PIISA

Piloting Innovative Insurance Solutions for Adaptation

D1.1 Role and potential of insurance in accelerating climate adaptation in Europe

Authors: Stefano Ceolotto, Matteo Colucci, Simone Taddeo, Adriaan Perrels, Marika Huttunen, Jaroslav Mysiak

Funded by the European Union

Disclaimer

Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European union or the European Climate, Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor the granting authority can be held responsible for them.

Document information

Grant Agreement	n° 101112841
Project Title	Piloting Innovative Insurance Solutions for Adaptation
Project Acronym	PIISA
Project Coordinator	Hilppa Gregow, Finnish Meteorological Institute (FMI)
Project Duration	DAY MONTH YEAR – DAY MONTH YEAR (# months)
Related Work Package	WP 1
Deliverable Title	Review report - Role and potential of insurance in accelerating climate adaptation in Europe
Related Task(s)	Task 1.1
Lead Organisation	CMCC
Contributing Partner(s)	All
Authors	Stefano Ceolotto, Matteo Colucci, Simone Taddeo, Adriaan Perrels, Marika Huttunen, Jaroslav Mysiak
Due Date	31 May 2024
Submission Date	31 May 2024
Dissemination level	Public

History

Date	Version	Submitted by	Reviewed by	Comments
15/05/2024	1	Stefano Ceolotto	Jaakko Juvonen, Saara Korjonen, Giulia Maggioni	
30/05/2024	2	Stefano Ceolotto	Hilppa Gregow	

Table of contents

List of figures

List of tables

Summary

Objective of the report

This review report is part of Task 1.1 of WP1 of the PIISA project. Its objective is to review and synthesise the state of the art on the supply and demand of climate insurance and alternative risk transfer mechanisms in Europe, to support the work of the whole PIISA project moving forward, especially for the innovation activities and the pilot studies conducted within WPs 2 and 3. More specifically, this is achieved through: (i) a systematic assessment and mapping of climate insurance systems across European countries; (ii) a stocktaking of demand-side, supply-side and other factors influencing the climate insurance protection gap; (iii) an overview of the new technologies and potential innovations that could help to close such gap and promote adaptation-enhancing insurance.

Methodology

In order to provide an overview of the state of the art, this report conducts a review of the academic and grey literature, which is complemented with the most up-to-date information on climate insurance penetration rates across European countries provided in the EIOPA "Dashboard on insurance protection gap for natural catastrophes".

The literature review consisted of two complementary methodologies. First, a systematic literature search. Thematic keywords are linked by Boolean operators to investigate the scientific literature databases of Scopus and Web of Science. Second, an AI-powered search. A set of relevant references identified by the authors is fed into the AI-powered tool Research Rabbit, which returns a citation-based mapping of the literature. The documents thus collected underwent a rigorous review process consisting of deduplication, preliminary title and abstract screening, full-text screening and data extraction, which was performed by members of all the partners of the PIISA project.

This pool of documents was further integrated by additional references which were sourced by the authors upon writing the report. These include grey literature which is not picked up by the systematic and AI-powered searches, cross-references contained in the previously-sourced documents or seminal papers which were outside the scope of the systematic and AI-powered searches but are instrumental to the discussion.

The systematic search returned 1,499 documents from Scopus and 4,612 from Web of Science. The AI-powered search returned 1,048 documents, plus 18 used as the base for the search. Finally, 182 documents were added by the authors. After the screening, review and writing phases, this report contains insights coming from 408 sources.

General considerations on the literature review outcomes

Some general outcomes that emerged from the literature review process are the following. Flooding (either coastal, fluvial or pluvial) is by far the most investigated hazard. This is followed by droughts (primarily in relation to developing countries and the agricultural sector), storms, hurricanes (in the US) and wind. Other hazards such as heatwaves, hail, snow, excessive rainfalls or biotic risk are investigated a lot less frequently. In addition, some studies refer to natural hazards or natural catastrophes in general. For the most part, these are review- and perspective-type documents, or macroeconomic investigations of the whole economy.

The United States is the most frequently investigated country (either as a stand-alone "case study" or as part of a multi-country investigation). Since the focus of the PIISA project is Europe, this report presents insights from non-European countries only insofar as they can be applied to a European context, or where no European-level information is available. Among European countries, those that received the most attention in the literature are Germany, the Netherlands, the United Kingdom, France and Italy. These present relevant and interesting cases on analysis in light of (a combination of) their national climate insurance systems and climatic hazards vulnerability. Smaller economies and Eastern European countries have received considerably less attention.

Regarding economic sectors, households are the most often investigated. This is in part due to a considerable number of papers employing empirical or experimental analysis based on surveys to study the determinants of climate insurance demand and possible interventions to overcome some of the barriers that hinder uptake. Similar empirical strategies are adopted also to investigate the agricultural sector, which is the second most frequently considered. Businesses are usually not considered alone, but rather in empirical analyses that also target households or in more general review-type documents which encompass numerous sectors. Forestry is rarely analysed, and the sourced documents typically focus on adaptation strategies rather than insurance. Insurance opportunities for ecosystems and their services remain almost unexplored.

Finally, the majority of the documents that we sourced deal with the barriers to insurance diffusion, and, among these, greater attention is put on the demand side. Fewer documents consider potential innovations, and only a subset of these conduct empirical or experimental analyses, or deal with climate insurance. On the one hand, this is not surprising, since new practices have inevitably had less time to be investigated. Moreover, a certain degree of extrapolation was expected given the very nature of innovations. On the other hand, however, further research and practical applications through pilot studies will have to be conducted to effectively evaluate the potential of these innovations and to develop business models and guiding principles.

Results of the assessment and mapping of climate insurance systems across European countries

Chapter 3 presents the outcomes of the systematic assessment and mapping of the national climate insurance systems and the current insurance penetration rates across European countries (EEA 30 plus the United Kingdom). The analysis considers four types of hazards, namely, coastal flooding, inland (i.e., fluvial and pluvial) flooding, wildfire, and wind. And two sectors, businesses and households. Special attention has been given to the agricultural sector. While no specific penetration rates maps are reported, the discussion focuses on the legal and regulatory framework, with a particular attention to the recent Common Agricultural Policy and how countries incorporate it to support the national agricultural insurance schemes. What emerges is that there is a considerable degree of variation across countries in terms of the characteristics of the national insurance schemes, which leads to multiple combinations, ultimately returning a situation where many different systems coexist in the European context. Voluntary market-based systems tend to have lower penetration rates, with the highest typically found in countries recurrently affected by large floods (e.g., Germany and Czech Republic), but even in these cases it is at most 50%. Where climate coverage is linked to other (more) salient products, higher penetration rates are achieved (e.g., Ireland, UK), and such a "soft compulsion" performs as well as legal compulsion (e.g., Romania). Systems that entail some form of public intervention, either in a private-public partnership or with the state acting as primary insurer, are usually characterised by higher penetration and a solidaristic principle through a cross-subsidisation of premiums.

Premiums tend to be risk-based in most market-based systems. While they are assumed to provide incentives to stimulate private investment in risk mitigation, they do not appear to be particularly effective in this regard (e.g., Italy), and they may entail unaffordability issues in high-risk areas (e.g., Ireland). Flat rates (on asset value) and fixed fees apply the solidaristic principle, with cross-subsidisation (across geographic areas and/or policyholders). This enhances affordability and achieves higher penetration rates, but it does nothing to incentivise risk reduction, which creates moral hazard and could make these systems untenable with worsening climatic conditions. Mixed systems (e.g., Denmark and the UK) seem to offer a good compromise between affordability, wide coverage and risk-reduction incentives.

Countries where ex-post disaster relief is provided through ad hoc interventions without a clear regulation (e.g., Germany, Italy) tend to have lower penetration rates due to the so-called charity hazards. Most European countries have dedicated public funds for post-disaster relief, which bring more financial sustainability for the recovery after sizable catastrophes. For both approaches, in some cases households or businesses that hold insurance coverage are precluded from receiving governmental relief (e.g., Austria, Slovenia). Finally, state guarantee brings the most advantages when put on the solvency of public (e.g., Denmark, Iceland) or PPP (e.g., France, Spain) entities, due to their ability to raise capital on the international financial market at advantageous rates.

Considerable differences between countries emerge also in terms of climate insurance penetration rates, across both hazards and sectors. Not surprisingly, coverage has a geographical component determined by the most prominent hazard types in the specific country, such as coverage against coastal flooding is more diffused in Atlantic countries. There are, however, a number of exceptions, like the low penetration rates for inland flooding in the Netherlands, for coastal flooding in Portugal, or for wildfires in Greece, just to name a few. It appears that the commercial sector tends to have higher take-up rates than households for all hazards, especially in countries with voluntary market-based systems. Whereas, on average, coastal flooding and wildfires are the hazards with the lowest penetration rates, for both households and businesses. Finally, while southern and eastern countries have generally lower penetration rates, particularly those with voluntary systems, in recent years they are starting to introduce some forms of mandatory requirements in an attempt to stimulate take-up. However, most of the penetration rates presented in this report (and reported in the EIOPA dashboard) come from qualitative estimates and approximations rather than precise quantifications, in good part as a result of the limitations in sourcing this information.

The systems that currently reach higher penetration rates present one or more of these features. (i) They are characterised by public involvement in the climate insurance system, either in the form of a PPP or a public insurer. (ii) They have some form of premium cross-subsidisation through fixed or flat rates. (iii) They have some requirements for the uptake of climate coverage, either as a specific legal prescription or by making climate insurance a prerequisite for other (more) salient products, like mortgage. (iv) They do not rely on ad-hoc governmental relief, but there are clear regulations and dedicated public funds for post-disaster compensation. The system that presents most of these features and currently performs best at achieving high take-up rates appears to be the Danish one. It is important to remember, however, that there is no one-size-fits-all solution. Different countries have different environmental, cultural and socioeconomic characteristics, and so each climate insurance system should develop to align with the needs of its specific national context. In addition, while flat/fixed rates appear to perform best, we maintain the conviction that premiums should be risk-based, with support to lower-income groups coming from public interventions and not cross-subsidisation from other policyholders. However, additional measures should accompany risk-based premiums to incentivize investments in risk reduction, integrating insurance in a holistic risk management framework.

Results of the literature review on demand-side, supply-side and other factors influencing the climate insurance protection gap

Chapter 4 presents the results of the literature review on the drivers of the climate insurance protection gap. Demand-side factors are divided into four categories: informational barriers, “rational” barriers, “irrational” barriers, and other personal and social factors. Informational barriers include imperfect information about risk, and imperfect information about low-probability events. “Rational” barriers are factors that may induce utility-maximising agents to reduce their demand for climate-risk insurance. These include: charity hazard, considerations connected to the affordability of insurance instruments, risk aversion, ambiguity aversion and loss aversion. “Irrational” barriers have to do with biases, heuristics and mental shortcuts that agents adopt in their decision-making processes and that might lead to suboptimal outcomes. These include: status quo bias, availability bias, herding, mental accounting, and a mismatch between the probability of event and the policyholders' threshold level of concern. Other personal and social factors include: age, education, financial literacy, property ownership status, trust, fatalism, wishful thinking, attribution of responsibility for protection, and substitutability between insurance and risk-reduction measures. Four supply-side factors are considered: limits to the insurability of climatic events, capital costs, moral hazard and adverse selection. Finally, the additional factors investigated are data availability and sharing issues, and considerations regarding the fairness and justice of climate insurance schemes.

Several studies suggest that people tend to have a low perception of climatic and natural risks, despite living in risk-prone areas. Previous experience with risk and social capital are important determinants in shaping people’s risk knowledge and perception. For instance, households that experienced climate events and losses in the past tend to perceive themselves at higher risk, whereas those that report having a supportive social network display lower perceived risk. In turn, lowered perceived risk decreases the demand for climate insurance. Fewer studies analyse the imperfect knowledge about low-probability events and the tendency of agents to insure against more frequent but less severe events rather than against less frequent but more severe ones (the so-called “LPHI-HPLI puzzle”). Some empirical analyses provide evidence in support of such a puzzle, but more research should be conducted on this front.

Regarding the rational barriers, for the most part the findings reported in the reviewed studies are in line with economic theory. When governmental relief is available agents tend to reduce their demand for climate insurance. Both income and prices are found to be significant determinants of insurance demand, and affordability issues are expected to become more relevant under a changing climate if premiums are consistently risk-based. More risk averse agents tend to have a higher demand for climate insurance. However, some mixed or counterintuitive results have also emerged, in particular regarding ambiguity aversion, or a negative effect of risk aversion on insurance uptake among farmers. Most of the evidence comes from theoretical analyses, or from experimental studies, which present limitations in terms of external validity. Empirical investigations based on real-world observations are more scarce and are typically unable to test causal relations.

“Irrational” barriers are less explored than “rational” ones, so several of these factors remain underinvestigated. In addition, many of the reviewed papers do not study the specific factor as a barrier per se, but rather as a potential stimulus to uptake. So, for instance, research on the status quo bias shows that making climate coverage the default in insurance contracts, as opposed to offering it as an opt-in component, increases penetration. This implies that today’s status quo of having climate coverage offered as an opt-in component fosters the protection gap. Likewise, herding is mostly studied in the context of a positive impact of social networks, showing that people are more likely to purchase insurance when they believe others would expect them to do so. Also in this case, most of the papers find effects which are in line with the expectations, and they rely on experimental investigations. The exception is availability bias, where several empirical studies on insurance uptake control for agents’ experience with climate events and losses, finding that it generally has a positive impact.

The other demand-side factors are generally included in empirical and experimental analyses as control variables to evaluate the determinants of climate insurance demand, but almost never are they the main element of the analysis. What emerges is that older and more educated individuals are generally more likely to have insurance (although in some cases insignificant or even negative effects emerge). A limited financial literacy or a lack of understanding of insurance products reduce the uptake of insurance; moreover, knowledge of probability concepts appears to be more important than financial literacy per se. Most of these studies, however, have been conducted in developing countries. Also, both empirical and experimental literature has shown that a lack of trust in insurance and/or financial institutions decreases uptake. Tenants are less likely than home and business owners to purchase climate insurance. This can be due to national legislation making the owners legally responsible for insuring the property (while tenants are responsible for content insurance); but possibly also the result of a principal-agent problem, where no such legislation is in place. Some authors have suggested that insureds might have an imperfect knowledge of their policies. In particular, it is argued that some households may incorrectly assume that certain hazards (like flooding, wind or hail) are included in their policy when in fact they are not, given that coverage against climatic hazards is offered as an add-on option in most standard policies. This, however, has not been empirically tested. Fatalism and, especially, wishful thinking are still rather underinvestigated, but studies have shown that when people perceive they do not have control over events, or when they have an external locus of control, they are less likely to insure. On the other hand, in some countries there is the belief that the responsibility of protection falls on the state and public administrations. However, the effect of the attribution of responsibility for protection is mostly investigated in the context of risk preparedness and protection more broadly, and evidence of the impact on the demand for insurance is still limited. Finally, contrary to expectations, most empirical and experimental investigations do not find evidence in support of the claim that agents view risk-reduction measures and insurance as substitutes. Conversely, some evidence of advantageous selection has been detected (i.e., those who have insurance coverage are more likely to put in place risk-reduction measures).

Supply-side barriers relate to frictions in the supply of insurance products that lead insurers to limit the offer of coverage, charge higher premiums, or to limitations connected to specific characteristics of insurance policies that reduce their attractiveness to consumers. Unlike the literature on demand-side barriers, most of the reviewed documents are theoretical analyses or review- and perspective-type papers, not empirical or experimental investigations. There is a general agreement that natural disasters and climate change present limitations in terms of insurability compared to other risks. Uncertainty regarding their occurrence and magnitude limits the ability of insurers to accurately quantify potential losses, and changing climate conditions reduce the reliability of loss estimations based on historical data. Yet, most of the actuarial models of primary insurers still use historical data and do not factor in climate change. Climate-related loss events tend to be spatially correlated, which generates adverse selection problems and decreases the scope for diversification. Also, extreme climatic events tend to have a distribution that is characterised by “fat-tails”, with a greater probability of catastrophic events occurring, which can threaten the solvency of insurers. Such features induce insurers to withdraw coverage for certain hazards and areas, and require them to hold large amounts of capital to ensure solvency. Insurance companies thus have to seek reinsurance and external sources of capital, which are more expensive than internal capital. These extra costs connected to uncertainties and capital reserves requirements are passed on to consumers in the form of higher loadings on insurance premiums, which have a negative effect on demand. In addition, some authors have also argued that capital costs can also distort managerial decision-making, leading insurance companies to adopt survival approaches rather than seeking profit maximisation. Moral hazard and adverse selection have seen more empirical and experimental investigation. While, for the latter, most studies confirm that areas at higher risk are more likely to demand insurance, which then leads insurers to raise premiums, evidence of the presence of moral hazards is mixed.

Regarding issues concerning data availability and sharing, what emerges is that data on the impact of climatic events is considerably less readily available than hazard data. This is often due to the additional costs connected to the collection and disclosure of this information, as well as to privacy reasons. Impact data also presents less standardisation in processing and representation practices. Standardised, quality-assured impact datasets with guaranteed periodic updating are crucial for adaptation-promoting insurance. However, different actors have different needs and requirements regarding data quality, (spatial) resolution, coverage, and combinability. A climate risk data policy is called for, which sets out clear rules, requirements and limitations to maximise access to relevant information while ensuring transparency, affordability and the protection of privacy. A first approach is being pursued in Norway, with the establishment of the Norwegian Hazard Damage Knowledge Bank.

Finally, from the review of the literature, it emerges that there does not appear to be a unique view of what justice and fairness mean in the context of climate adaptation and climate insurance. According to some authors, a just insurance scheme should be fully solidaristic, so as to ensure that all have access to coverage, even if this entails premiums cross-subsidisation between policyholders. Others suggest that premiums should be reflective only of the level of risk that policyholders are directly responsible for. Whereas others still argue that cross-subsidisation is unfair, and actuarial fairness should apply. Irrespective of the principles one subscribes to, most of the literature seems to agree that the present climate insurance regimes do not perform particularly well on the justice front, and that such an issue is likely going to be aggravated by climate change.

Results of the literature review on innovations and opportunities to close the climate insurance protection gap

Chapter 5 presents the results of the literature review on new technologies and potential innovations that could address the barriers identified in Chapter 4 and promote adaptation-enhancing insurance. The review considered four types of innovations: innovations in insurance products' characteristics, innovative insurance and risk-transfer measures, innovations in data collection and analysis, and opportunities for strengthening multi-actor collaborations. Product characteristics innovations include: multi-year contracts, bundling, opt-out contracts, and various forms of premium reductions (discounts, subsidies and means-tested vouchers combined with mitigation loans). Innovative insurance and risk-transfer products include: parametric insurance, insurance-linked securities, microinsurance, takaful, insurtech, decentralised insurance solutions, and natural insurance. Data collection and analysis innovations include: drone imagery, satellite imagery, blockchain and artificial intelligence.

