun to impact the survival of certain markets, as evidenced by recent strategic moves in the USA, see (California, 2023). As a result, quantifying the impact of past and future climate change on both theoretical and practical insurance fundamentals has become an urgent task for all those involved in insurance risk assessment, management, and sustainability.

In this paper, our objective is to present an actuarial perspective on the study of climate change's impact on the insurance industry and its study in scientific publications. We explore more specifically some key insurance sectors, namely property, health and life, and agricultural insurance.

Subsequently, we introduce and rationalize the need for a standardized method of measuring climate change. This is crucial for comparing various locations worldwide and applying it consistently across diverse insurance sectors, thereby standardizing the analysis. A significant conclusion drawn from this exploration is the necessity of establishing an actuarial climate index to quantify climate change consistently.

We examine recent scientific literature to assess progress towards creating such an actuarial climate index. Additionally, we address the central issue of how to quantify the impact of climate change on essential insurance variables, like total losses, premiums, and risk measures that determine solvency capital. This would allow us to correlate these variables with the climate change proxy provided by an index, leading to valuable insights for insurance risk assessment and management.

2. Impact of climate change in property insurance

(Moody's, 2018) highlights the negative impact of climate change in the property and casualty (P&C) insurance sector: the losses could be far beyond the model predictions, due to the difficulties of forecasting catastrophic losses and to the high correlation of climate-exposed risks. Research about modeling and quantifying these climate risks becomes crucial to help the insurance industry mitigate the present and future economic and social impacts of climate change.

The risks of floods, droughts, hurricanes, typhoons, tornados, hail, natural wildfires, landslides, storms, and sea level rise are usually cited among the most important climate-related risks affecting property insurance. These risks are not independent: for instance, hurricanes, typhoons and big storms often provoke severe floods and landslides. Globally, **floods** are the most destructive natural disasters (Michel-Kerjan, 2010) and there is evidence that the last decades constitute an exceptional "flood-rich period" in Europe (Blöschl et al., 2020). Consequently, flood insurance has been, by far, the most studied topic in the literature. (Lin et al., 2023) have performed a bibliometric analysis of the research hotspots related to climate risk insurance. The authors have divided the period between 1975 and 2022 into three parts, the *start-up phase* 1975–2007, the *development phase* 2008–2014 and the *boom phase* 2015–2022. According to them, most research papers in the first two phases were devoted to the study of different aspects of flood insurance, and only in the last phase there has been a growing interest in other types of risks. (Lucas et al., 2021) have carried out a systematic

review of the literature focused on the particular case of home insurance, reaching similar conclusions about the overall importance of flood insurance.

Although there is extensive research about flood risk, the contribution of the actuarial specialists has been relatively small. There are several reasons for this lack of interest, related to the special characteristics of this kind of risk, very different from the risks that actuaries are used to working with (Prettenhaler et al., 2017). For instance, the difficulty of correctly estimating low-frequency, high-impact risks gives rise to asymmetries of information between the insurers and the policyholders that can cause serious moral hazard and adverse selection problems in the portfolio of policies. Also, it is common to find a high degree of correlation between the damages, because the floods can affect large geographic areas. Besides, flood insurance premiums are often not risk-based, because they are subsidized or subject to other forms of state intervention (for descriptions of flood insurance systems in the US and some European countries, see (Paudel, 2012; Michel-Kerjan, 2010; Shively, 2017; Surminski and Eldridge, 2017). All these features could make less interesting the implementation of actuarial methods. Nevertheless, in the last years there has been an increased interest in the application of the actuarial techniques to flood insurance problems.

(Furman et al., 2019) sketch the standard methodology for modeling and pricing this kind of risk. The main components to consider are the *Flood Hazard* (frequency of occurrence of floods), the *Flood Risk Exposure* (valuation of the properties and infrastructures exposed to the risk) and the *Vulnerability* (susceptibility to the flood intensity). Historical discharge data or, when these are not available, rainfall data, together with topographical information, allow the analysts to build the hydrographical models for predicting the frequency and intensity of the floods. The vulnerability is usually quantified by means of the so-called *depth-damage curves*, describing the relationship between flood depth and asset damage.