Several empirical and experimental studies suggest that multi-year contracts would increase the demand for climate insurance. However, at present they are not widely adopted, due to a number of factors. Insurance companies are unlikely to offer policies longer than five years, since this reduces their flexibility to adjust prices to new circumstances, an issue which is further aggravated by climate change reducing pricing accuracy. In addition, longer-term contracts typically entail higher premiums, although experimental findings show that consumers would still prefer them to one-year contracts. As discussed also in Chapter 3, linking climate insurance with other products (such as fire insurance or mortgages) allows for higher penetration rates to be achieved. Conversely, while multi-peril coverage is postulated to provide benefits to both insurers (reducing correlation and increasing insurability) and policyholders (lowering transaction costs and removing ambiguity), the body of evidence on its effectiveness is still scarce. Likewise, the benefits of opt-out contracts have been investigated only in two experimental analyses, and no empirical evidence based on real-world observations was found. Nevertheless, those papers suggest that including climate coverage by default in insurance policies would lead to higher take-up rates, albeit with some differences depending on the context. Finally, the various forms of premium reductions that have been proposed present several trade-offs. While subsidies increase uptake, they reduce incentives to invest in risk reduction. The effectiveness of premium discounts appears to be smaller than what theory would assume, with some authors questioning their validity as a stimulus to risk reduction. Theoretical investigation of means-tested vouchers combined with mitigation loans suggests that they have the potential to improve affordability and uptake, not crowd out risk reduction, and decrease the pressure on public finances. However, in practice, no such scheme has proven successful so far.

Most of the academic literature on parametric insurance focuses on developing countries, and such products are rather different from those adopted in developed countries. Despite these differences, in both cases parametric insurance is mostly used in the agriculture sector, with triggers based on temperatures and precipitation (or lack thereof). However, it emerges that basis risk remains a limitation in the eyes of consumers, especially for more risk-averse ones and in contexts with consolidated insurance markets, which reduces its diffusion. Microinsurance and takaful are also mostly studied in developing countries. Both are meant to increase penetration by reaching under- or unserved segments of the population. The former is tailored to the needs of low-income households and it often involves clear-cut terms, limited coverage and lower premiums. The latter is a form of insurance that abides by Islamic law by following the principle of mutual assistance and shared risk. However, they both still do not effectively address certain demand-side barriers like lack of trust, low consumer awareness, information asymmetries, and lack of financial literacy. In addition, the lack of standardised regulations for such products challenges their growth; moreover, ensuring Shariah compliance increases the operational costs of takaful and limits its innovation potential. Decentralised insurance solutions function without central authorities or intermediaries. Similarly to takaful, they are also based on principles of mutuality, and as such they can achieve high levels of transparency, security, and trust among participants. Yet, regulatory uncertainties remain, since the legislative landscape is still evolving and could significantly differ across jurisdictions, which could limit the potential for scalability. Insurtech leverages new data collection, processing and analysis methods (blockchain, AI, DLT, machine learning, remote sensing) to develop insurance products that are more transparent, easy to use, can be tailored to the needs of individual policyholders, and allow for more rapid claim payments. The use of such methods, however, entails a number of limitations (as it will be discussed below) which might reduce their attractiveness from the insurers' perspective. Insurance-linked securities, such as catastrophe bonds, have been around for quite some time. They represent an alternative form of (re)insurance which sources finances from international capital markets, thus increasing diversification and enhancing liquidity, since international investors are more risk-neutral than national agents. However, as such they are mostly restricted to larger agents, whereas small insurers and SMEs typically are less able to issue them. The literature suggests that parametric bonds are more efficient than indemnity-based ones, and are preferable to standard (re)insurance, particularly in cases of high (re)insurer default risk, low basis risk and in high-risk layers. Finally, insurance of and from nature remains significantly underexplored, although more interest has been devoted to them in recent years. The reviewed studies confirm the effectiveness of ecosystem-based insurance in promoting environmental conservation, enhancing resilience to climate change, and closing the protection gap. However, challenges remain due to the complexity of measuring and quantifying ecosystem services; uncertainties on the performance of nature-based solutions, especially under worsening climatic conditions, which reduces the willingness of decision-makers to invest in them as a form of insurance; and public goods issues.

Only a limited number of documents investigates the considered data collection and processing innovations in the context of insurance, and even a smaller subset explores their potential to close the climate insurance protection gap. In theory, such innovations would enable more precise and effective pricing of risk, reduce operational and transaction costs, improve the characteristics of insurance products, ensure faster claim payments, improve transparency and ease of use, and enhance customer experience. They could be used to improve the standard indemnity policies, but also to develop new and efficient parametric and insurtech solutions. Drone imagery allows the collection of detailed micro-level data, which can improve underwriting but also incentivise adaptation. However, these expected advantages have not been tested empirically. Its use presents limitations in terms of coverage, and still requires human input on the ground, so the cost reduction potential is not as high as for other technologies. Satellite imagery, on the other hand, allows the collection of risk and damage data on a much larger scale, albeit this entails a lower degree of precision than drone-retrieved information. Satellite imagery is also highly dependent on weather conditions and terrain morphology, which means that data accuracy is subject to considerable variability. Most of the insurance literature considers satellite imagery in relation to parametric products for policy design and event triggering, whereas opportunities to use it for damage estimation in indemnity contracts are still underexplored. Blockchain and artificial intelligence can improve the underwriting process. The former enhances transparency, allowing for a reduction in information asymmetries and greater consumer trust. The latter has the potential to enable a more accurate pricing of risk thanks to the ability to process large amounts of data. Both can afford the opportunity to reduce operational costs, to design insurance policies tailored to the needs of the single customers, to streamline claims settlements and to ensure rapid payments. There remain concerns about the transparency of the underlying processes. In addition, the use of artificial intelligence opens issues in terms of the ultimate responsibility for its decisions, which decreases its attractiveness from the insurers' perspective. Finally, as the industry continues to move toward greater digitalization and technologization, issues concerning cybersecurity will become more relevant. While, at present, cyber risk is not explored yet in the context of climate insurance, the insurance industry regards it as a bigger protection gap than natural catastrophes.

A final aspect that emerged from the review of the literature is a consensus on the need for greater collaboration between actors, like multi-sector partnerships or public-private insurance regimes. Such collaborations are expected to ease the collection of resources to cope with extreme losses, foster adaptation and enhance the risk-reduction capabilities of insurance schemes. This, in turn, would reduce the pressure on insurance mechanisms, thus improving their affordability and resilience. National insurance organisations and pools allow diversification to be improved and increase the volume of resources to finance extreme losses, which facilitates the insurability of certain risks and areas and improves the solvency of the industry. As for the untapped potential for cooperation, it is suggested that insurers could collaborate with construction companies to facilitate the inclusion of risk-reduction measures in their projects, leveraging better insurance conditions as selling points. Moreover, insurance companies (or national insurance organisations) should also establish closer relations with public administrations to inform urban planning as well as the development of certificates and building codes, as this would reduce their exposure by ensuring that fewer properties are located in risky areas. Also, in light of the evidence that better-performing insurance systems see some form of public involvement, several authors advocate for moving toward a multi-layered PPP approach, with clear attribution of risks and adaptation responsibilities to different actors. However, several barriers limit the establishment of such collaborations. For instance, unclear responsibilities for who is in charge of managing certain risks, and obstacles to the sharing of information (either because of privacy protection reasons or for the reluctance of insurance companies to disclose information), create friction and reduce the scope for coordination. In addition, regulatory frameworks can prevent actors from cooperating, such as competition laws limiting the ability of insurance companies to cooperate in fear of possible anti-competitive behaviour.

Keywords

Climate change; climate risk; insurance; insurance protection gao; barriers; innovation; adaptation; risk reduction

Abbreviations and acronyms

Acronym	Description
AI	Artificial intelligence
API	Application programming interface

ARI	average recurrence interval
CAP	Common Agricultural Policy
CAT	Catastrophe
BDA	Big Data Analytics
BDT	*Bureau de tariffication*
CBCI	Community-based catastrophe insurance
CCR	*Caisse Centrale de Réassurance*
CCS	*Consorcio de Compensación de Seguros*
CNC	*Caisse Nationale des Calamites*
DCE	Discrete choice experiment
DeFi	Decentralised Finance
DIS	Decentralised insurance solutions
DLT	Distributed Ledger Technologies
DSB	Department of Emergency Management
EAFRD	European agricultural fund for rural development
EEA	European Economic Area
EIOPA	European Insurance and Occupational Pension Authority
EU	European Union
EUSF	European Union Solidarity Fund
EUT	Expected utility theory
GCM	General circulation model
GIS	Geographical information system
HPLI	High-probability low-impact
ILS	Insurance-linked securities
LAI	Leaf area index
LPHI	Low-probability high-impact
MS	Member state
NATCAT	Natural catastrophe

NbS	Nature-based Solutions
NDVI	Normalised difference vegetation index
NGO	Non-governmental organisation
NIA	National insurance association
NSF	Italian national solidarity fund
NTI	*Náttúruhamfaratryggingar Íslands (Natural Catastrophe Insurance of Iceland)*
PAID	*Pool-ul de Asigurare împotriva Dezastrelor Naturale*
PPP	Public-private partnership
PRAC	Romanian Program for Catastrophe Insurance
RB	Resilience bond
RCM	Regional climate model
RR	Research Rabbit
RSPV	Reinsurance special purpose vehicles
SCC	Securitisation cell companies
SME	Small and medium enterprise
UAV	Unmanned aerial vehicle
WoS	Web of Science
WP	Work Package
WTP	Willingness to pay
WTS	Wet Tegemoetkoming Schade bij rampen en zware ongevallen

1 Introduction

It is widely recognized that the global climate is changing (IPCC, 2014). The concentration of greenhouse gases has increased, especially in the past twenty years; the atmosphere and oceans have warmed; the amounts of snow and ice have diminished; the sea level has risen and the oceans' heat storage and acidification have increased; extreme weather events have become more frequent and severe (IPCC, 2014; WMO, 2020). This is having widespread impacts on natural and human systems, with millions of people displaced, interruptions to business activities, disruptions to the agricultural sector elevating levels of food insecurity, causing tens of billions of dollars in economic losses and hundreds of thousands of casualties (IPCC, 2014; Wing et al., 2021; WMO, 2020, 2023).

The average annual losses due to natural hazards have increased steadily worldwide, from around $421 billion in 2011 to over $3,000 billion in 2022 (GFIA, 2023). The trend is expected to continue in the future, with absolute losses expected to grow at 5% per annum (GFIA, 2023), due to worsening climatic conditions and more value moving in hazards' ways. In Europe, total losses are projected to double by 2050 and triple by 2100 (Gagliardi et al., 2022). Despite this situation, more than 60% of global natural catastrophes (NATCATs) were not insured in the period 2011-2022, with this share approaching 100% in low-income countries (GFIA, 2023). The share of uninsured losses decreased globally over the last three decades, and uninsured losses are expected to grow at a lower rate than total losses (4% per annum; GFIA (2023)). Yet, this reduction is mostly limited to high- and upper middle-income countries (Schanz (2018), reporting information from Munich Re NatCatSERVICE). In Europe, only one-fourth of the losses caused by extreme weather events are insured, with high variability across countries (EIOPA, 2023b).

This report reviews the current state of European climate-risk insurance systems, the factors that limit the demand from climate insurance and the opportunities to stimulate take-up and the design of adaptation-enhancing insurance products.

1.1 Background on climate risk and insurance

According to the EU Disaster Risk Management Knowledge Centre (Poljanšek et al., 2017), natural hazards can be divided into three main typologies of natural phenomena: (i) geophysical phenomena, such as earthquakes, volcanic eruptions and tsunamis; (ii) hydrological phenomena, such as floods, landslides, wave actions and tidal activities; and, (iii) meteorological, climatological and biological phenomena, such as storms (including cyclones, hurricanes, medicanes), extreme temperatures, droughts, wildfires, and biotic risks (like epidemics and pests). While geophysical phenomena are among the most severe threats in many parts of the world and can generate enormous economic and human losses, these events have their origin in the Earth's lithosphere and are not influenced by climate change. The other two types of phenomena, on the other hand, derive from climatological and atmospheric sources and are profoundly impacted by changing climatic conditions. This report restricts its attention on climate risks, focusing primarily on hazards that fall within the second and third category. Indeed, the number of hydrological and meteorological disasters appears to be growing at a faster rate than geophysical ones, and geophysical risk is generally less relevant across Europe (Kron et al., 2019). Only in rare cases will the discussions consider geophysical phenomena, when the underlying principles or methods can safely be applied to climate-related risks.

In order to manage risk, agents (including households, businesses, and public administrations) can adopt risk-reduction measures and/or risk-sharing measures. The former are interventions that aim at lowering the level of risk, and by extension the extent of losses suffered. They can include a wide array of strategies, which vary greatly depending on the hazards and agents involved. Some examples include structural flood protections (like dykes and levees), regulations that prevent development in high-risk areas and mandate minimum resilience standards for new constructions, cultivating weather-resistant crops, flood-proofing buildings, early warning systems, and so on. Risk-sharing strategies, on the other hand, do not reduce the underlying level of risk per se, but rather aim at lowering its consequences by sharing it with other agents or (re)distributing it across time. Insurance falls within this category, and, more specifically, it represents a risk pooling strategy, since insurance companies pool risks from many different clients, located in many different places, who are subject to many different risks. This diversification allows insurance companies to guarantee the provision of coverage in a profitable way. For the insureds, the cost they incur to share their risk with other agents is considerably smaller than the potential loss they might face. Other forms of risk sharing include, among other, mutual funds, and securitised products such as catastrophe bonds or weather derivatives. However, the two types of risk management strategies should not be considered mutually exclusive. Risk reduction should not crowd out the demand for insurance (and other forms of risk-sharing), since these measures typically do not protect against any event, but they are often designed for events up to a certain magnitude (e.g., a levee for a 100-year flood). There is thus a residual risk, which could be exacerbated by changing climatic conditions, and risk-sharing strategies can alleviate the potential consequences of this risk by spreading them across multiple agents (Botzen, 2013). On the other hand, being insured against a certain event should not crowd out the incentives to invest in risk reduction, as reducing the underlying risk level would improve the terms of the insurance policy, enhancing the resilience of insurance markets and societies alike (Surminski et al., 2016).

As reported by Hudson et al. (2020), the Sendai framework for disaster risk reduction prioritises developing resilience through measures that finance recovery while incentivising risk reduction (Mysiak et al., 2016). Indeed, climate risk insurance has the potential to serve this function by presenting numerous benefits. First of all, by attaching a price tag to risk, insurance sends a signal to agents allowing them to modify their behavior accordingly (Botzen & Van Den Bergh, 2009; Kunreuther & Michel-Kerjan, 2013; J. E. Lamond et al., 2009; Surminski, 2014). The insurance sector can thus play a pivotal role in fostering risk reduction, by incentivising both potential policyholders and public administrations to implement mitigation and adaptation measures (Botzen, 2013; Botzen & Van Den Bergh, 2009; EIOPA, 2023b; Kron et al., 2019; Surminski, 2014). Second, insurance provides funds for recovery and reconstruction, thus covering direct economic damages and limiting indirect damages resulting from business interruptions and negative consumption shocks (Botzen, 2013; Hoeppe, 2016; Kraehnert et al., 2021; J. E. Lamond et al., 2009). Such funds are also provided more quickly than governmental aids, ensuring a faster recovery and further limiting potential distortions (EIOPA, 2023b; Surminski et al., 2016; Thieken et al., 2006). Indeed, RMS (2017) estimates that the effectiveness of early interventions can be more than three times as large as that of delayed aid payments. Moreover, shifting the responsibility of financial compensation away from public administration has additional benefits. On one hand, it reduces the volatility of payments (Unterberger et al., 2019), as governmental aid is not only unpredictable (EIOPA, 2023b; Surminski et al., 2016) but it is often dedicated primarily to rebuilding infrastructure rather than assisting private agents (Holzheu & Turner, 2018). On the other hand, it lowers the fiscal pressure of disasters (EIOPA, 2023b; OECD, 2021), as governmental relief is financed through taxpayer money. This also helps achieve more financial certainty for public budgets (Unterberger et al., 2019) and reduces the risk of default, which represents a particular cause of concern since various countries which have been historically vulnerable to disasters have high debt-to-GDP ratios (EIOPA, 2023b). “In economic terms the justification for any insurance is derived from the welfare function, which means that the provision of insurance can increase the expected utility of individuals, companies or society” (Surminski, 2013, p. 229). Indeed, well-functioning insurance systems have been proven to accelerate recovery after severe natural and climatic events (C. Otto et al., 2023), and to mitigate their negative effects on the economy, especially in countries with good institutions (Breckner et al., 2016).

Despite these advantages, as mentioned above, the diffusion of insurance against climate-related risks in Europe is still fairly limited, with considerable differences between countries, sectors and hazards. In some cases, the penetration rates of climate insurance are to be below what might be economically and socially optimal. This discrepancy is labelled (climate) insurance protection gap (IPG). There are actually various ways to define the IPG. For instance, The Geneva Association defines the insurance protection gap as the difference between the economically beneficial amount of insurance and amount actually purchased, since, from an economic standpoint, it is neither possible nor desirable to insure all potential losses (Schanz, 2018). Conversely, the GFIA (2023) characterises the IPG as the difference between total economic losses and insured losses (not including governmental reliefs)[1]. Since evaluating the “economically beneficial amount of insurance” would require a more sophisticated socio-economic analysis and optimisation exercises specific to each country-sector-hazard combination, which are beyond the scope of this report, in the following discussion IPG refers to the difference between total and insured economic losses, unless specified otherwise. This is also the characterisation used by the European Insurance and Occupational Pension Authority (EIOPA) in its “Dashboard on insurance protection gap for natural catastrophes” (EIOPA, 2023a).

1.2 State of the art and scope of this report

This report, which is conducted within the Task 1.1 of Work Package (WP) 1 of the PIISA project, is meant to review and analyse the supply of and demand for insurance and risk transfer for climate-related risks in Europe. This is achieved through: (i) a systematic assessment and mapping of climate insurance systems across European countries; (ii) a stocktaking of the factors influencing the IPG; (iii) an overview of the new technologies and potential innovations that could help closing the gap. The final goal is to build a body of knowledge which, together with the outputs of the Task 1.2 of WP 1, will form the basis for the entire PIISA project moving forward, particularly for the innovation activities and the pilot studies conducted within WPs 2 and 3.

This report builds on previous work developed by the academia, the insurance industry, international organisations, national governments and the European Union. Global reports on IPGs typically consider NATCATs in general rather than focusing on climate-related risk (e.g., GFIA, 2023; Schanz, 2018). Systematic assessments of European climate insurance systems and penetration rates exist, but they typically consider fewer countries and were produced before the publication of the EIOPA’s Dashboard (EIOPA, 2023b; European Commission, 2017, 2021;

[1] The Geneva Association terms this “risk protection gap” (Schanz, 2018).

Hudson et al., 2020). Some studies also focus primarily on the characteristics of these systems, but they cover a smaller number of hazards and sectors (e.g., Paleari, 2019). In light of the recent evolutions of the legislative framework (among others, the new EU Common Agricultural Policy), and of the reforms to national climate and NATCAT insurance systems that various countries are undertaking in response to mounting environmental threats, revisiting and updating those assessments with newly available information is a useful exercise to gauge the current state of the European climate insurance market.

Secondly, while several authors have discussed the factors that influence the demand for and supply of coverage against climate-related events (see, among others, Holzheu & Turner, 2018; Kunreuther, 2021; Kunreuther & Michel-Kerjan, 2013; Surminski, 2014), many of these investigations were not based on a systematic review of the literature, or considered a smaller subset of factors. In addition, new evidence has been produced over the last few years, especially on the behavioural phenomena that inhibit climate insurance uptake and on the evolution of underlying climate risks which determines their insurability. Moreover, new technologies and opportunities are emerging in terms of insurance product design, data collection and analysis, which could address such barriers and help closing the IPG (see, for example, Sheehan et al., 2023). It is thus important to, once again, survey the recent findings regarding barriers and facilitators for both climate risk insurance demand and supply.

With this in mind, the present report conducts a systematic literature review and mapping exercise to provide insights on the current state of the climate insurance market in Europe (including characteristics, penetration rates and features that perform best at reducing the IPG); on the demand-side and supply-side barriers that limit the diffusion of coverage against climate-related events; and on advancements in terms of product characteristics, alternative forms of risk sharing, and data collection which can lead to better product design and underwriting processes. These insights will serve to obtain a better understanding of the areas (both geographical and product-related) that need improvement and gauge the potential for insurance to not only be a risk-sharing tool but also to play a broader role in enhancing adaptation and resilience as recommended by the Sendai framework for disaster risk reduction. The remainder of this report is organised as follows. Chapter 2 details the methodology adopted to source, screen and review the relevant documents. Chapter 3 presents the systematic assessment and mapping of European climate insurance systems. Chapter 4 presents the results from the review of the literature on the factors driving the IPG. Chapter 5 presents the results from the review of the literature on the opportunities for innovation. Finally, Chapter 6 concludes.

2 Methods

The literature review was conducted using two complementary methodologies. First, a systematic literature search: thematic keywords are used to create a search query which is then fed into a literature database that returns a list of documents containing those keywords. Second, an AI-powered search: starting from a set of relevant references, an AI-powered tool returns a series of documents that are closely connected to the initial set.

2.1 Systematic literature search

2.1.1 Research databases and filters

Scopus and Web of Science (WoS) were used as literature research databases. The two present differences in terms of language and functionality. The necessary adjustments were made to ensure that the two interrogations were qualitatively as similar as possible. On Scopus, the search was conducted over "Article title, Abstract, Keywords". On WoS, the search was conducted over "Topic", which is the equivalent of title-abstract-keywords. The difference between search query strings is explained below. However, the two queries were qualitatively identical.

2.1.2 Thematic categories and keywords

Five key categories of keywords were used to write the search query for the research prompts:

1) Climate risk

Definition. In the context of climate change, risks can arise from potential impacts of climate change as well as human responses to climate change. In the context of climate change impacts, risks result from dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system to the hazards (Reisinger et al., 2020).

Keywords. "Climate", "Risk*", "Climate risk*", "Natural hazard*", "Catastrophe*", "Natcat*", "Low-probability event*", "Risk perception"

2) Climate (risk) modelling

Definition. Quantitative methods to simulate the interactions of the important drivers of climate, including atmosphere, oceans, land surface and ice. They are used for a variety of purposes from study of the dynamics of the climate system to projections of future climate (IPCC, 2014)).

Keywords. "Modelling", "Forecast*", "Projection*"

3) Climate Risk management

Definition. Plans, actions, strategies or policies to reduce the likelihood and/or magnitude of adverse potential consequences, based on assessed or perceived risks (Reisinger et al., 2020).

Keywords: "Management", "Reduction", "Transfer", "Pooling", "Insurance", "Reinsurance", "Protection gap*", "Adaptation"

4) Other key topics linked to insurance

Definition. Set of principles, market structure arrangements and customs around which national natural disaster protection schemes are built upon, maintained, or may evolve towards.

Keywords. "Insurability", "Affordability", "Justice", "Solidarity", "Individual responsibility", "Solvency", "Public-private partnership", "PPP", "Disaster compensation", "Disaster relief", "Ecosystem service*", "Nature-based insurance"

5) Barriers

Definition. Drivers of insurance protection gaps that prevent a greater uptake of coverage by citizens, business and institutions. Barriers can have different roots with respect to economic actors within the market and society. Barriers can relate to the demand side, the supply side or the regulatory and legal frameworks.

Keywords. "Imperfect information", "Asymmetric information", Charity hazard", "Risk aversion", "Loss aversion", "Ambiguity aversion", Heuristics", "Status quo bias", "Availability bias", "Mental accounting", "Herding", "Threshold level of concern", "Trust", "Awareness", "Religion", "Social comparison", "Social norm*", "Basis risk", "Transaction costs", "Rapidity of payment*", "Cost of capital", "Moral hazard", "Annual contract", "Annual pricing", "Long-term contract", "Long-term pricing", "Bounded rationality", "Bias in risk perception", "Accessibility challenges", "Regulatory barriers"

2.1.3 Search query and results

Upon writing the script for the search query, keywords within a category were linked through the Boolean operator OR, while categories grouping were chained via the Boolean operator AND. The sole exception was made for the categories "Climate (risk) modelling" and "Climate risk management", grouped up together through the OR Boolean operator. Such a choice was made because otherwise the conditions would have been too restrictive, considerably limiting the number and scope of documents returned by the search. Finally, the term 'health' was excluded through the use of the Boolean operators NOT (Web of Science) / AND NOT (Scopus). This allowed us to exclude for the search the literature on life insurance products, which is outside the scope of Deliverable 1.1. The final search query is structured as follows, where each bracket contains the keywords of the respective category reported in Section 2.1.2:

(Climate risk) AND ((Climate (risk) modelling)) OR (Climate Risk management)) AND (Other key topics linked to insurance) AND (Barriers) NOT health

Since WoS and Scopus use slightly different languages, the search queries strings have a different composition, but they are qualitatively identical. The two search query strings are reported in Appendix A.1.

The search returned 1,499 documents from Scopus and 4,612 from WoS. These were exported in a .ris file (full record mode), to be subsequently uploaded into Hubmeta for the screening phase.

2.2 AI-powered search

To integrate the systematic literature research, an AI-powered search was employed.

Funded by the European Union

2.2.1 AI tool

The AI-powered search was conducted on Research Rabbit (RR),[2] an online, free, "citation-based literature mapping tool". Starting from a document chosen by the researcher, RR generates a map of relevant documents that are connected to it (either because they are cited by it, they cite it, or they are thematically similar). This allows researchers to construct a set of relevant references for a given topic.

2.2.2 Starting documents

A set of 18 papers and reports were selected as a starting point and fed to RR to construct the map of connected literature. The selection of the 19 documents was based on a prelaminar review conducted by the authors, and they represent the most important references for the topic(s) of the deliverable. A list with the selected files is reported in Appendix A.2.

2.2.3 Results

Research Rabbit's algorithm returns a finding of 1,048 connected documents. These were also exported in a .ris file.

2.3 Literature review

A project was created on Hubmeta[3] to carry out the next phases of the literature review. Hubmeta is an online, free, open-source platform for literature reviews and meta-analysis. It allows users to deduplicate, screen and analyse documents. It also allows the project to be shared with multiple researchers to collaborate.

2.3.1 Deduplication

Previously obtained .ris files were imported into the data entry, for a total of 7,177 documents: 1,499 (Scopus) + 4,612 (WoS) + 1,048 (RR) + 18 (relevant references used as a base for AI-powered search). After the deduplication process, Hubmeta accepted 6,227 documents as unique. These moved to the title screening phase.

2.3.2 Title screening

The set of papers was analysed (title, abstract, date) looking for thematic affinity to the topics covered in the deliverable. Further exclusion criteria have been applied for literature antecedent the year 2000 or dealing with life insurance. In the end, 572 out of the 6,227 documents were accepted and moved to the full-text screening and data extraction phase.

2.3.3 Additional documents

The documents collected through the systematic and AI-powered searches were further integrated with documents collected by the authors through independent research (43) and by the project proposers during the drafting phase (20). These documents were automatically moved to full-text screening and data extraction. Moreover, in writing the deliverable, more documents still were added (119), for example grey literature not picked up by the systematic and AI-powered searches, cross-references contained in the previously-sourced documents or seminal papers which were outside the scope of the searches but are instrumental to the discussion. The list of all additional documents is reported in Appendix A.3.

---

[2] More information available here: https://www.researchrabbit.ai/

[3] More information available here: https://hubmeta.com/

Funded by
the European Union

2.3.4 Full-text screening and data extraction

The total number of documents that underwent full-text screening is 639 (576 sourced through systematic and AI-powered searches, and 63 sourced through independent searches). The documents were equally divided among reviewers. There were 11 reviewers, resulting in 58 documents per reviewer, with the remaining documents being taken by the WP leader.

During the full-text screening, reviewers also proceeded with the extraction of the relevant data and information from the same. This was done according to a number of variables defined by the WP leader and agreed upon by the reviewers, which contain important pieces of information for the deliverable. The variables used for data extraction are reported in Appendix A.4.

A Google Sheet document was created and shared with the reviewers. This contained a description of the variables used for data extraction and their entry values, and a data extraction matrix with the documents to be reviewed assigned to the respective reviewers. In addition to having to enter the information for the aforementioned variables, reviewers had to indicate whether a document was to be accepted or rejected and to provide a motivation for the decision. These were then double-checked by the authors of the deliverable for consistency with the scope of the same.

In the end, 364 documents were accepted following the full-text screening and their relevant data was extracted. To these, the 119 extra additional documents sourced by the authors were added. This brings the total number of documents that forms the basis for the deliverable to 483, even though not all of them have been used in the discussion. Figure 2.1 displays the literature review process.

2.4 Mapping of climate insurance penetration

The information regarding climate insurance penetration rates and IPGs extracted from the literature were complemented with estimates of insurance penetration rates provided by EIOPA within its "Dashboard on insurance protection gap for natural catastrophes" (EIOPA, 2023a). These have been used to produce the maps reported in Chapter 3.

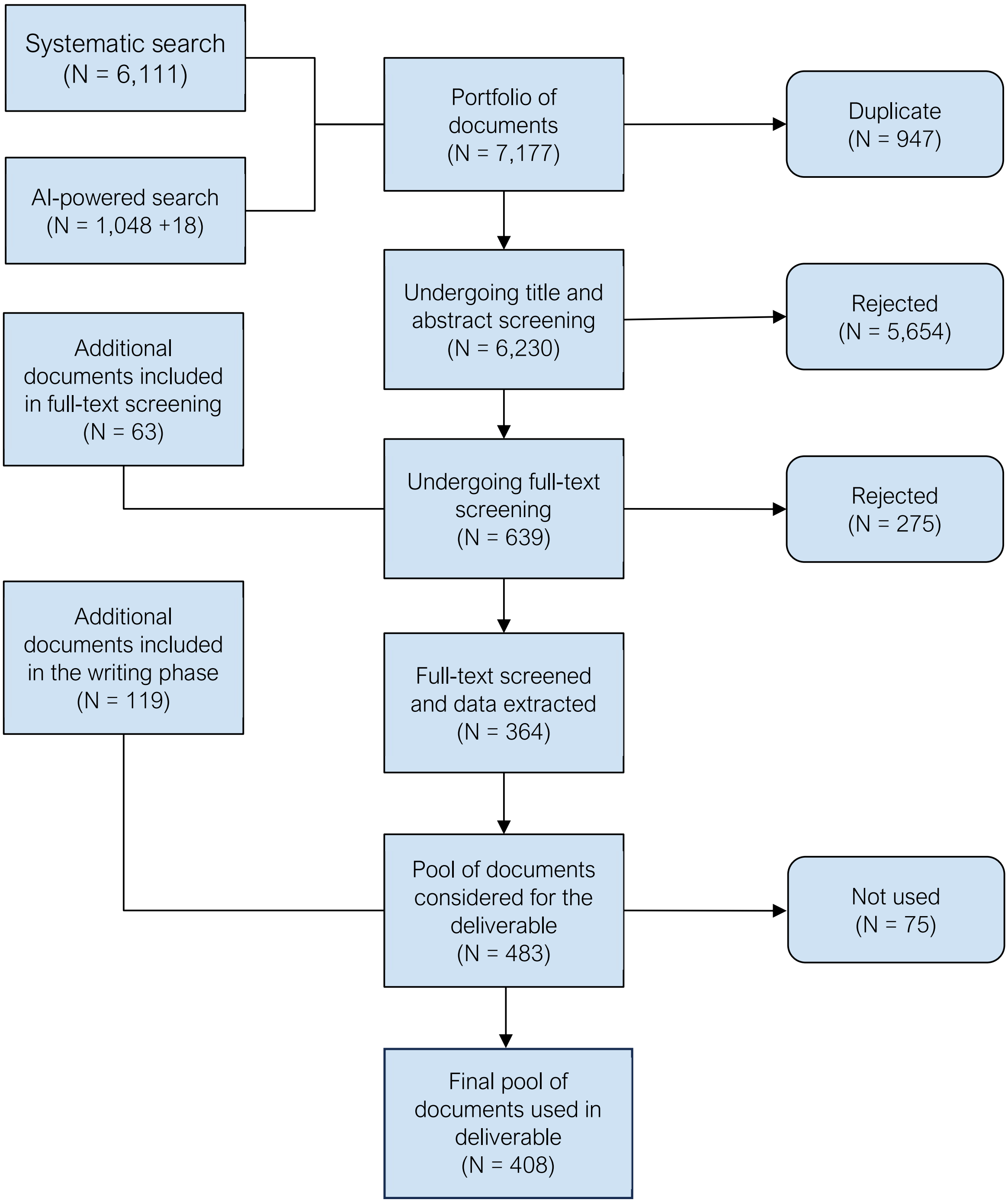

Figure 2.1: Literature review process

3 Mapping of climate-risk insurance systems and the climate-risk insurance protection gap in Europe

This chapter presents the various regimes that European countries have developed to manage, insure against and compensate NATCAT and climate-related risks. The aim is to look into differences in features of national systems to explain the variation of insurance penetration rates for four major climate hazards (windstorm, wildfire, coastal flood, and riverine/pluvial flood) across three main sectors (households, businesses and agriculture). The analysis considers the following countries: with Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic (Czechia), Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, and the United Kingdom.

The chapter begins by outlining the regulatory framework currently in place in Europe that sets out the rules and guiding principles that countries and insurers have to follow when designing their risk management strategies and climate insurance systems (Chapter 3.1). It then presents a systematic overview and assessments of the characteristics of such systems (Chapter 3.2) and how they translate into the insurance penetration rates for the various country-hazard-sector combinations (Chapter 3.3). A separate discussion is done for the agricultural sector (Chapter 3.4). Finally, it concludes with considerations on underlying trends, best performing features and recommendations (Chapter 3.5).

3.1 European Union's common framework for financial resilience against natural catastrophe risk

The greatest part of the national systems analysed belongs to member states (MS) of the European Union (EU). They share a common union-wide framework of institutions and mechanisms for dealing with climate disaster risk and financial stability. This section briefly presents the relevant contemporary common policy framework.

3.1.1 European Union Solidarity Fund (EUSF)

The European Union Solidarity Fund (EUSF), created in 2002, is a union-wide fund that provides financial assistance to MS following a catastrophic event. It is activated at the request of a MS or negotiating country when natural disasters occur or, since the revision of 1 April 2020, in the case of a major public health emergency. Eligibility is determined by total direct damage exceeding a country-specific threshold, distinguishing for disasters of national or regional level. The aid available in a given year is divided among qualified requests. To be activated, the EUSF must receive the full backing of the MSs and the Parliament, and it is not just an administrative decision by the Commission. The stated total budget for EUSF (2021-2027) is €4.1 billion, not including the total amounts for the Solidarity and Emergency Aid Reserve.[4] Insurable damage is excluded from the compensation, even though the term 'insurability' lacks a formal definition. Thus, under the EUSF, all private assets (residential, businesses, agriculture, etc.) are considered insurable and are, therefore, not suitable for relief. By contrast, all non-insured publicly owned assets (e.g.,

[4] For more details see: https://commission.europa.eu/strategy-and-policy/eu-budget/performance-and-reporting/programme-performance-statements/european-union-solidarity-fund-performance

buildings, infrastructures) are potentially eligible for aid. Prevention and preparedness investments are also excluded from the scope of the EUSF. Nonetheless, reducing existing risks by 'building back better' is encouraged by covering the additional funding needs from other sources (which may also include the European Regional Development Fund and EU Cohesion Fund; (European Commission, 2021)).

3.1.2 Solvency II

Solvency II (Directive 2009/138/EC) is the common European regime for insurance and reinsurance undertakings in the EU, which entered into force in January 2016. Its main goal is to ensure adequate protection of policyholders, setting requirements for insurance and reinsurance companies and beneficiaries. The Solvency II directive has EEA (European Economic Area) relevance, and it is centred around the management of risk exposure, including climate change-related risks.[5] Its rules require the use of risk-based premiums, which are considered a tool for risk signalling and foster private investments in mitigation; private prevention investments are indeed allowed to be set as conditional for underwriting a contract. EIOPA has delivered advice and an opinion on integrating sustainability in Solvency II, as part of the 2020 European Commission's Review of the Solvency II Directive. It is set to focus, among other features, on the contribution of the insurance sector to the European Green Deal, and the strengthening of the common insurance market (European Commission, 2021).

Below are reported some relevant Solvency II articles related to natural catastrophes.

Art. 104 'Design of the Basic Solvency Capital Requirement'. 6.: 'With regard to risks arising from catastrophes, geographical specifications may, where appropriate, be used for the calculation of the life, non-life and health underwriting risk mod'.

Art. 105 'Calculation of the Basic Solvency Capital Requirement'. 2. 'The non-life underwriting risk module shall reflect the risk arising from non-life insurance obligations, in relation to the perils covered and the processes used in the conduct of business …It shall be calculated, …, as a combination of the capital requirements for at least the following sub-modules: (b) the risk of loss, or of adverse change in the value of insurance liabilities, resulting from significant uncertainty of pricing and provisioning assumptions related to extreme or exceptional events (non-life catastrophe risk)'.

3.1.3 Common Agricultural Policy (2023-2027)

The current EU Common Agricultural Policy (CAP) recognises the importance of supporting the farming sector to successfully deal with risks including market risks and crises related to agricultural production. National strategic plans are allowed to support farmers against severe loss of production value or farm income, through participation in insurance schemes, possibly subsidised, and mutual funds (European Commission, 2023).

3.2 European national climatic risk coverage systems features

Differences among European countries in NATCAT coverage penetration rates can be explained through the characteristics and evolution of their national regimes. Differences in culture, geographic exposure, political values, and state involvement in the economy are determinants of

[5] For more details see: https://www.eiopa.europa.eu/browse/regulation-and-policy/solvency-ii_en

Funded by the European Union

the architecture of disaster coverage and compensation systems. This section presents an analysis of relevant features and differences between national regimes.