Actuarial methods can help improve several aspects of the standard methodology. For example, (Boudreault and Ojeda, 2022) use clustering techniques to define more homogeneous ratemaking territories, increasing the risk differentiation of the policies and reducing adverse selection. (Prettenhaler et al, 2017) apply extreme value theory to model flood risks with heavy-tailed distributions and calculate estimates of the Value at Risk and Expected Shortfall for the total losses of the European countries. (Shen and Yuan, 2022) also apply extreme value theory together with hydrological models to price flood insurance policies. (Kousky et al., 2017) use actuarial principles to evaluate the NFIP (National Flood Insurance Program) rating system. Furthermore, many papers are devoted to the explanation of insurance data related to water flood damages in terms of meteorological, geographic, demographic, and property/building-based variables (see Gradeci et al., 2019) for a review of the literature).

The increasing frequency and severity of floods and other weather hazards in coastal zones is clearly related to the **sea level rise** induced by climate change. More than 10% of the world's population live in low elevation (below 10 m) coastal zones (McGranahan et al., 2007), and most of the world's biggest cities are located in these regions. Despite the great vulnerability of this population (Neumann et al., 2015), a great part of these risks remains uninsured (Evans et al., 2020).

The severe droughts and large periods of high temperatures associated with climate change are one of the main drivers of the increasing incidence of **wildfires**. Countries such as the EU, Canada, Chile, Portugal, Spain, France, and Greece, among others, have recently suffered destructive wildfires that caused huge damages. Although forest insurance is available in many countries, there is a great variability in its penetration rate, which has motivated the research on the determinants of forest insurance demand and the influence of public assistance (Brunette and Couture, 2023). So far, classical actuarial problems related to wildfire insurance have not received much attention, although this can change in the future. Actuaries should pay attention to this risk, given its potential to cause large losses in many sectors of the economy (Sousounis et al., 2021).

The literature on **droughts** and **hailstorms** is mainly concerned with their impact on agriculture and farming. In relation to property insurance, (Heranval et al., 2023) estimate the damages to infrastructures and individual houses in France, caused by ground movements. These damaging horizontal and vertical movements are caused by the clay shrinking and swelling, in response to the changing degree of dryness of the land. The goal of the paper is to estimate the total damage of future drought events. As for hailstorms, (Gao and Shi, 2022) use a spatial point pattern framework to model the frequency and geographical distribution of hail damage claims. (Shi et al., 2024) propose a deep learning method to incorporate dynamic weather information in the predictive modeling of the insured losses for reported claims. Also, (Tzougas et al., 2022; Mobley et al., 2021; Knighton, 2020) apply decision tree methods such as random forests and gradient boosting to the prediction and classification of insurance claims.

3. Impact of climate change on life and health Insurance

Several survey papers study the global impact of some aspect of climate change on mortality and/or morbidity. For example, (D'Ippoliti et al., 2010) defines what constitutes a heat wave and links them mortality data for 9 European cities, while (Song et al., 2017) gives a comprehensive survey of studies on the impact of ambient temperature and (Arsad et al., 2022) looks at heat waves, on both, mortality and morbidity.

In some countries governments have taken measures to mitigate the effect of climate change on their populations (adaptability). For example, after the severe 2003 heat wave France adopted health watch warning systems (Pascal et al., 2006). These are based on prognostic factors that can help prevent heat wave related deaths, see for instance (Bouchama et al., 2007), or (McGeehin and Mirabelli, 2001) for US urban areas data (midwestern cities), (Peng et al., 2011) for Chicago, and (Gasparrini and Armstrong, 2011) study also the effect of the duration of heat waves in 108 communities in the US (see also their *dlnm R* package, Garparrini, 2011, or more recent studies, Garparrini, 2015, 2017), while (Smid et al., 2019) ranks European capital cities with respect to their heat wave risk. More recent studies focus on the seasonal variations in mortality and the role played by temperatures (Madaniyazi, et al, 2021, 2022).

Adaptability to heat waves is a key aspect of the problem as these are bound to occur with increased frequency, see for example (Fouillet et al., 2008) on how France adapted after 2003, or (Zacharias et al., 2015) for occurrence data and the impact on mortality in Germany. Although the way heat waves are evolving is challenging already

the warning systems that were devised just a few years ago (Pascal et al., 2021). Similar studies look at the health care costs of heat waves, see for instance (Adélaïde et al., 2021) for French data or (Alsaïqali et al., 2022) for Belgium. For more on population adaptability and vulnerability, see (IPCC, 2022).

By contrast, several papers propose to use instead some climate index that summarizes and synthesizes the multiple facets of climate change; for example (Di Napoli et al., 2018) uses the Universal Thermal Climate Index (UTCI), and similarly (Nayak et al., 2018) studies the Heat Vulnerability Index for New York state data. In fact, climate scientists use a variety of indexes. For example the National Oceanic and Atmospheric Administration (NOAA) Heat Index (Rothfus et al., 1990) or that of the joint CCI/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI), see (Peterson, 2005).