3.2.1 Climate insurance supply systems

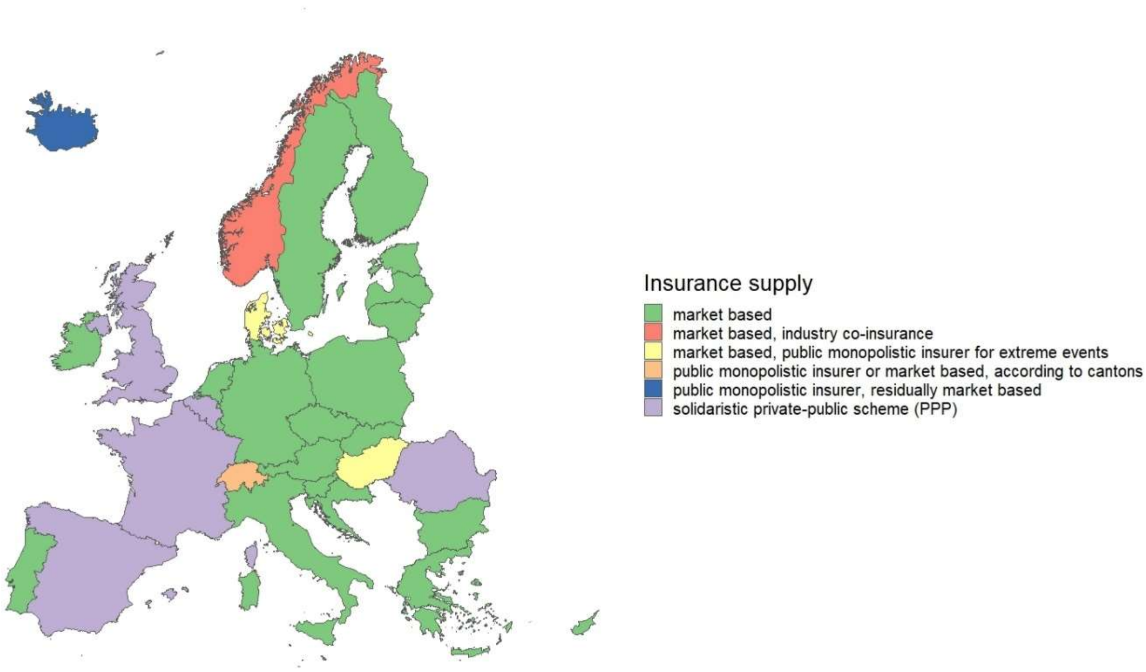

Figure 3.1: Insurance supply regimes

National NATCAT coverage frameworks for businesses and households in Europe can vary greatly and in multiple directions. The spectrum of variance generally depends on the involvement of the state as a regulator or active provider of insurance. Uptake of coverage can range from voluntary to mandatory for all unmovable assets. Likewise, public involvement in the supply of insurance can span from maintaining a functioning free market to the institution of a legal monopoly, with various degrees of collaboration with the insurance industry in between these extremes. The combination of coverage requirement and supply system thus determines how national stakeholders acquire insurance for their assets.

3.2.1.1 Voluntary market-based systems

We start by discussing national regimes based on the voluntary purchase of coverage through a free market system.

Funded by the European Union

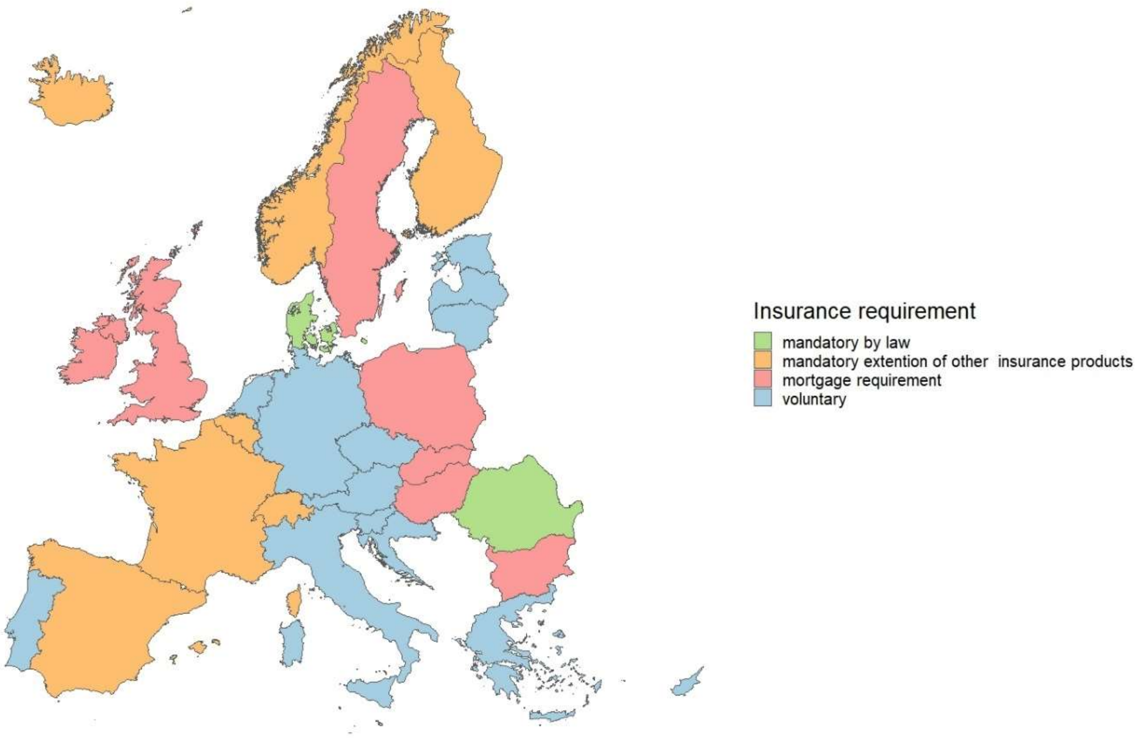

Figure 3.2: Insurance requirements

Germany is denoted by a market-based insurance system, with regional regulatory differences between Länders (i.e., the states that form the German federation). Penetration of private climate insurance in Germany is low, with a country average of around 40% as of today (EIOPA, 2023a), which is nevertheless a relatively high share compared to other European markets characterised by non-mandatory regimes. There is, however, a great degree of regional variation, owing mainly to pre-reunification political regimes.[6] Post-disaster recovery is usually managed through ad hoc ex post national measures. In the attempt of making the national climate insurance system more efficient, numerous reforms were formulated over the years, the most important one related to the introduction of mandatory comprehensive disaster insurance inspired by the French system. Despite a fervent political debate in 2004, such a reform was ultimately not enacted (Surminski & Thieken, 2017). In the following years, even though policy change had lost momentum, there has been an apparent paradigm shift from all involved stakeholders, moving in the direction of having more citizens' responsibilities, limiting ex post state aid and strengthening the collaboration between the private and public sectors. Notable pieces of federal legislation in this sense are the Federal Water Act of 2009 (Wasserhaushaltsgesetz vom 31. Juli 2009) and the Flood Control Act II (Hochwasserschutzgesetz II Vom 30. Juni 2017).[7]

[6] For instance, the average penetration rate in the state of Baden-Württemberg reaches 95% (Surminski & Thieken, 2017) while in the Free Hanseatic City of Bremen it is only 11% (Keskitalo et al., 2014).
[7] For instance, the Federal Water Act states that 'there is no individual entitlement to flood protection' and that 'every person who may be affected by floods is, as far as possible and reasonable, obliged to take appropriate precautionary measures'.

Funded by
the European Union

The Austrian system is comparable to the German one, albeit with the federal state guaranteeing partial compensation to all affected citizens. In this sense, the regime works as a widespread insurance tool for the public. Despite such assured public relief, Austrian homeowners display relatively high levels of investments in private protection measures. An explanation for such a counterintuitive trend may be found in the general engagement of homeowners in the construction of their properties (Hanger et al., 2018). Fostering this tendency, the collaboration between the private insurance industry and Länder has allowed the publication of the HORA online platform, providing free access for citizens to risk zoning for natural hazards in Austria (Seifert-Dähnn, 2018).

The Netherlands represent a peculiar case, in light of their history of strategic water management as a national interest. In the aftermath of the disaster of the North Sea floods of 1953, the Dutch insurance industry, historically well developed, collectively issued a so-called ‘binding decision’ applying to all their members, prohibiting them from insuring flood and earthquake risks (Bruggeman & Faure, 2019). The stated reasoning behind the declaration was that a private insurance market against such risks would have led to adverse selection from the few households and businesses interested in underwriting. The industry was also concerned about the limited financial sustainability of the regime in case of a major event, and the lack of data and modelling capabilities to calculate premiums. The state’s response was to undertake sizable investments for the construction of dykes, dams, and other infrastructures to protect against coastal inundations, the so-called ‘Delta Works’. As of today, this system protects from flooding events with return periods of up to 10,000 years along the coast, and 1250 years along riverbanks (McAneney et al., 2016). With the constitution of the EU and the single market, the Dutch insurance industry's ‘binding decision’ had to be modified, since competition rules, and it was subsequently withdrawn in 1998, with Dutch insurers being allowed to cover disaster risk (Bruggeman & Faure, 2019). To this followed the creation by the government of a public disaster fund (called Wet Tegemoetkoming Schade bij rampen en zware ongevallen, or WTS), which declares the aim of the state to compensate the loss resulting from a disaster (such as floods) using public resources deriving from taxpayer income. A declaration of calamity and subsequent compensation are at the discretion of policymakers. Since the 2000s, there have been many attempts by both the academia and the insurance industry to push for a Public Private Partnership (PPP) solution, all of which have been consequently rejected by the state for more ideological and less pragmatic reasons: moral hazard on the ground of financial guarantee and unjust redistribution of risk by mandatory insurance extension. The national government has also typically responded negatively to any EU regulatory push to expand private coverage against natural disasters. The possibility of a collective industry-owned reinsurer entity was also surveyed, but the attempt was discarded by most insurance companies due to concerns over financial sustainability (Bruggeman & Faure, 2019). The current scheme still embeds some important principles that leave room for future reforms: individual commitment by policyholders for prevention, a stated future goal to reach a working PPP management, and a reaffirmed ultimate responsibility of the state in prevention as a matter of national security (Bruggeman & Faure, 2019).

In Slovenia, there is no public mandatory scheme for insurance (EIOPA, 2023a), and the offer by the insurance industry is not diversified by risks (Zorn et al., 2016). The transition to a market-based insurance system of insurance following the dissolution of the former Yugoslavia has been slow, both from institutional stakeholders and private parties. As of today, the law ascribes the responsibility for personal protection to the local community, rather than explicitly to individuals (Republic of Slovenia, law 97/2010). Slovenia's landscape has been affected by unregulated urbanisation in the second half of the 20th century. The vast majority of illegally built dwellings of the Cold War era are located in flood-prone areas and have been condoned ever since. This has heightened risk levels, particularly around the main urban areas (Zorn et al., 2016).

In some market-based systems in Southern Europe, as the impacts of climate change have become more severe, there has been some momentum of reform in the last few years, for the introduction of some mandatory requirements.

Owners or managers of large or communal residential property in Cyprus must cover against wildfire, earthquake and lightning (Cyprus Civil Defence, 2020). Greece and Portugal, could see longer and more intense wildfire seasons in the next decades (OECD, 2021), together with accrued flood risk. This will cause a growth in the uninsurability of such risks for a large portion of the country by the middle of the century, once assuming that the premium pricing remains risk-based (Tesselaar et al., 2022). In Greece, the debate around mandatory universal insurance for the wider public has recently returned to the political stage and, in the last year, underwriting of private coverage has taken up. This is due to widespread public recognition of climate change effects and an arrangement for a 10% discount in the Single Property Tax for asset owners covered for earthquakes, fire or floods.

The Italian insurance market for NATCAT has always been based on voluntary purchase and presents significant geographical and sectoral variations. Penetration rates have generally been considerably lower than in other European countries, despite the high homeownership rates of Italian families. Reasons for such a limited diffusion could be cultural, like low trust in financial institutions and modest average financial literacy (Roder et al., 2019), as well as structural charity hazards due to recurrence of ex post governmental relief after disasters, even if uncertain in quantity for the final beneficiary (Tesselaar et al., 2022). The first attempts at national policy reforms of the NATCAT risk management framework are found in the aftermath of the 1980 Campania earthquake (Gizzi et al., 2016). After more than thirty years of attempts to establish some form of a national pool or mandatory uptake requirement, today, according to the budgetary law of 2024 (Legge 30 dicembre 2023, n. 213), every business, except farms, must acquire actuarial protection against earthquakes, pluvial and fluvial floods, and landslides. Insurers are obliged to offer coverage at any condition, calculating it through risk-based assessment. The Italian state, via its controlled SACE fund, should act as a public reinsurer under a limited public finance guarantee.

3.2.1.2 Quasi-mandatory systems

In a subset of market-based systems, financial institutions generally require coverage for at least some climate-related hazards as a precondition for mortgages. These conditions create a de facto mandatory underwriting requirement, even though by linking national coverage rates to estate purchases. Thus, national penetration rates may fluctuate according to the trends of the domestic housing market, in systems based on NATCAT insurance as a requirement for mortgage.

The Polish system of disaster risk management has evolved from the fall of the socialist political and economic regimes in eastern and central Europe, in a similar fashion to the Czech Republic and Slovakia, presenting now relatively high penetration rates of private insurance. Disaster risk management had been treated as a secondary issue during the overhaul of the social, political and institutional system of Poland after the fall of the Eastern Bloc and the joining of the EU. It was the flood of 1997, and the adherence to the common European market to give force to reforms. The catastrophic flood of 1997 triggered a deep revision of the system, and there was an (unsuccessful) attempt to institute a countrywide universal mandatory insurance provision for every household (Matczak et al., 2016). Political opposition at the time maintained that it would have eventually diminished the effectiveness of recovery. However, the 1-in-200-year event pushed the state to enact considerable investments in flood defence infrastructures on national and regional levels. The building of the modern policy framework for disaster risk management comes with the drawing of the Water Act of 2001 (Polish Journal of Laws January 1, 2002) and the accession to the EU. The Implementation of the EU Floods directive brought the development of flood hazard and damage maps and risk management plans (Matczak et al., 2016). After a second large flooding event in 2010, Poland saw a renewed attempt to foster its risk management capacity. There was a second (also unsuccessful) attempt to draft a compulsory catastrophe insurance law, foreseeing the two state-owned companies (PZU and Warta) to offer standalone insurance to every homeowner, while partially reinsuring the risk of the international markets. Meanwhile, the Water Law was amended, including flood risk maps, designed by the State Water Company Wody Polskie, into local zoning plans (Pollner, 2012). This gave local governments the ability to deny construction rights in high-risk areas and eventually stop them altogether after 2018 (EIOPA, 2023a). A compulsory scheme for protection does indeed exist in the country, and concerns farms and rural dwellings which apply for state support (European Commission, 2017). Thanks to the increasing requirement of coverage by mortgage lenders, and the spread of mortgage institutions after the fall of socialism, homeowners' underwriting of NATCAT insurance as an addition to property insurance has increased (Pollner, 2012).

The Republic of Ireland is subject to the hazards of riverine and coastal floods, due to (recurring high tides, as well as windstorms. The supply of insurance is left to a free market system; however, some areas may not be covered by private insurance, as they are deemed too risky and prone to flooding (EIOPA, 2023a). In fact, the uninsurability of high flood-risk areas is expanding in the country (OECD, 2021). There is some form of public backup for low-income households, and no legal requirement for homeowners or small and medium enterprises (SMEs) secured by immovable property to be covered. Anyway, mortgage lenders require underwriting of insurance as a guarantee (Tesselaar et al., 2022). Deflating rates of mortgage uptake, and the possibility of opting out by policyholders, may have had a restraining effect on the spread of insurance coverage in the last few years (EIOPA, 2023a). In 2016, legislation was drafted in the Irish parliament to prevent insurance corporations from discriminating against new contracts due to past claims, but it has not been enforced (OECD, 2021).

Since 2014, Finnish land- and homeowners have found flood insurance integrated into their property coverage, which is widespread in the country (Tesselaar et al., 2022). This change was the output of a reform towards individual responsibility in financial protection against natural hazards, as in the same year public guarantee (on land and non-movable properties) was restricted from events with a return 20-years period to a 50-years return period (EIOPA, 2023a). In Sweden, due to the low historical relevance of natural disasters as a threat to economic development, the climate risk management system is institutionally decentralised and integrated only along economic sectors; the result is a multi-level governance structure (Wiering et al., 2017). Swedish mortgage lenders require property insurance (residential and commercial) as a condition for underwriting (Tesselaar et al., 2022). Property owners are also legally required to use their property in a way that does not increase the risk of flooding of a neighbouring property. Given the prominent role of developers in local spatial planning, urbanism in the country has endogenously progressed to flood risk avoidance (Wiering et al., 2017). However, future climate scenarios could put under stress the affordability and sustainability of the arrangement (European Commission, 2017). A sign of this is the increasing call for engagement of the national government in dealing with climate-related risks (Wiering et al., 2017).

3.2.1.3 Private-public partnership systems

The insurance industry can autonomously find arrangements to better manage and diversify risk, as Norway's example shows. The Norwegian Natural Perils Pool (*Norsk Naturskadepool*) was established in 1980 as an intra-industry co-insurance scheme, and it is regulated by the Natural Perils Insurance Act (*Lov om naturskadeforsikring,* (OECD, 2021)). NATCAT insurance in Norway is thus bound with fire insurance for commercial and residential dwellings. In the pool, every insurance company providing fire and NATCAT coverage is involved in Norsk Naturskadepool, and the pool itself functions as a central equaliser for the industry, settling claims and expenses in the participating companies along their national market share (EIOPA, 2023).

Some national systems push the arrangements further than the Norwegian one, with a structural collaboration between the state and the insurance industry. These are generally denominated private-public partnership (PPP) systems, and, among them, the state can have an active role in being a direct supplier of coverage, or be a guarantor of financial resilience, absorbing extreme risk.

The French system for natural catastrophe recovery is one of the most prominent examples of stated national solidarity. Such principle, specifically addressing climate hazards, is embedded in the Constitution of the Fifth Republic, preamble, paragraph 12: 'The Nation declares all French citizens to be equal and united in solidarity when faced with loss resulting from natural disasters.' The current French system, set in place in the first year of the Chirac government in 1982, after disastrous flooding events occurred the year before, is centred around the *Caisse Centrale de Réassurance* (CCR), a state-owned entity for competing in the free domestic market. The CCR fulfils various roles in the industry of natural disaster insurance. In particular, the institution is both a state-backed reinsurer, in competition with other reinsurers and a prime reinsurer for businesses and citizens (Keucheyan, 2023). The Caisse from being an emanation of the Republic became a state-owned limited responsibility company in 1993 and recently spun off its reinsurance duties in CC Re (CCR, 2021).[8] The principle of individual and communal responsibility has been embedded since the inauguration of the system. featuring a series of upfront deductibles for policyholders, encouraging the adaptation against preventable risks. Prevention is also incentivised as municipalities ought to design and enact risk prevention plans. These links between compensation and prevention have been strengthened by a sliding scale that adjusts deductibles applying to communes that do not have risk prevention plans, to encourage them to introduce them. Accordingly, with the reform of January 2001, in municipalities without risk prevention plans, it has been possible to adjust (upwards) deductibles after two government declarations of disaster concerning the same types of peril (except for motor insurance policies; (CCR, 2021)). This feature is designed for citizens to put pressure on local governments and thus be proactive in risk-reduction. In terms of financing damage-mitigation measures, since 2005 the Fund for the Prevention of Major Natural Risks, also called the ‘Barnier’ fund, has been providing subsidies of up to €125 million per year for studies on assessments of natural disaster risk and potential

[8] In the present report they are still counted as the same entity for simplicity.

prevention and protection measures for buildings (Poussin et al., 2013). In such an arrangement, expertise employed both by the private and public sectors is engaged in providing solutions, mapping risks, and collecting data. However, thanks to geographical information systems (GIS) development, and the knowledge monopoly that CCR built and maintained through the decades thanks to the direct provision of national intelligence, it is now under pressure from the private sector. Large groups could in theory provide more accrued risk calculation and consultancy for prevention investment in the future, tempting them to break away from the framework (Keucheyan, 2023).

The closest system to the French one is probably Spain's, centred around the PPP entity *Consorcio de Compensación de Seguros* (CCS). CCS was founded in 1941 as a public instrument during the reconstruction after the Spanish Civil War of 1936-39, to indemnify Spanish insurance companies against claims arising from unpredictable events including natural disasters (McAneney et al., 2016). Although state-owned, CCS assets are separated from public ones, and in its directive board of twelve members, six seats are held by high-level executives of private insurance companies (Jarzabkowski et al., 2018). Thus, the stated aim and the practice of the system is to allocate all the uninsurable extraordinary risks outside the market mechanisms. Insurers must apply a surcharge on every premium in Spain, be it life, health, estate, or business insurance, and collect it to fund the CCS. It must be highlighted how private insurers can in fact opt out of the CCS mechanism but must provide by law extraordinary risk coverage to policyholders while transferring the surcharge, minus a 5% deduction, to cover transaction expenses (Hudson et al., 2020). Being this latter option financially riskier compared to the public one, there is hardly any alternative supply.

The Belgian Waarborg Natuurrampen system has recently evolved from direct post-disaster state aid to an extensive PPP regime. Such policies have resulted in a semi-compulsory penetration of insurance for 90-95% of the Belgian population (Bruggeman & Faure, 2019). The first reform to the arrangement came with the Act of 21 May 2003, which introduced flood coverage as a mandatory extension to the fire insurance policies concerning simple risks (which were made already compulsory for homeowners in 1992). The mandatory extension of 2003 applied exclusively to estates built on flood-prone land (an optimal extension was indeed available for property outside this risk area). The three Belgium's regional governments had been entitled to design legally binding risk maps to be updated. The subsequent act of the Act of 17 September 2005 introduced full national solidarity as a founding principle of the regime, expanding the mandatory coverage extension to the whole territory. To mirror other successful continental PPP schemes, the state-owned *Caisse Nationale des Calamites* (CNC) was established in 2007, giving it analogous tasks to those of CCR and CCS (Paleari, 2019).

The Romanian framework for disaster risk management and recovery appears as a unicum in Central and Eastern Europe, inspired by the continental public-private partnership experiences, even though lagging behind in terms of the coverage gap. Romania's territory is periodically subject to earthquakes and riverine inundation. From 1960 to 1990, the socialist republic engaged in extensive construction of hydraulic protection infrastructure for the mitigation of inland flood risk (EIOPA, 2023a). Due to the consequences in terms of ecosystem well-being and increased intensity of the impact of flood events caused by the transformation of the landscape, the engineering measures of the later 20th century can be considered examples of maladaptation (Hanger et al., 2018). With the country joining the EU in 2007, and to expand coverage among households and farmers, the government instituted a compulsory insurance scheme against the major risk of flood, landslide and earthquake, the so-called PRAC (Romanian Program for Catastrophe Insurance), co-financed by the World Bank. The prescription of adherence lasted until 2015 (European Commission, 2017), and, in the meantime, the government and the private industry joined forces to provide an affordable offer to the public. In 2009 the system was reformed with the introduction of the *Pool-ul de Asigurare împotriva Dezastrelor Naturale* (PAID), a separate and novel insurance and reinsurance company made up of a consortium of private insurers and reinsurers (Hanger et al., 2018). PAID provides two affordable sets of policies against flood, earthquake and landslide to all national homeowners. Overall, the policy framework entitles the private industry to the important responsibilities of supplying affordable products and spreading risk awareness, while local authorities have to ensure compliance (World Bank, 2018). Even though the system appears to be sophisticated and pushing for compulsory widespread take-up, penetration rates appear to be low and stagnant, especially in Romania's countryside. The root of this shortcoming may be found in a general distrust of financial institutions, low awareness of risk and knowledge of national policies, and limited ability to enforce regulations (Hanger et al., 2018).

The United Kingdom's approach to insure against natural catastrophes is rather unique in the European panorama. In the likes of other Atlantic countries, Britain has flooding as its major climate hazard, whose correlated risks are projected to increase drastically in this century (Surminski, 2018). Britain has one of the longest-standing traditions of insurance market penetrations in the modern world. With a slow evolution throughout the decades, today's system centred around a PPP entity called Flood Re. The approach held in addressing the insurance protection gap has traditionally tried to combine, on the one hand, the principle of profitability for the insurance industry and, on the other hand, a widespread coverage and affordability for policyholders (the latter, inadvertently, has given an unstated solidaristic structure to the British system). As extreme events have acquired strength and intensity in the last thirty years, the financial sustainability of the traditional system (the so-called 'Gentlemen's Agreement' established in 1961) has been compromised, and the industry and the government have attempted slow steps toward reshaping it along the actuarial principle of personal responsibility (O'Neill & O'Neill, 2012). After formal litigations between the Association of British Insurers (ABI) and the government, a series of new compromises in the form of subsequent Statements of Principles (SoP) were agreed upon in the 2000s. This SoP gradually restricted the commitment to universal affordability of insurance and coverage of the industry, while requiring more state intervention. Some estates, albeit a very small number, were rendered uninsurable since the industry pledged to cover only homes with a probability of being flooded in any single year of 1-in-75 or less, or where flood defences planned for the next five years would bring the risk down to that level. For another, the premiums and excesses charged by insurers would now be allowed to reflect different levels of flood risk; affordability of cover was no longer guaranteed, and for the first time the postulate of individual responsibility for the policyholders was introduced in the national arrangement (Christophers, 2019). On the other hand, as the housing crisis unfolded in the 2000s, the central government put mounting pressure on municipalities for new estate development, which led them to neglect the commitment to not develop on high-risk greenfields (Martin, 2014). Such urban expansion was oftentimes used for social housing, and its dwellers could not often acquire coverage from the new market scheme nor influence municipal investments against hazards. To address this parallel accruement of risk, another provision was added as output by the continuous bargaining between ABI and the government: the industry would no longer guarantee coverage on estate built after 1st January 2009 in flood-prone areas. The implication is that homes constructed beyond this date will either be constructed outside of floodplains, or in flood-resilient ways if they had to receive market-provided coverage. However, the statement of principle scheme left a considerable portion of dwellers uninsured country-wide. Plus, the implicit streamline of cross-subsidies remained largely intact, as the ABI estimated that 78% of policyholders were paying a premium that did not fully reflect their flood risk (DEFRA, 2014). After years of bargaining and the situation becoming more and more unsustainable for municipalities, businesses, and citizens, a new regime of natural hazard insurance was inaugurated in April 2016 with the institution of Flood Re. Flood Re, differing from other continental PPPs already shown, is owned by the private insurance industry, although still being accountable to parliament under the terms of the 2014 and 2015 legislation that mandated its establishment (Christophers, 2019). Flood Re would act as a reinsurer for the market on a not-for-profit basis, collecting levies from every flood insurance in place issued by participating private insurers, in accordance with risk and property value, while from its part also seeking reinsurance cover from the global reinsurance market. However, Flood Re has been created to be a medium-term rather than a definitive solution. It was designed to have a due date of 25 years, after which the system would, in theory, fully convert into an actuarial, risk-reflective pricing system (Christophers, 2019). The government's and industry's stated goal under Flood Re is to slowly divert from implicit countrywide cross-subsidies while investing in adaptation (or managed retreats). With this in mind, Flood Re rates would be revised on a five-year basis as economic development unfolds and new data is collected. A study by Surmisnki (2018) shows that the pool is beneficial in its function to provide affordable insurance, even under climate change. In particular, the findings suggest that Flood Re would achieve its aim of securing affordable flood insurance premiums. However, the analysis also highlights that Flood Re would be placed under increased financial strain if challenged with increasing risk as highlighted by future climate change projections.

3.2.1.4 Public insurance provider systems

Finally, hereafter are presented examples of countries that provide public insurance against natural hazards. These systems range from coverage options for uninsurable homes in high-risk areas to monopolies encompassing all assets. These kinds of regimes allow for collaboration with the insurance industry and are backed by the state for solvency while imposing solidaristic principles and providing coverage for uninsurable areas.

In Hungary, homeowners are usually required to underwrite contracts of insurance for mortgage borrowing. They acquire protection through a market-based system. The Magyar government provides publicly backed insurance for those households deemed uninsurable by the free-market industry (Radu, 2022). Dwellings situated in high-risk floodplains can opt-in for a compensation fund (*Wesselenyi Miklos Ar-es Belvizvedelmi Alap*) to gain access to eventual ex-post relief. This system prevents the declaration of ad hoc post-disaster laws (Pollner, 2012), which risk exacerbating charity hazard. However, even though the participation rate remains very low, the government has phased out the signing of new contracts after 2016 to discourage new development of high-risk areas (European Commission, 2017).

Looking at Switzerland, in 19 of the 26 cantons coverage against climatic risk is provided by public monopoly insurers, and for the remaining parts by the private insurance market (EIOPA, 2023a). Insurers are involved in enforcing building codes, drawing land-use planning and investing in prevention infrastructures (an average of 15 % of their premium incomes) along with the Swiss state. Public monopolies also fund fire and cantonal civil defence services and provide warning services, while some private groups have combined public natural hazard maps with national economic and claims data to create better risk maps accessible to the public (Seifert-Dähnn, 2018). Natural disaster coverage is underwritten by homeowners and businesses as a flat-rated and compulsory extension of fire insurance, that takes into account broad risk characteristics, such as location in specified hazard zones and type of construction (OECD, 2021).

The Icelandic system of financial protection against natural catastrophes is centred around the Natural Catastrophe Insurance of Iceland (*Náttúruhamfaratryggingar Íslands*, NTI) one of the first dedicated public pools in the world, founded in 1975 (Johannsdottir, 2017). NTI is a public institution that operates as a primary and exclusive insurer against all natural hazard risks (usually earthquakes, volcanic eruptions, landslides, avalanches and floods) except for floods due to snowmelt or precipitation (EIOPA, 2023a). Participation in the pool is mandatory. Coverage is required by law for every movable and immovable property (residential and commercial) and public infrastructure. Private industry insurers can cover minor events using risk modelling, incentivise private risk mitigation, and are allowed to redraw contracts in case no property-level mitigation measures are enacted in the aftermath of loss events (Seifert-Dähnn, 2018).

The Danish Storm Council was instituted in 1990, as a response for the growing unaffordability of flood insurance, particularly for coastal dwellings (European Commission, 2017). It is a public insurance pool, structured to allow the Danish state to cover damage and losses caused by flooding (riverine or coastal) with a 20-years return period or greater (Seifert-Dähnn, 2018). The collaboration between the insurance industry and municipal institutions has led to data sharing and participative risk mitigation efforts (Seifert-Dähnn, 2018). This was the product of a particular condition that would have been hardly possible in a free market arrangement: first, companies and municipalities had to mutually prove their contribution and, second, the presence of a public provision of protection facilitated the sharing of usually industrially-held and strategic claim data. Data sharing is also protected in terms of privacy by the anonymity of spatial inputs and their limited temporal availability. A considerable degree of trust has thus been built between private and public stakeholders thanks to the availability of common platforms (European Commission, 2017).

3.2.2 Premium structures

Where the state is more involved, PPP entities or industry arrangements are established, and premiums are generally not risk-based. Instead, they can take the form of fixed fees or flat rates of other baseline premiums or value of the asset covered. Diverging from actuarial methods, fixed fees and flat rates are instrumental in the application of a solidaristic principle. They are also generally matched with some form of mandatory requirement for households and businesses, extending the base of potential policyholders and diversifying risks. Premiums not based on risk modelling impose cross-subsidization into the system, as demand from different geographical and socioeconomic conditions faces the same terms of offer, regardless of exposure (European Commission, 2017). This is particularly true in larger countries whose diversity of climates, geography and local development tends to be higher**.** National schemes with non-risk-based premiums also allow less technically developed insurance companies to compete in the market (European Commission, 2017). Incentives for individual risk reduction investments are featured in these regimes through specifically designed policies.

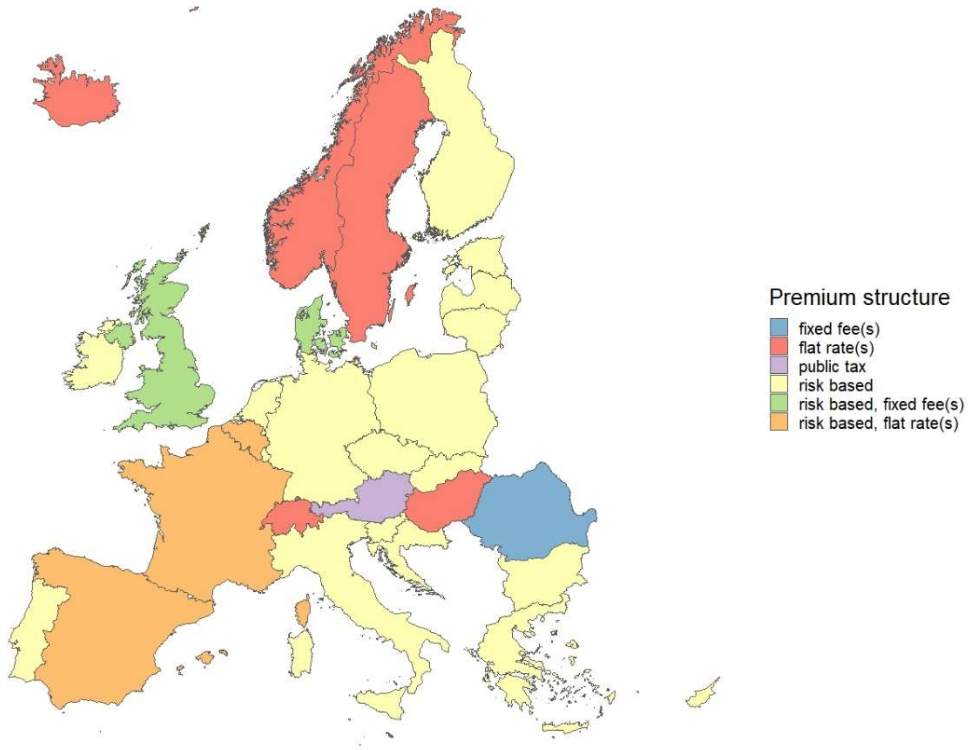

Figure 3.3: Premium structure

Among market-based systems, some peculiar cases can be highlighted. Polish households can choose between insuring at cadastral value or current market value, with the former being the preferred choice in fear of higher premiums, despite leading to claim payments considerably lower than the actual reconstruction costs (Pollner, 2012). In 2001, in Germany, the collaboration between the German Weather Service and the insurance industry led to the establishment of ZURS, a zoning system of risk for the whole country. Initially, it divided the German territory based on the probability of inundation, with the objective of being used as a baseline for risk assessment. It evolved into ZURS GEO in 2003, becoming publicly available to citizens. Nowadays, the risk zones are four, with flood probabilities ranging from less than 1/200 to greater than 1/10 (Hudson & Berghäuser, 2023). While it is an important tool for raising awareness and providing risk assessment for the collectivity, further specific evaluation is needed upon underwriting insurance policies. In 2014 the insurance industry developed a 'flood passport' (*Hochwasserpass*) for homeowners in an attempt to raise awareness and promote private measures of prevention. A *Hochwasserpass,* if well-rated, is intended to be functional for bargaining mortgages with financial institutions (Surminski et al., 2020). In Ireland, premiums are risk-based and the insurance industry has available a sophisticated set of mapping tools to set premiums and coverage availability (EIOPA, 2023a). While enhancing individual responsibility for mitigation, the highly developed actuarial capacity of the Irish industry has contributed to widespread uninsurability and unaffordability for high-flood-risk zones in recent years. Finally, Sweden represents a unique case since, despite being a pure market-based system, the premium structure is flat and independent from risk exposure. This, however, does not seem to affect affordability or penetration rates (Surminski, 2014), probably due to mandatory requirements for mortgage underwriting.

In the presence of PPP entities, it is possible to distinguish a subset of national regimes centred on flat additional premiums. CCR is financed primarily by the so-called 'mandatory extension of guarantee' ('*extension obligatoire de garantie*'). When a policyholder, being a person or a company, buys insurance for their home or office (regardless of whether they are the owner or a tenant), vehicle, or, in the case of businesses for operating losses, the policy is set as a 'baseline contract' ('*contrat socle*'). It mandatorily includes an amount dedicated to natural disasters that the policyholder or the insurer cannot opt out of. This is called an 'additional premium' or 'surpremium' (*'prime additionnelle*' or *'surprime'*), which is a predetermined percentage of the premium. This premium surcharge automatically gives the policyholder a right to insurance in the event of a natural catastrophe. The level of the surcharge is defined by the state, and periodically updated. It amounted to 5.5% of the home-owning baseline contract when the regime was created. Today, it amounts to 12%, and to 6% for vehicles (Keucheyan, 2023). This sum is collected by private insurers as a specific class of premiums. A similar system is adopted also in Spain. The surcharge applied on every insurance policy by CCS depends only on the type of insurance interest, with no progressive measures based on the assets' value or geographical risk, and with premium surcharges ranging from 0.008% to 0.021% of the insurance premium (Mysiak & Pérez-Blanco, 2016). France and Spain have similar surcharge regimes, even though the latter, having any category of insurance contract signed in the country as a base, can impose rates that are a thousandth of those of CCS. The Belgian case has a more developed regulation, controlling also for the price of baseline contracts. The Belgian government has instituted the *Bureau de tariffication* (BDT) whose main task is to arrange premium rates, setting upper limits (Atreya et al., 2015), and contractual conditions for natural disaster risk that allow insurers to refuse cover under certain terms (EIOPA, 2023a). The compulsory *surprime* to the fire and simple risk insurance is set as a 12% rate for all homeowners in the country, whether they are located in risk areas or not, in line with the French system (Bruggeman & Faure, 2019). Every new estate developed in a risk-prone area after at least 18 months of the publication of the regional flooding risk maps shall not benefit from the cap on premiums set by the BDT, and insurers are not obliged to provide landlords with any coverage (Atreya et al., 2015). This is an example of risk reduction incentives through risk-based modelling within a solidaristic regime.

An analogue use of flat rates can also be found in countries with public or industry arrangements not developed into PPPs. In Norway, insured businesses and homeowners face a flat addition to premiums collected by Norsk Naturskadepool (OECD, 2021). In similar fashion, for the funding of the Icelandic NTI, premiums are legally set at 0.025% for properties and contents and 0.02% for infrastructure, in line with the Spanish rate (Johannsdottir, 2017). Flat rates are also in place in Hungary, as a flat percentage of general household property insurance premiums. This more solidaristic structure can be seen as an incentive for takeup and a factor contributing to the widespread coverage in the country (European Commission, 2017). Lastly, although with differences between cantons, in Switzerland natural disaster coverage is purchased by homeowners and businesses as a flat-rated and compulsory extension of fire insurance. This, however, takes into account broad risk characteristics, such as location in specified hazard zones and type of construction, which the Swiss insurance industry helps to design (OECD, 2021). The Swiss premium structure thus represents a hybrid between a solidaristic and risk-based system.

With regards to fixed fees, they are present only in strongly interventionist systems. The Danish Storm Council is financed through the collection of a fixed surcharge of around €4 on mandatory property fire insurance (European Commission, 2017). Fixed premium pricing schemes allow for cross-subsidisation between low-risk and high-risk policyholders, while, on the other hand, supporting affordability for the wider public (OECD, 2021). Coverage of minor climatic risk is left to the free market, which generally uses traditional risk modelling (see Chapter 4.2.1) for premium pricing. In the UK, Flood Re collects levies from every flood insurance in place issued by participating private insurers. These fees differ in accordance with risk and property value and are used to directly subside premiums for estates deemed uninsurable under the previous regime, around 2% of the total of the country, while lowering premiums for all other policyholders in medium and low-risk areas. Even though sophisticated, solidaristic and accounting partially for risk, the British system seems not to be unaffected by questions of social justice. It must be highlighted how Flood Re covers top-end riverside mansions in council tax band H, even though the original proposal was for these to be excluded, in the likes of estates developed after 2009 in high risk zones (DEFRA, 2014). Indeed, it is expected that homeowners in affluent but relatively flood-prone parts of the south-east of England, such as the Thames Valley, will be Flood Re's 'biggest beneficiaries' (Ralph, 2016). Surminski (2018) points out that the gap between subsidised and risk-reflective premiums under Flood Re is likely to continue increasing, which raises serious questions about how policyholders will be able to afford premiums after Flood Re transitions to risk-reflective pricing beyond 2035.