Here we adopt an actuarial perspective and look at studies that have linked a physical climate risk, as those described above, to the frequency or the financial losses (severity) associated with life insurance (mortality) and health insurance (morbidity) contracts.

For example, (Kim et al., 2016) uses regression to relate the occurrence of heat waves to deaths from heat disorders in Korea. Similarly, (Miljkovic et al., 2018) uses US data to show that climate change related weather events significantly contribute to property damages, which in turn impact on mortality rates. Then, (Crisóstomo Mazaira, 2022) finds strong correlations between excess mortality and the 95-percentile of high temperature records, for most regions of Spain, while (Díaz et al., 2015) looks at the relation between extreme temperatures and mortality in Madrid. Using more modeling, based on advanced extreme value theory, (Li and Tang, 2022) analyzes Joint extremes in temperature and mortality, with a bivariate peaks-over-threshold (POT) approach, to unveil the strongest type of dependence for US data.

One technique that actuaries use commonly to predict future mortality improvements is the so-called Lee-Carter model, see (Lee and Carter, 1992). In a series of papers, the method has been extended to include explanatory terms based on a heat index, see (Seklecka et al., 2017, 2019). These successfully link the physical climate risk, through the index, to the mortality risk predictions.

For additional literature on the impact of climate change on health and life insurance see (Bhattacharya-Craven et al., 2024, and the references therein).

4. Impact of climate change on agricultural insurance

Crop insurance constitutes a very special case within the general panorama of the insurance business because of its extensive variety of lines of business, each dedicated to a specific crop, such as wheat, soybeans, apples, wine grapes, table grapes, greenhouse horticulture, etc., and insurable risks (frost, flood, drought, hailstorm, windstorm, plagues, etc., for a systematic classification, see Marin, 2019). In addition, due to the high importance of agriculture in social and economic terms, many countries subsidize agricultural insurance. A situation that is exceptional within the overall framework of the insurance business. Finally, agricultural insurance mechanisms may fail for various reasons, such as spatially correlated risks, moral hazard, adverse selection, and high administrative costs (see Maestro et al., 2018). Risk assessment and

management are so particular that, in some cases, insurance companies form a coinsurance pool that manages all the technical work in a unified manner for the entire country or region (see, for instance, the Spanish case where Agroseguro pools 17 insurance companies; Agroseguro, 2024). The indemnity mechanism is also rather different, based on the lost plot yield caused by a claim. Furthermore, the technical approach (total loss modeling, premium calculations, etc.) is quite different because it is based on the yearly tracking of the crop yield probability model that must be particularized to individual plots. Natural hazards and general climatic evolution add complexity to this risk modeling process.

Research on agricultural insurance before 2020 is summarized in the survey by (Vyas et al., 2021), where topics related to climate change can also be found. Climate change impact on insurance claims is a growing discipline where advanced methodologies derived from Data Science and machine learning are being applied, as seen in (Lyubchich et al., 2019) and (Crane-Droesch, 2018). Climate change was soon identified as a threat to crops, and discussions ensued about to what extent agricultural insurance mechanisms would be a valid tool for de-risking and adapting farms, as discussed by (Falco et al., 2014; Jørgensen et al., 2020; Simbürger et al., 2022). A negative answer to this question is given by (Wang et al., 2021a; Miao, 2020); both argue that crop insurance can act as a disincentive for climate change adaptation in agriculture. Finally (Wang et al., 2021b) investigate the influence of cover crops⁴ on US insurance losses due to extreme weather events like droughts, floods, and excess heat, using panel data and linear fixed effects econometric models. They find evidence that counties with higher cover crop adoption tend to have lower crop insurance losses due to drought, excess heat, or excess moisture (flood), outlining cover crops as an effective climate change adaptation strategy to attenuate insurance losses in US agriculture.

A classical way of studying the relationship between climate change and insurance losses is to investigate its influence on crop yield distribution. As a rule, there is a recognition that climate change decreases mean crop yields and increases crop yield risk (Wang et al., 2021a). More detailed research is carried out by generating simulated scenarios for some climate variables and estimating their impact on crop yields by fitting parametric yield distributions to assess the potential long-term implications of climate change for crop insurance portfolios. (Beach et al., 2010) applied this kind of analysis to several US crops. (Rodziewicz and Dice, 2020) estimate that US farmers' losses from extreme drought can reach 20 percent of production value for corn and wheat and 35 percent for soybeans. (Tack and Ubilava, 2015) show that the extreme climate event known as El Niño Southern Oscillation (ENSO) alters cotton yield distributions in the Southeastern US, translating into economically meaningful effects on crop insurance premium rates. Different climate change impacts on the lower and upper tails of the crop yield distribution are modeled as heterogeneity and the methodology of mixing distributions (Schuurman and Ker, 2024).