In Romania, on the other hand, fixed fees constituted the sole kind of premiums, with the fee varying depending on the kind of property insured: Type A (policy limit of €20,000 per dwelling with a premium of €20) and Type B (policy limit of €10,000 per dwelling with a premium of €10), for more basic construction (EIOPA, 2023a). Although granting affordability for the public, these fees do not appear to effectively incentivise the take-up of coverage, which is still very low (20%), especially in light of the legal requirement for homeowners to purchase it (Radu, 2022). Finally, Austria represents a unique case. Funds for federal post-disaster relief is collected through a public tax, which is excluded from property insurance policies, and applies the social justice principle, as low income households are generally relieved more than proportionally (T. Thaler & Hartmann, 2016).

3.2.3 Climate reinsurance systems

Risk managed by an insurance company may be ceded to a second financial institution, called a reinsurer, to protect against the possibility of insolvency and default. Secondary risk can be dealt with innovative products, such as catastrophe bonds, high-yield debt instruments designed by the insurance industry for raising capital in the event of a natural disaster. Risk transfer through reinsurance mechanisms is usually managed through access to international capital markets. This is the default condition for national market-based schemes, regardless of insurance requirements. Some differences can arise in the level of recognition of advanced financial instruments. An example is Malta, where the insurance industry and the public regulatory frameworks have been modernising in the last few years, recognising reinsurance special purpose vehicles and securitisation cell companies (SCCs). An SCC is a single legal entity that can establish one or more segregated cells for the purpose of entering into securitisation transactions, including insurance-linked securities transactions such as catastrophe bond issuances.

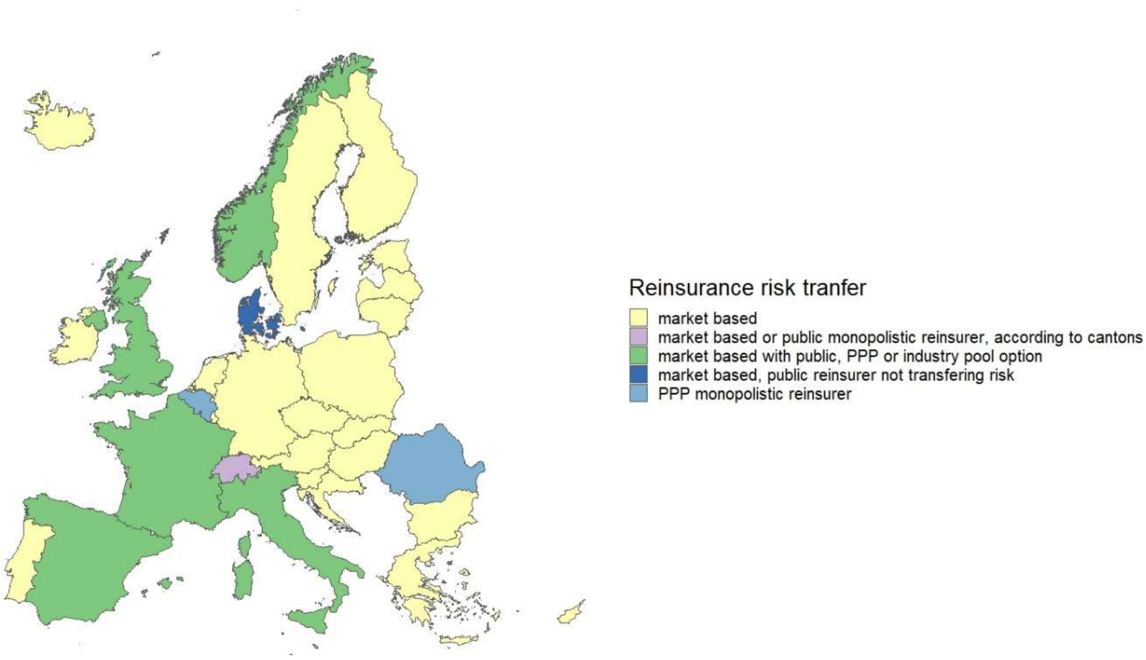

Figure 3.4: Reinsurance regimes

In countries where the public sector is more involved in climate risk management, the industry has built a shared pool or PPP entities have been established, reinsurance services can be offered at advantageous conditions thanks to better risk distribution through the industry or a state financial guarantee.

The State or public entities can offer reinsurance services in an environment of free access to the international capital market. In Norway, for instance, the industry pool engages in risk transfer to the reinsurance market, without the financial backing of the state (OECD, 2021). In Switzerland, most of the canton monopolies participate in a public reinsurance pool, absorbing exceeded losses (OECD, 2021). With the novel reform, the Italian state entity SACE is foreseen to act as a reinsurer for NATCAT risk for the industry, guaranteeing a solvency carpet up to €5 billion for the next 3 years. The Italian national insurance association (ANIA) has raised doubts about the sustainability of a listed reinsurance service since providers face mandatory offer conditions. In case of major disasters creating exceeding damages and losses, ANIA argues, solvency conditions for the whole industry might be direly undermined[9].

However, public institutions can also refrain from relying on international finance entirely for reinsurance operations. For example, the Danish Storm Insurance Council's pool guarantees compensation from extreme flooding without any limit, while remaining one of the few protection providers in Europe to not trade risk to the reinsurance market (OECD, 2021). At the present day,

[9] For more details, see: https://documenti.camera.it/leg19/documentiAcquisiti/COM05/Audizioni/leg19.com05.Audizioni.Memoria.PUBBLICO.ideGes.23068.10-11-2023-11-28-49.016.pdf

Funded by the European Union

there are no concerns for the financial sustainability of the scheme, and this may be due to the mandatory condition of underwriting for the public.

In the presence of established PPPs entities, these generally have the role of (re)insurer of last resort, which acquires financing on markets, with or without the advantages of public guarantee. In France, CCR can also raise funding through the international capital market backed by state guarantee, which allows the Caisse to acquire capital at lower rates compared to competitors, as it, in fact, is denoted with the same rating of the French State. Even though buying reinsurance from CCR is not mandatory, state guarantee and lower interest rates than those faced by competitors allow it to operate as a virtually monopolistic supplier for reinsurance against NATCAT in France, with a 90% share of the secondary market. However, CCR must, by law, reinsure any prime insurer or private reinsurer that requests so (Keucheyan, 2023). An analogue discourse can be applied to Spain's CCS state backing (Hudson et al., 2020), as well as to the Belgian system. In Belgium, the state-owned CNC operates as a reinsurer of last resort. The difference with the aforementioned countries lies in the mandatory requirement and the PPP acting as the sole option of NATCAT risk allowed in the system. CNC, however limits indemnities and its ultimate reinsurance after determined thresholds (Paleari, 2019). Romania represents another kind of exception to the case: the PAID industry consortium acts as a monopolistic reinsurer for natural calamities risk (Hanger et al., 2018), and does not appear to be an object of public guarantee for its solvency. Finally, even though a PPP system, the British one departs from the continental: the British Flood Re acts as a reinsurer on a not-for-profit basis for participating private insurers, while from its part also seeking reinsurance cover from the global reinsurance market Flood Re solvency is not directly state-backed, but the kingdom guarantees the tail risk on extreme events, strengthening the financial sustainability of the regime (Christophers, 2019).

3.2.4 National ex post disaster relief frameworks

Below are some prominent examples of ex post national recovery schemes outside insurance regimens, how they interact with the latter, and the ways they can foster demand barriers or strengthen financial sustainability in the aftermath of catastrophes.

Some trends emerge from national reforms of the last decades. Countries are strengthening their financial resilience by creating dedicated reserves budgets, while at the same time tightening the requirement to activate them after a climate-related disaster.

Even though high risk areas are virtually covered by a public insurance option, a reserve fund for high impact disasters is nevertheless present in the Hungarian risk framework. Every year Budapest allocates resources to the national Force Majeure Fund for constructing public assets damaged by large events, while regional governments must devote at least 2-3 percent of their annual budgets to emergency needs. An unfixed amount of aid is then distributed to the affected populations after the national declaration of calamity and damage evaluation carried out with insurance companies (Pollner, 2012).

In Cyprus, public restoration funds are allocated following income criteria and the state encourages the public to take up insurance (Cyprus Civil Defence, 2020). In Slovakia, by the law (Slovak Republic, Decree No. 387/2005), loss and damage evaluation is charged to the Ministry of Environment and the entitlement to aid and subsidies is not linked to individual underwriting of insurance, as well as there is no preset limit to the amount of aid that the public can receive (Pollner, 2012).

Funded by
the European Union

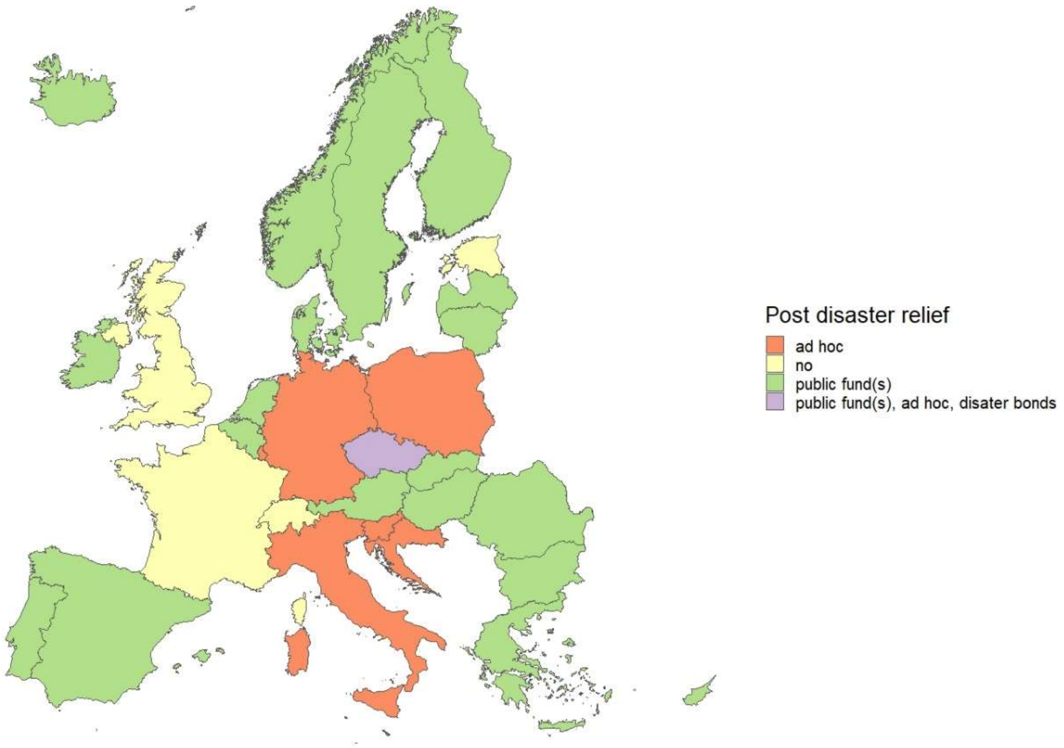

Figure 3.5: Ex-post disaster relief regimes:

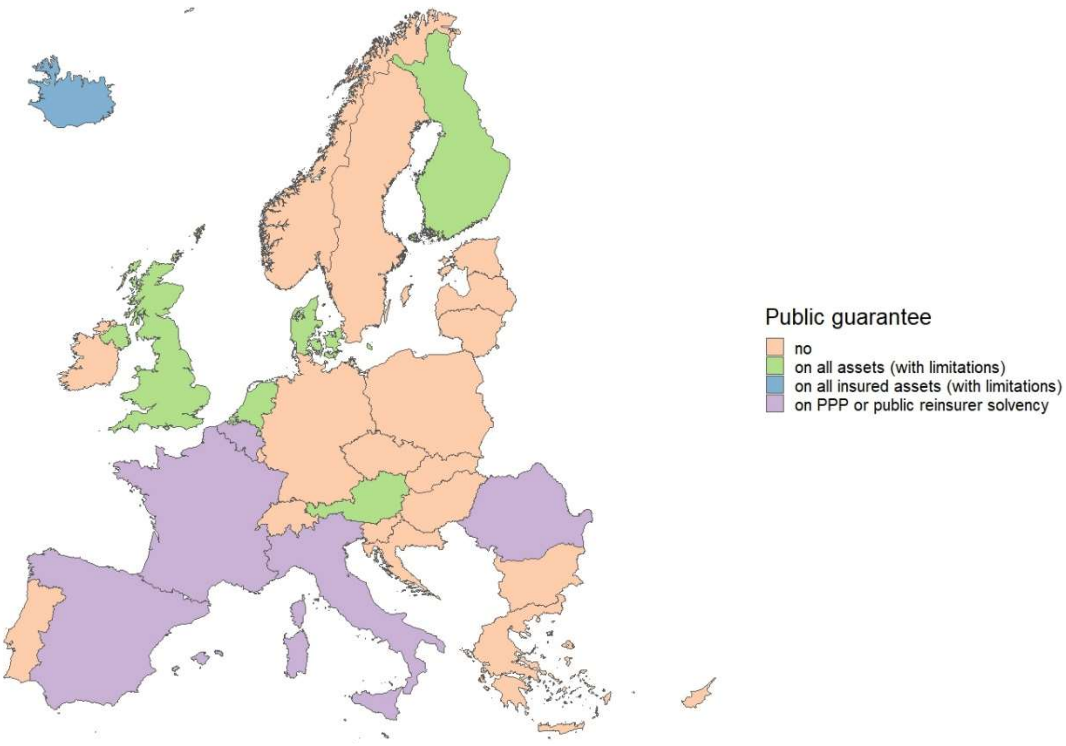

Figure 3.6: Public guarantee regimes

Funded by
the European Union

As for previously analysed features, the Austrian system is rather unique in Europe. The federal state assures compensation for private homeowners and businesses, although limited to 20%-30% of the replacement value of the private asset (Osberghaus & Reif, 2021), creating a major disincentive for purchasing private insurance (Tesselaar et al., 2022). Länder, however, have different rules governing the level of compensation, administration processes and legal exemptions in cases of social hardship (T. Thaler & Hartmann, 2016).

In Belgium, public aid is explicitly included in the national NATCAT insurance scheme, although its functioning depends on the regional policy framework (EIOPA, 2023a). The disaster fund compensations can be triggered once a natural catastrophe is officially declared. The disaster must have public recognition by the government, and while there are set thresholds for gravity of damage to be met, it is ultimately a political process (Bruggeman & Faure, 2019).

In the Republic of Ireland, the approach is more humanitarian than aimed at protecting citizen's socioeconomic safety. The main Irish public support instrument in place is the Emergency Humanitarian Support Scheme. It aims to aid small businesses, sports clubs, community and voluntary organisations affected by flooding events but unable to secure flood insurance. The scheme is supposed to lighten the hardship rather than provide full compensation for damage to lower-income citizens and civil society; this means that the Irish state grants only emergency income support payments and damage to the home and its essential contents, if not covered by an insurance policy (EIOPA, 2023a).

In the Netherlands, post-disaster compensation is deemed as public duty, albeit the National Disaster Fund has not been utilised extensively. During the Delta Works development, which lasted from 1954 to 1998, the law assigned the responsibility of adaptation and disaster prevention to the Dutch state as a matter of national security. Still today, the law requires that Delta Works protect from sea level spillovers equaling or exceeding an average recurrence interval (ARI) of 10,000 years along the coast, and to 1250 years along the riverbanks (McAneney et al., 2016).The Dutch Government has the discretion to apply the 'Reimbursement for Damages' where compensation may be available (EIOPA, 2023a). This combination of principles does leave the insurance industry without particular obligations or the need to build more autonomous capacity. As a result, damage resulting from the flooding of rivers not originating in the Netherlands and saltwater flooding remains uninsurable (EIOPA, 2023a).

Iceland's Disaster Fund (*Hamfarasjo´ður*) was established in 2016 after a reform of the existing framework, in the aftermath of the grievous earthquake in South Iceland in 2008. It is now also in charge of covering investments in adaptation and mitigation of large infrastructures (Johannsdottir, 2017). On the other hand, public guarantee capacity on NTI is virtually unlimited, though there are set restrictions for indemnity on a yearly or recurrence basis (OECD, 2021).

Some countries have historically relied on one-off public measures of relief, financed with general public spending or debts. These choices have generated charity hazard in the national risk management framework, as citizens do not deem themselves responsible for private financial recovery. Some kinds of reforms are however underway due to climate change and the mounting pressure on public finance which ad hoc measures generate.

Germany represents the most analysed system among those based on ad hoc post-disaster public measures, and it is representative of the malus it can generate. It has been demonstrated that in a disaster protection system built around state aid, in which policymakers are not limited by strict underwritten regulation, the size, object and timing of the recovery can greatly vary following the electoral cycle (in the case of democratic institutions). Higher disaster relief payments are found in election years, as well as in regions that are strategically important for the governing coalition (Bruggeman & Faure, 2019). The regime is thus ambiguous, as, by law, it does not guarantee compensation to citizens. There is a general expectation from them for this to happen, as every time an ad hoc measure has eventually been enacted both by Länder or the federal state. This uncertainty creates a charity hazard (Raschky & Weck-Hannemann, 2007; Tesselaar et al., 2022). As a result, households that are entitled to provide for their safety and coverage would not do so due to expected public aid. The share of the populations exploiting such negative externality is found to be around 25%, differing according to past experience of damage. The ambiguity of relief affects also the public budget and long-term territorial planning (Osberghaus & Reif, 2021). As said before, an implicit transformation is underway. The most evident sign of a contemporary paradigm shift from the political class has been the recent response against the dramatic 2021 Rhineland floodings. Facing a total of €4,5 billion of losses and damages, Chancellor Angela Merkel, in her last days of public office, has only granted €200 million of compensation to the affected areas, expecting Länder to (only) double the amount. Private uptake of insurance has been registered to be increasing in the last few years as a consequential social response to this large event (EIOPA, 2023a).

In Slovenia there is a historical problem of charity hazard and iniquity, which surfaced in the aftermath the earthquake of 1998, when the government confiscated and then redistributed insurance benefits of those covered for the generally affected population. In general, post-disaster public aid has typically not benefited those who had underwritten insurance contracts (Zorn et al., 2016).

In Croatia, post-disaster recovery is usually fulfilled by one-off national measures, though compensation is limited to a maximum of 5% of loss and damages, reported and confirmed through a national bottom-up approach consisting of citizens and farmers' application to the local commission for assessment of the damage, ministries and, finally, a state commission. This rigorous process and limits to public recovery should function as incentives for private coverage take-up (Radu, 2022).

The Polish state still provides first-aid and infrastructure reconstruction funding in times of need. Ad hoc measures for private reconstruction are not ruled out by the framework, but the political and economic uncertainty around their eventual implementation by one-off post-disaster laws make them a non-guarantee for the affected populations (European Commission, 2017).

Italy is another example of historical and structural charity hazard due to the government's use of unchecked disaster recovery. While the magnitude and recurrence of climate disasters are increasing (Ivčević et al., 2021), ex-post funds are generally slow and insufficient (Roder et al., 2019). Moreover, such mechanisms have not been ruled out from the recent reform, as households are still not required to underwrite insurance contracts by law.

The Czech Republic has given itself a varied set of financial recovery instruments for its citizens and its institutions. The state has different tools for enhancing fiscal resilience in the aftermath of a disaster, particularly after the reform which allows for deficit increases, budget reserves and extraordinary collection to cover disaster relief (Radu, 2022). Prague can issue extraordinary state bonds (Czech Republic, Regulatory Act No. 163/1997); budgetary allocations for emergency and immediate measures aimed at rescue of the affected population (Czech Republic, Regulatory Acts

No. 239/2000 Sb. and No.240/2000 Sb); and, budgetary allocations for property reconstruction and revitalisation in the form of interest-free loans to municipalities, firms and households. (Czech Republic, Acts No. 12/200 Sb and No.186/2002). This assistance is funded by a 0.3% annual state budget allocation (Pollner, 2012).

The French system does not foresee direct public aid after a major disaster. This is due to the high penetration rate of CCR insurance. France, however, can be seen as a cautionary example of how a system centred around a strong PPP can generate moral hazard. The solidaristic principle allows NATCAT insurance to be geographically neutral and it is precisely a political choice of design. In fact, the French Republic encompasses all the *outremer* territories, spanning five continents, so the range of mounting climate hazards it faces is very broad and future trends might differ from other European countries. Even though scientific and empirical data requirements are needed for the declaration of a natural catastrophe (i.e. floods, droughts, cyclonic winds with average wind speed greater than 145 km/hour over 10 minutes or gusts of 215 km/hour, earthquakes, volcanism, tsunamis and avalanches officially recognised as a NATCAT event at a local level; (EIOPA, 2023a)), together with the publication in an official journal of the calamity, the system of compensation is not immune to political interests. A regime built around a public guarantee of solvency and underlying political dynamics could be fertile ground for moral hazards. There is some evidence of this: the efficiency and quickness of policymakers in triggering compensation, after disasters hit, often prevents estate developers to be taken accountable for preventable damages on poor quality buildings (Keucheyan, 2023). The UK, having an extensive PPP system, has no reserved public budgets for recovery in place. The Crown is the guarantor for the extreme residual tail risks of flood, that is, full direct payment for disaster due to events with ARI equal to or above 1 in 200 years (Christophers, 2019). As a conclusive remark on state guarantee, it can be argued that it generates positive impacts to national frameworks. Public guarantee can provide stability to systems of risk management, as well as advantages to public or PPP entities in terms of international capitalization. However, it must be highlighted how, as climate change unfolds, risks are likely to grow dramatically, putting pressure on public budgets once major events hit and damages and losses accumulate through the years. It should not be forgotten that interest rates ultimately depend on countries' financial trustworthiness on international markets, and thus public (re)insurers might not always benefit from lower costs.

3.3 European national estimated insurance penetration rates

Precise disaggregated data on insurance take-up in national markets is hardly available, and this is particularly true where the public regulator is less involved. Most of the relevant literature in determining penetration gaps is based on aggregate economic data, historical damage and losses, or on local surveys. This section presents estimated national penetration rates, derived from the latest (estimated) national NATCAT insurance penetration rates published by EIOPA (2023a), and data extracted from the reviewed literature.

The current insurance penetrations, defined by EIOPA, come from a cross-assessment of several sources, both quantitative and qualitative, in collaboration with the supervisory authorities of EU countries. The insurance penetration has been defined as the ratio between total sum insured and its replacement value. Sum insured relates to the property values covered by NATCAT policies in a reference country, and replacement value corresponds to the overall property value in a reference country (from RiskMap and LitPop data) (EIOPA, 2023b). Estimates found in the reviewed literature may use different methodologies, such as market penetration (European Commission, 2017) or insured share of aggregate economic losses (OECD, 2021)

The maps displayed below have been constructed around the four main European climatic hazards (windstorm, wildfire, coastal floods, riverine/pluvial flood), and distinguishing between insured economic sectors, these being residential (households) and commercial (businesses). Data output has been organised, by colour, around 6 penetration rate ranges: 0 (no marine access); 1-20% (very low); 21-40% (low); 41-60% (discrete); 61-80% (high); 81-100% (very high). Due to the aforementioned reasons, these maps should not be intended as a product of quantitative research, instead as a general synthesis of the performances of the various national systems, of a more qualitative nature.

3.3.1 European national estimated windstorm hazard insurance penetration rates

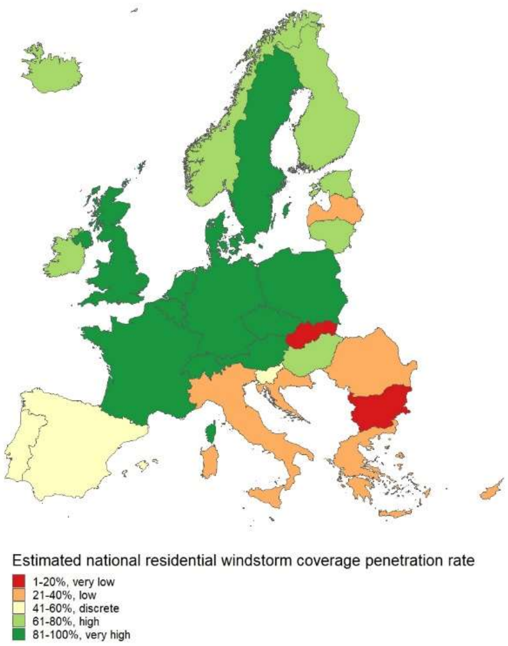

Figure 3.7: Windstorm insurance penetration rates (households)

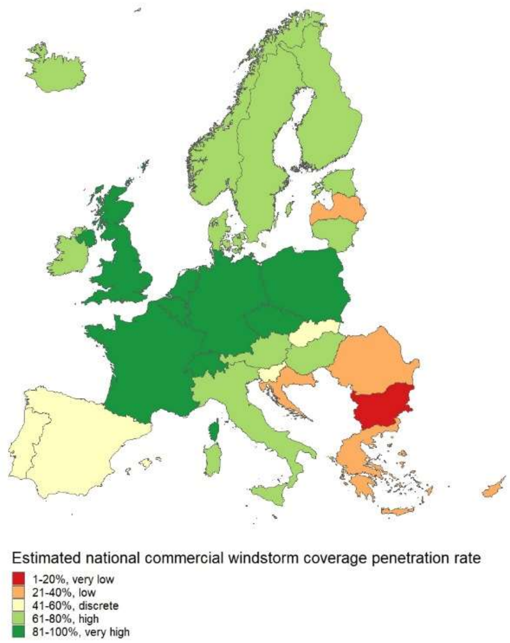

Figure 3.8: Windstorm insurance penetration rates (businesses)

Northern and Atlantic counties are, in general, more covered against windstorm hazard than southern and eastern countries. This is due to their geographic exposure to strong winds (EIOPA, 2023a), as well as wind risk being usually included in standard property insurance. The effect of mortgage requirement on wind coverage can be seen by comparing two countries with similar populations and which both face the Atlantic Ocean. Portugal, which has a voluntary purchase system, performs lower than Sweden. Leal et al. (2022) argues that differences in outcome of protection can be also attributed to more unequal structure of Portuguese society (Leal et al.,

Funded by the European Union

2022). Residential and commercial penetration rates are comparable, with considerable differences localised only in Slovakia and Italy.

3.3.2 European national estimated wildfire hazard insurance penetration rates

Wildfire is the fastest-growing risk in Europe, especially in southern and central regions. For Mediterranean countries, the wildfire risk could become structural as their wildfire seasons may become more intense and be one month longer by 2050 (OECD, 2021). Wildfire penetration gaps are concentrated in central and eastern Europe. The gaps can vary greatly, but it is notable that countries where some form of requirement is present tend to perform better. In Italy and Germany, voluntary systems based on ad hoc compensation (which are rarely enacted in case of wildfire) score better than other comparable frameworks, in particular in the commercial sector. The lack of requirement of state intervention is particularly problematic in the two current most affected countries: Portugal and Greece. On the other hand, the Nordic countries (Denmark, Finland, Iceland, Norway, and Sweden) have high penetration rates, even if hazard is not significantly present (N.B. the Icelandic NTI covers against volcanic eruptions, not wildfires).

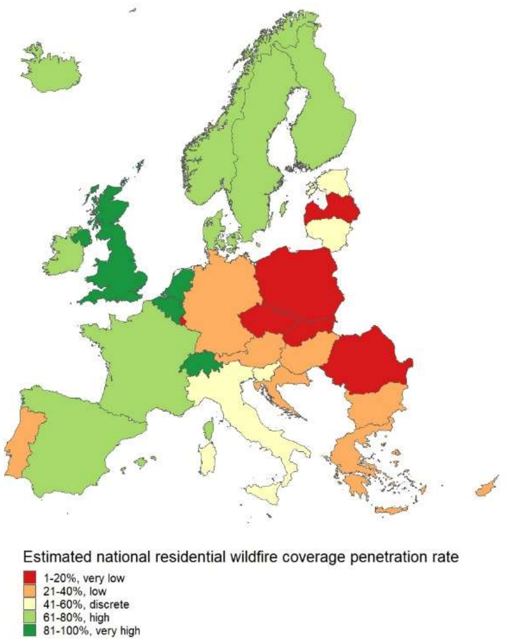

Figure 3.9: Wildfire insurance penetration rates (households)

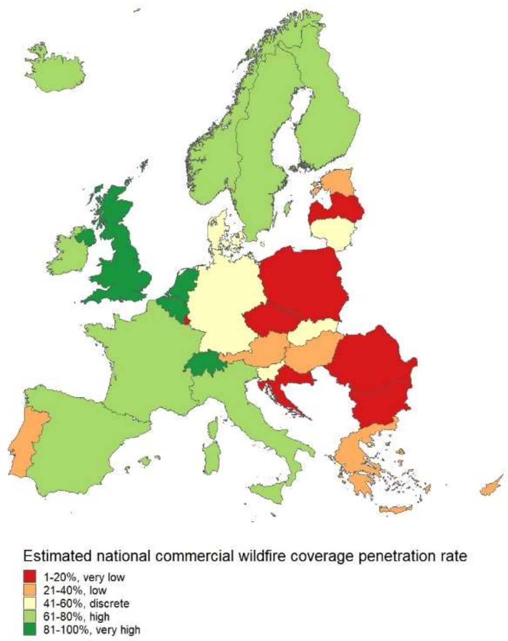

Figure 3.10: Wildfire insurance penetration rates (businesses)

3.3.3 European national estimated coastal flood hazard insurance penetration rates

Coastal flooding is the least addressed hazard by the European national coverage systems. The only high or very-high penetration rates are present in countries with functioning PPP systems or public insurance providers, concentrated in the North Sea and Atlantic region. Market-based countries with voluntary systems are those more recurrently subjected to seaborn inundation, like Finland and Ireland. It has already highlighted how regions of the Republic of Ireland have become uninsurable against recurring high tides by the local industry. In Germany, public coastal protection is highly developed (EIOPA, 2023a) and even more so than in the Netherlands, where the state has been historically responsible for managing such risk and investing in protection infrastructures. Lastly, coastal flooding could become a concern for every European country with marine access in the next decades, due to sea rising. There are no significant differences between commercial and residential penetration rates in European countries.

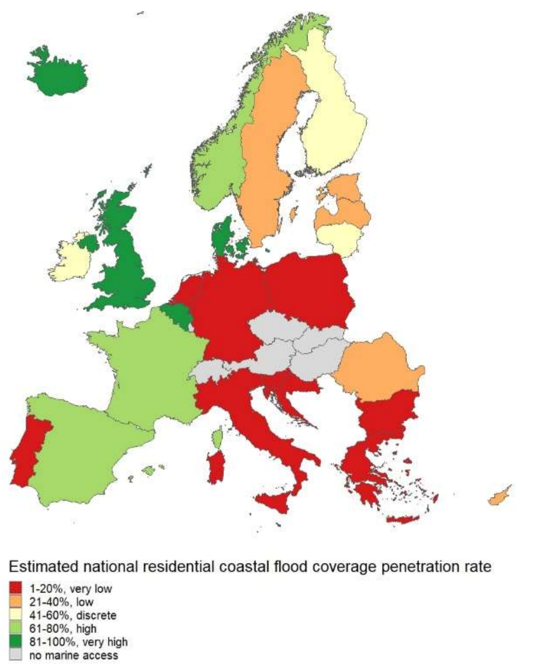

Figure 3.11: Coastal flooding insurance penetration rates (households)

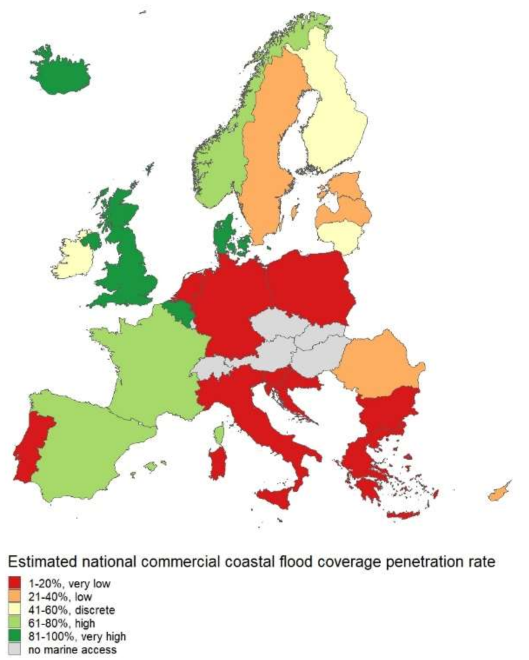

Figure 3.12: Coastal flooding insurance penetration rates (businesses)

3.3.4 European national estimated riverine/pluvial flood hazard insurance penetration rates

Inland (i.e., riverine and/or pluvial) flooding is the most widespread hazard in Europe and has historically been a major source of damage and losses, seldom as consequences of single extreme events (like the aforementioned 1953, 1997 and 2003 floods). PPP and public monopolistic systems perform best, together with countries with legal or mortgage requirements. Nordic European countries (Denmark, Finland, Iceland, Norway, and Sweden) present a very high degree of penetration of coverage against major natural catastrophe risks. Such results can be traced to high levels of trust in institutions, relative affordability of insurance compared to high economic development and per capita income, and engagement of the insurance industry in providing information and incentives for private prevention (European Commission, 2017). Romania, on the other hand, exemplifies the underperformance of many south-eastern European systems. The PAID pool, the joining of which is mandatory, covers approximately 20% of Romanian households (Radu, 2022). Hence, a limited ability to enforce regulations depletes the effectiveness of such a legal requirement. This couples with a general distrust for financial institutions, low awareness of risk and knowledge of national policies, which all contribute toward the low coverage rates (Hanger et al., 2017).

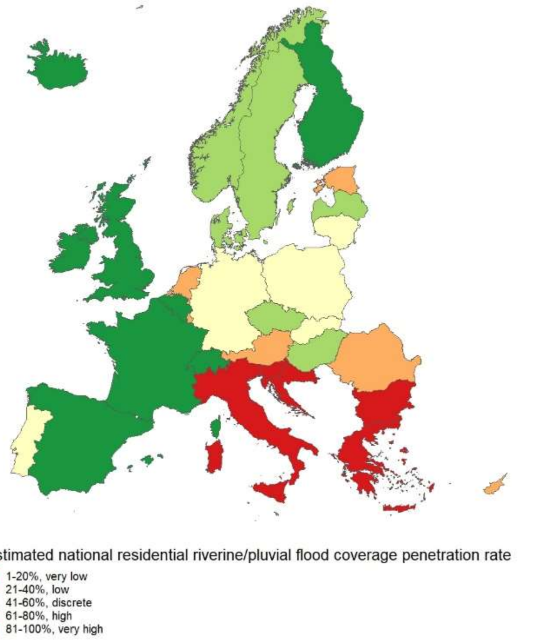

Figure 3.13: Inland flooding insurance penetration rates (households)

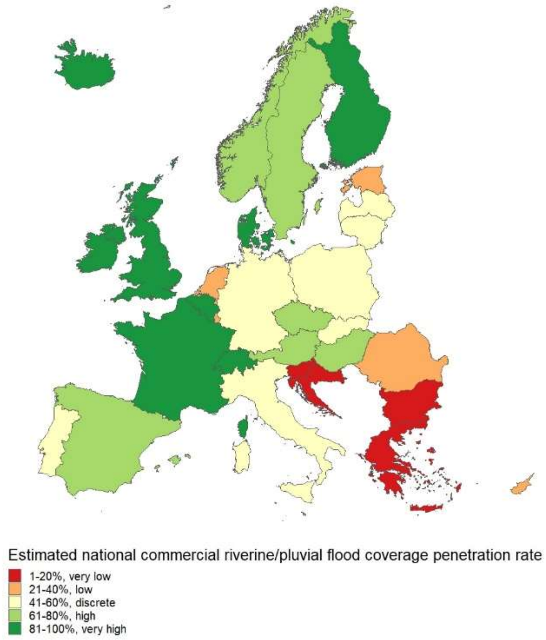

Figure 3.14: Inland flooding insurance penetration rates (businesses)

3.4 Agriculture

This section presents a brief digression on relevant information on national climate risk systems for the agricultural sector. The reviewed literature contained limited, contrasting or outdated data regarding national European agriculture systems, their penetration rates, and how they were defined. Thus, it was not possible to build reference maps to support the discussion on insurance penetration rates. A fairly comprehensive overview of penetration rates across selected EU countries is contained in the report by Le Den and co-authors (European Commission, 2017), so interested readers can refer to that document. In any case, oftentimes the establishment of agricultural climate insurance schemes predates those for other economic sectors, and national frameworks tend to be more interventionist.

3.4.1 CAP national risk management tools

As noted before, the CAP framework allows for the disposition of support for risk management tools in national plans. They can take the form of insurance schemes and mutual funds, covering insurance premiums. Several of the Member States that do not plan such EAFRD-funded risk management tools, apply nationally funded insurance schemes to address this need. Following the contemporary approved plans, fourteen countries have chosen to do so: Bulgaria, Croatia, Estonia, France, Germany, Hungary, Italy, Lithuania, Latvia, Netherlands, Poland, Portugal, Romania and Slovakia. Collectively, the Strategic Plans that devote funding for risk management should cover around 15% of EU farms.

Most countries not using the European Agricultural Fund for Rural Development (EAFRD), finance national insurance schemes to support agriculture. Three Member States (BG, IT and RO) use the new possibility to assign funds from the direct payments to finance farmers' contributions to a risk management tool as complementary to the support for risk management under EAFRD. Italy and Romania decided to transfer 3% of their allocation for direct payments for this purpose, which is the maximum, and Bulgaria 1.5%. Member States that make use of this option must apply it to all farmers receiving direct payments in a given year. Consequently, the share of farms participating in the risk management tools in these countries is high relative to other MS. Altogether at the EU level, financial support from the CAP for EAFRD risk management tools amounts to 18% of total public expenditure (European Commission, 2023).