⁴ A cover crop is a type of crop that is planted primarily to manage and improve the soil rather than for harvesting for direct human consumption. Farmers use cover crops to protect and enhance the soil's fertility, structure, and health. These crops are typically grown during periods when the main cash crops are not in the field, such as during the off-season or between planting cycles. Examples of cover crops are legumes like clover and peas, grasses such as rye and barley, and other plants like mustard.

Another important line of research is the investigation of the impact of some climate variables (such as temperature for instance) on insurance losses. (Diffenbaugh et al., 2021) use panel regression with fixed effects to calculate the relationship between temperature, precipitation, and crop indemnities in the US, showing that global warming has already contributed substantially to rising crop insurance losses in the US. The risk of spring frosts for apple orchards in Europe is studied by (Unterberger et al., 2018), whose primary finding is that the overall frost risk for apple growers yields would remain in a warmer climate and potentially even increase.

In (Pfleiderer et al., 2019), temperature is analyzed with regards to apple trees in Germany, applying a scenario analysis that assumes a 2° C warmer world; they conclude that due to early blossom, there might be an increased risk of frost damage as a result of warmer winters. In (Fusco et al., 2018) precipitation and minimum temperatures are shown to be the most influential risk factors for Drought risk in Italy, regarding total premiums and insured values of crop insurance. They find this by applying panel data and pooled ordinary least squares regression, obtaining as a main result an explanation of between 44% and 51% of the variation in the insurance-dependent variables.

In (Diffenbaugh et al., 2021), temperature and precipitation are also taken as independent variables to apply panel regression with fixed effects to calculate their relationship with crop indemnities in the US. They monetize climate change, finding that county-level temperature trends have contributed to 19% of the national-level crop insurance losses over the 1991–2017 period. Also by simulating a large suite of global climatic models, they conclude that anthropogenic climate forcing has increased U.S. crop insurance losses.

Precipitation and minimum and maximum temperatures are used in (Botzen, 2010) to predict hailstorm damage cost to increase if global warming leads to further temperature increase. This is done by estimating Tobit models between normalized insured hailstorm damage to agriculture and several temperature and precipitation indicators for the Netherlands, deducing different effects for the cases of damage costs for greenhouse horticulture or outdoor farming.

In summary, these studies aim to identify the impact of climate change by utilizing statistical methods that correlate meteorological variables such as precipitation or temperatures, with insurance metrics like costs or premiums. Notably, some studies go beyond, seeking to monetize the prospective evolution of climate change within the insurance business. However, the use of one or another meteorological variable as a proxy for climate change is a subject of discussion, as different regions and crops may be influenced by different variables. The use of diverse variables in these studies results in highly heterogeneous conclusions, making it challenging to compare and collectively discuss findings. This is especially true for monetizing climate change in the insurance business within a specific geographical area.

5. Measuring climate change from an actuarial point of view

To address these aforementioned drawbacks, efforts are underway to mitigate them through the development of actuarial climate indexes designed to comprehensively encapsulate all relevant information on climate change within a specific geographical

area. This initiative aims to establish an actuarially significant, more homogeneous, and objective measure of climate change.

Just as the Consumer Price Index (CPI) tracks changes in the cost of a standard basket of goods and services over time, an actuarial climate index aims to measure climate risks through a basket of extreme climate events and changes in sea level. The use of extreme values instead of averages is very important here because extremes have a greater impact on policyholders and their insured goods, as well as on society and the economy.

The first achievement in this line was the Actuaries Climate Index™ (ACI), jointly developed by the Canadian Institute of Actuaries (CIA), the Society of Actuaries (SOA), the Casualty Actuarial Society (CAS), and the American Academy of Actuaries (AAA), from climate data in North America (see ACI, 2018). The ACI consists of six components, warm and cool temperatures, precipitation, drought, wind speed, and sea level. Each one forms a monthly time series starting in 1961, from records of the National Oceanic and Atmospheric Administration (NOAA, see Menne et al., 2012), GHCNDEX1 (CLIMDEX, see Donat et al., 2013), and the Permanent Service for Mean Sea Level (PSMSL, see Permanent Service for Mean Sea Level, 2023).

The impact of the Actuarial Climate Index (ACI) is steadily expanding worldwide. (Curry, 2015) investigates extending the use of the ACI formula to the UK and Europe, finding it applicable to this region without change, although it would need appropriate regional data.

In 2018, the Institute of Actuaries of Australia developed the Australian Actuaries Climate Index (AACI), using the ACI methodology, to monitor climate change in Australia (see AACI, 2018). Also, (Nevruz, et al., 2022) propose to apply the ACI in Turkey, adapting it to the conditions in Ankara, and develop an index suitable for this region. This methodology has been applied also to define a high-resolution Iberian Actuarial Climate Index (IACI, see Zhou et al., 2023), obtaining in particular cases the Spanish (SACI) and Portuguese Actuarial Climate Indexes. Finally, (Garrido et al., 2023) extend the ACI methodology by applying it to French data to define the French Actuarial Climate Index (FACI), and illustrating the use of this index in parametric insurance.

The second and final stage involves employing the concept of actuarial climate index to gauge the impact of climate change on insurance risks. Through this approach, it is possible to investigate both the historical and prospective influences of climate change on the insurance business, ultimately addressing its sustainability. In the realm of this research, two recent examples stand out. (Pan, Porth, and Li, 2022), delve into the effectiveness of the Actuarial Climate Index (ACI) in predicting crop yields for (re)insurance ratemaking. Their findings highlight the ACI's significant predictive power for both crop yields and yield losses. They argue that a high-resolution index could prove advantageous for the insurance industry.

Another noteworthy study by (Zhou and Vilar-Zanon, 2024), investigates the impact of climate change on hailstorm risk in Spanish crop insurance, specifically focusing on the wine grape sector. Utilizing linear and quantile regression methodologies with the SACI as an independent variable, the researchers successfully determine its influence on key insurance metrics obtaining an explanation for up to 81% of the variation in the insurance-dependent variables. These metrics include the monthly number of

claims, number of loss costs equal to one, and total losses. Furthermore, they quantify the effect of future climate shifts, as measured by the SACI, within crucial insurance metrics such as the mean and value at risk (VaR) of monthly total losses. This insight is crucial for premium and solvency calculations, shaping our understanding of the future evolution and sustainability of this line of business.

6. Conclusions

Health insurance faces the threat of increased disease propagation, as climate change creates favorable conditions for the proliferation of infectious diseases. Simultaneously, the adverse consequences of heightened temperatures and air pollution on human health act as catalysts, elevating the risks associated with health insurance and thereby intensifying the frequency of claims.

The life insurance sector is undergoing transformations in the wake of climate change. Regions confronting heightened mortality risks, particularly stemming from extreme heat waves or natural disasters, experience an upsurge in mortality rates. Concurrently, health complications arising from climate change amplify the vulnerability of policyholders and hence an added risk for life insurance losses.

Agricultural insurance is significantly impacted by climate change, affecting nearly all crops and regions worldwide. Scientific research aims to quantify this impact on essential insurance metrics, including premiums, total losses, loss costs, risk measures, and the number of claims. Statistical methods, such as linear and quantile regression methods, as well as linear mixed models, have been crucial in this research endeavor. The definition of a compound index to measure climate change is of great help because it enables its incorporation into statistical methods to investigate its influence on these insurance metrics.

Also property insurance is impacted by climate change, increasing the exposure of many regions to risks like floods, droughts, hurricanes, typhoons, tornados, hail, natural wildfires, landslides, heavy storms, sea level rise, etc. Measuring and quantifying these risks is crucial to mitigate their potential catastrophic consequences, and the actuarial techniques are proving to be useful for this task.

In recent research, a methodology akin to that employed in the Actuaries Climate Index™ was applied to formulate the Iberian Actuarial Climate Index, defined to measure climate change within the Iberian Peninsula (Spain and Portugal). The primary objective of this index is to provide insurers, actuaries, and policymakers with a straightforward and efficient instrument to quantify climate change (see Zhou et al., 2023). Furthermore, the Spanish Actuarial Climate Index, a sub-index of the Iberian Actuarial Climate Index (IACI) framework, was used to assess the impact of climate change on both the frequency of hail damages and the severity of losses incurred by Spanish wine grape producers (see Zhou and Vilar-Zanón, 2024). This article briefly reviews the observed impact of climate change on agricultural insurance.

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