3.4.2 National funds

Dedicated national funds for agriculture risk are present in various countries. The Belgian Disaster Fund (Rampenfonds) was instituted with the Act of 12 July 1976 on the 'Repair of Certain Damage Caused to Private Goods by Natural Disasters'. It was meant to be an emergency state aid stock, to be financed in the aftermath of a natural catastrophe by advance funding from the Treasury, loans, and, where necessary, allocations drawn from the state budget, gifts, legacies, and profits from the National Lottery. The law, however, has foreseen the funding mechanism to be activated only once the natural catastrophe is officially declared (Bruggeman & Faure, 2019). The Act of 1976, though, continues to exist for those events and properties not included in the Act of 2003, namely for those goods that are not insured because of the low financial capabilities of the victim, and for agricultural damage.

In Iceland, in addition to NTI, the NATCAT risk management system foresees a set of public funds for loss, damages and reconstruction which cannot be covered otherwise: the Emergency Relief Fund (*Bjargra´ðasjo´ðir*), today dedicated exclusively to agriculture, founded in 1913, covering livestock failure and biotic risk too.

For the Hungarian agricultural sector, the risk management framework was lastly reformed in 2012 with the 'Complex Agricultural Risk Management System' (MKR), designed to provide compulsory coverage for the farming industry and to be a partnership between the government and the insurance industry. The state covers crop losses from droughts, inland waters and frost through the National Agriculture Damage Compensation (NAR) if farmers suffer a yield loss of at least 30% due to extreme weather events at the crop level. This regime has taken up most of the arable land in the country. The remaining area has opted out of the publicly subsidised private insurance schemes, which, however, gives compensation after an attested loss of more than 30% for hail and storms and 50% for floods and droughts (European Commission, 2017).

In France, the National Guaranty Fund for Agricultural Disasters (*Fonds National de Gestion des Risques en Agriculture* - FNGRA), administered by the CCR, provides compensation to agricultural holdings for material damages arising from agricultural calamities. These calamities comprise uninsurable damages of exceptional severity caused by variations of extraordinary intensity in natural weather phenomena that may not be prevented or resolved by normal measures.

Finally, Italy has one of the most interventionist frameworks in the EU landscape regarding agricultural risk management. This is historically rooted in the National Solidarity Fund (NFS) established in 1970. The NSF nowadays can cover against hazards deemed uninsurable by the private industry by the central government, and with at least 30% of losses for farmers (European

Commission, 2017). Under the CAP Strategic Plan and EAFRD, in light of the strong and recurrent climatic events that highly affect farmers, Italy has established four risk management interventions worth almost €3 billion. These interventions aim to help farmers to better face growing climatic adversities through subsidised insurance, income stabilisation tools, and a new national mutual fund for catastrophic events (covering frost, floods, and drought damage). The latter will see for the first time ever the participation of all Italian beneficiaries of direct payments, around 800,000 farmers (European Commission, 2023).

3.4.3 Alternative national frameworks

Other countries do not use dedicated funds for farmers' recovery after disaster but have institutionalised some form of protection mechanisms. In Denmark, with respect to crop financial protection, there are no relevant public subsidy policy for farmers, while reforestation funds targeting forests hit by major windstorms are granted by the Storm Council at the following conditions: the affected area must have been subject to insurance coverage against windfall in its entirety; the portion of area overturned must be greater than 1/60th of the total forested area managed; and, the forest must be under public environmental protection arrangements (European Commission, 2017).

In Croatia, where ex-post disaster recovery is usually carried out through ad hoc governmental measures as said before, public compensation for agriculture faces the same limitations as the other sectors (i.e., compensation limited to 5% of losses and high degree of bureaucratisation of the application and evaluation processes). Even though in Poland there is no legal requirement of coverage for households and businesses, a compulsory scheme for protection does indeed exist in the country for agricultural activities and linked rural dwellings which apply for state support. The scheme provides coverage against crop losses and major climatic events, though the take-up rate appears to still be marginal given the legal obligation (farmers are required to cover against some risk of technical nature but not against natural hazards, and most of them acquired only insurance against hail; European Commission (2017)). Since 2016, in Romania, *Die Österreichische Hagelversicherung România* has launched an insurance scheme for farmers against the mounting effect of drought (European Commission, 2017), in the likes of PAID (Hanger et al., 2018).

The Swedish crop protection model has been reviewed as one of the best in Europe. Clear and secure compensation is assured in general, and the multi-hazard nature and the generalisation to all farmland instead of addressing only hotspots of risk (Hudson et al., 2020). The elevated level of penetration in the countryside is a result of a particular historical evolution. Sweden has never engaged in insurance subsidies and has implemented a compulsory, publicly-provided system for farmers until 1994 when it was deemed too costly and incompatible with CAP regulations. The private insurance industry, dominated by two industries, has since filled the gap for comprehensive coverage in agriculture (European Commission, 2017).

Austria's framework has also been indicated as one of the best-performing by the European Commission (2017) and Hudson (2020). It is built around the Austrian Hail Insurance Company. It has a mutualistic, voluntary and non-profit structure that allows it to serve social goals and reach widespread protection. The key to its high take-up rate (60 % of cultivated land) may lie in its long tradition of supplying multi-peril coverage, coupled with a wide distribution of risks which allows also risk intensive areas to be covered.

3.5 Final remarks and take-aways

Based on the previous discussion, some conclusions can be drawn on which features are best suited to reducing climate insurance gaps.

Insurance supply system

The highest penetration rates in free voluntary markets are those of Germany and Czech Republic, which reach at most half of the insurable households. Coverage as mortgage requirements generally perform equally to those imposed through binding laws. However, under such arrangements, penetration of climate coverage tends to fluctuate with home purchase and ownership rates (e.g., Ireland and Poland). Mandatory legal imposition may also not have the desired outcome, as the Romanian case shows. PPP and public provider national systems, among all the European regimes, cover the widest share of population (in particular, those of France, Belgium and the UK), with, again, the notable exception of Romania. Public monopolistic insurers score similarly (Denmark, Iceland), and, in any case, the presence of publicly supplied insurance options (Hungary) fosters take up by citizens.

Premium structure

Actuarial modelling for premium calculation is the most accurate way to signal risk to policyholders and stimulate private risk reduction. However, as the cases of Hungary and Ireland show, risk-based pricing can lead to unaffordable or uninsurable conditions for entire regions, leaving them uncovered. Flat rates or fixed fees are the best solution to apply the solidaristic principle: they are a redistributive factor, both in terms of risk determined by geographic differences, and socioeconomic inequality, granting, generally, more affordability for the wider public. They however require some forms of mandatory requirements to expand risk pools and should thus be completed with incentives for private risk-reduction measures to avoid creating moral hazard. Mixed systems, in the likes of France, Spain, Denmark and UK seem better suited for enhancing underwriting rates among households and businesses.

Relief and guarantee

Ex post ad hoc measures are the most counterproductive system to manage relief and financial recovery. They create structural charity hazards (e.g., Germany, Italy) and impose ambiguity in the time and entity of aid the affected stakeholders will receive. As a result, they may cause low penetration rates, and can sometimes penalise households and businesses that signed up for private coverage (e.g., Slovenia). Dedicated public funds are generally limited in terms of financial capacity for recovery after a major disaster, but they decrease or prevent the amount of strain on public budgets. They are usually matched with strong checks on claims and final receivers (as in Austria). Having almost complete coverage of assets through insurance virtually removes the need for public compensation. This condition is present only in some PPP-based systems (France, UK, Belgium). Finally, state guarantee brings the most advantages when put on the solvency of public (Denmark, Iceland) or PPP entities (France, Spain). This is due to their ability to raise capital on the international financial market at advantageous rates. The public guarantor role should not be limited (as in Italy).

Best-performing features

Overall, France's (and alikes) and Denmark's systems appear to perform better in reducing protection gaps and maintain financial sustainability to the system. However, as highlighted before, some elements of moral hazard are present in the French framework. Thus, in contemporary Europe, the Danish system built around the Danish Storm Council public monopolistic provider, could be indicated as the best example of a national coverage system against climate hazards.

Summing up Climate insurance protection gaps are best reduced under systems with the following characteristics:

- Premium partially or entirely structured around fixed fee(s) or flat rates(s);
- The presence of a public or PPP entity acting as primary insurer;
- Legal requirements of NATCAT insurance uptake for asset owners;
- Avoidance of ex-post-disaster ad hoc relief measures by the state; but, rather, there should be the establishment of dedicated public budgets, pools or PPP entities.

As a final consideration, it must be remarked that every national system of NATCAT coverage reflects the historical, geographic and political peculiarities of each country. The features listed as most efficient in reducing climate insurance protection gaps should not be taken as a definitive, one-size-fit-all solution, but declined to match specific regulatory and socioeconomic contexts in order to work properly. The example of Romania, in this sense, is truly exemplary. Also, while systems that structure premiums through flat rates or fixed fees appear to the best-performing at achieving high penetration rates, these systems must be accompanied by a series of complementary policies for incentivising private investments in mitigations. Conversely, if left unregulated, they will likely be a source of moral hazard, thus generating maladaptation. Moreover, since over the next decades climate impacts will grow in intensity and frequency as a result of climate change, frameworks that perform efficiently today may see their financial and social sustainability put under rising pressure. Policymakers should set up national systems to enable reforms and transformations, even structural ones, ahead of possible profound evolutions of environmental and socioeconomic settings. All in all, holistic and dynamic approaches will also be key in assuring affordable coverage to the widest population possible.

Funded by
the European Union

4 Causes of insurance protection gap

This chapter discusses the potential drivers that might explain the limited diffusion of climate-risk insurance highlighted in Chapter 3. These are divided into three main categories. Demand-side barriers (Chapter 4.1) are those factors that (negatively) affect the insurance purchase decisions of prospective policyholders. Supply-side barriers (Chapter 4.2) include elements that limit insurers in their supply of coverage or that lead them to raise the price of policies. Finally, additional considerations regarding justice, data availability and other regulatory and legislative constraints are discussed (Chapter 4.3).

4.1 Demand-side barriers

There is a plethora of reasons why people do not insure against climate-related risks. In this section, we present the main findings from the literature review, distinguishing between informational, rational and irrational barriers.

4.1.1 Information barriers

4.1.1.1 Imperfect information about risk

It is claimed that oftentimes people present imprecise perceptions of risk, which could result from probability weighting or mental shortcuts to cope with the (intangible) costs of gathering information (Hudson et al., 2016). Understanding whether agents are capable of accurately assessing the level of risk is important, since perceived risk has been found to affect insurance demand (Savitt, 2017), more so than scientifically estimated risk (Palm & Hodgson, 1992).

Several studies conducted over the last two decades suggest that people in Greece (Diakakis et al., 2018), Italy (De Masi & Porrini, 2018; Gizzi et al., 2021; Salvati et al., 2014; Scolobig et al., 2012), the Netherlands (Botzen et al., 2009a, 2015; Mol, Botzen, Blasch, et al., 2020), the UK (J. E. Lamond et al., 2009) and the US (Ludy & Kondolf, 2012) tend to have a low perception of climatic and natural risks, despite living in risk-prone areas. For instance, roughly one third of surveyed British households living in flood prone areas believe they are not at risk of flooding (J. E. Lamond et al., 2009). Less than half of surveyed households in Italy who live in areas impacted by severe flood events in the past expect similar ones to happen in the future, and there is the propensity to discount personal risk compared to community risk (Scolobig et al., 2012). And, the majority of respondents living in floodplains in a Dutch survey underestimate the water level of a flood (Mol, Botzen, Blasch, et al., 2020). Also, it seems that floods are perceived as less important than earthquakes in Italy (Salvati et al., 2014) and Greece (Diakakis et al., 2018), with wildfire risk also being deemed more relevant than flooding in the Hellenic case. From a survey among affluent and well-educated households protected by a “100-years” levee in the US, it emerges that more than 60% assess their risk of flooding as low or absent, and more than 80% were at most somewhat concerned; only 20% had purchased a flood insurance policy (Ludy & Kondolf, 2012). The authors conclude saying that despite the levels of education and income, households did not understand the risk of being flooded, believing that the “100-year” levee protects them from all flooding.

Attention has thus been paid also to the factors driving the (mis)understanding of climate risks. One of the most comprehensive investigations of the determinants of flood risk perceptions was conducted by Botzen et al. (2015). Considering a sample of American households, the authors compare perceived flood probability, damage and risk (defined as probability × damage) with experts' assessments. The results highlight that only a minority of subjects have accurate estimations. Conversely, the majority tends to overestimate probability but underestimate damage. The reasons for these effects are to be found in past flood experience (or lack thereof), worry, and threshold level of concern. In particular, the overestimation of perceived flood probability is positively affected by the number of times respondents were flooded in the past, while the underestimation of damage by not suffering flood damage in the past. Likewise, high(low) levels of worry and the perception that flood probability is above(below) the threshold level of concern explain the overestimation(underestimation) of flood probability(damage). A similar relation between direct experience with events and higher perceived risk has been detected also in other studies (Harvatt et al., 2011; Roder et al., 2019; Scolobig et al., 2012), even though experience of certain hazards has more long-lasting effect than others (Salvati et al., 2014). Knowledge about the hazard and its causes also have a positive relation with risk perception (Botzen et al., 2009a; Roder et al., 2019). Another important determinant is social capital, with higher levels of social capital typically reducing perceived risk. A study among flood-prone Austrian households reveals that those who judge their social environment positive and supportive tend to perceive themselves at lower risk, evaluating the flood probability lower and the potential consequences less severe than households with lower levels of social capital (Babcicky & Seebauer, 2017). Similarly, flood risk awareness has been found to be significantly higher among Italian households who live in isolated vis-a-vis urban communities (Scolobig et al., 2012). In another investigation of flood risk perceptions in Italy, Roder et al. (2019) find that trust in the government (regarding flood risk management), which the authors characterise as an essential element of social capital, has a negative impact on threat appraisal. Finally, other factors that have been found to influence risk perceptions are homeownership, age and education, with homeowners displaying higher levels of threat appraisal (Roder et al., 2019), while older and more educated individuals showing lower levels of perceived risk (Botzen et al., 2009a).[10]

The investigation of the impact of risk perception on risk preparedness and the adoption of mitigation measures has returned mixed results. From a review of the literature on flood risk, Bubeck et al. (2012) conclude that there is little to no evidence of a relationship between perceived risk/probability and the adoption of mitigation measures, with coping appraisal being a more important determinant than threat appraisal in the decision to adopt such measures. However, the authors also report that in those studies that elicit the intention to adopt, rather than actual adoption, a significant and positive relation with risk perceptions is detected. The papers focusing specifically on climate-risk insurance, however, seem to provide a more cohesive picture. Botzen & Van Den Bergh (2012b) show that risk perception affects the WTP for flood insurance among Dutch households. In particular, the belief that climate change causes higher flood risk, the expectation to suffer flood damage and the expected (log) value of damage increase WTP; while the belief to be at lower risk than the average, the expectation to not suffer any damage, the expectation of a zero return period and the logarithm of the expected return period decrease WTP. This translates to the WTP for flood insurance being, respectively, 25% lower for individuals

[10] The positive effect of homeownership is probably due to the fact that an event would have a greater impact on them than on tenants, since homeowners can potentially lose both the property and its content while tentnats only the latter. The negative effect of age could be attributed to older households discounting the future more than younger ones, and thus being less worried about possible future negative events. While the negative effect of education is more surprising, especially given that the analysis was controlling for income levels, but, as the findings from Ludy & Kondolf (2012) show, even well-educated individuals can misunderstand their level of risk.

Funded by
the European Union

believing their risk is less than the average, 41% lower for individuals believing they won't suffer damage, and 20% lower for individuals expecting a zero return period. Botzen et al. (2009b) find qualitatively similar effects of the same risk perception measures on the willingness to purchase sandbags in exchange for a discount on flood insurance premiums. From a survey among German and Dutch households, Seifert et al. (2013) show that the willingness to insure and the WTP for flood insurance is significantly higher for individuals who perceive flooding to be more likely and who expect greater damage. Likewise, in the US, Petrolia et al. (2013) find that households expecting hurricanes to produce greater damage to their homes are more likely to have flood insurance, and Shao et al. (2017) reveal that perception that the amount of flooding has increased and that hurricanes have become stronger significantly increase voluntary purchase of flood insurance. A couple of studies, however, fail to detect a significant relationship between risk awareness/perception and flood insurance (Lo, 2013a; Rufat et al., 2024).

4.1.1.2 Imperfect information about low-probability events

Apart from not having a proper understanding of the level of risk associated with climate hazards, agents might tend to "discount" rarer events that have a low probability of occurring, such as natural catastrophes. According to Expected Utility Theory (EUT), individuals should be more inclined to insure against low-probability events with a high potential damaging factor (from here on referred to a low-probability high-impact (LPHI) events), than against more frequent events with a lower damage potential (high-probability low-impact (HPLI) events), since the consequences of the latter are easier to cover through private savings or social networks. However, evidence seems to suggest that agents behave in the opposite way, opting to seek coverage for HPLI events and to remain unprotected against LPHI ones (Browne et al., 2015). Kunreuther & Pauly (2004) state that the reason could be found in the costs required to collect the necessary information to make informed decisions.[11] In fact, given that the probability of such events is by definition extremely low, sourcing information on the possible consequences and appropriate protection measures might require a level of effort that agents deem excessive. This combination between low probability of occurrence and high costs can lead people to not consider it worthwhile to seek (information about) insurance coverage against LPHI events. Indeed, in a consideration on the Italian NATCAT insurance market for residential properties, Gizzi et al. (2016) state that the information material provided by insurance companies usually does not include data on the occurrence probability of a certain hazard and the loss probability of the assets. This yields support to the argumentation of Kunreuther & Pauly (2004), since the extra efforts required of consumers may hamper insurance demand even in the presence of affordable premiums. Hence, this issue is particularly problematic in countries with voluntary climate insurance systems (Kraehnert et al., 2021).

A number of studies have documented the presence of this "LPHI-HILP puzzle". In an experimental analysis in the US, Shafran (2011) finds that participants were more likely to protect themselves against a HPLI event than a LPHI event. On top of that, those facing a HPLI risk with a high cost of protection were twice as likely to protect as those facing a LPHI one with a low cost of protection, even though the latter would have earned more money from choosing to protect. While the experiment focuses on self-protection, the results can be applied to insurance purchase. Surveying Dutch households, Botzen & Van Den Bergh (2012b) highlight that a large portion of

[11] These are opportunity costs, namely the cost of time spent to source information that could be devoted to other utility-enhancing activities instead. As well as possible psychological costs connected to the disutility generated by having to deal with information that is complex to process and understand.

respondents neglect the low probability of flooding and they are more willing to insure when the flood probability is larger. Moreover, Seifert et al. (2013) find that the WTP for insurance against the medium-probability medium-impact flood risk in Germany is higher than for the LPHI flood risk in the Netherlands.[12]

In order to address this issue, in addition to increasing the provision and accessibility of information on climate risks (by both insurers and public authorities), Kunreuther (2021) suggests that stretching the time horizon when presenting information on the probability of occurrence of an event might alleviate the tendency to discount LPHI events. For instance, the author says that rather than presenting a flood as a 1-in-100-years event or as having a 100-year return period, people might be told that the chances of experiencing a similar event over the next 30 years are more than one-in-four. However, results from an experimental analysis on insurance decisions against low-probability losses reveal that "the sensitivity to the probability of loss depends on the way the loss is framed", warning that "a policy focusing on probability misperceptions may be fundamentally misguided and may not solve the problem of under-insurance" (Laury et al., 2009, p. 18).

4.1.2 "Rational" barriers

Insuring fat-tailed and dependent risks is expensive. These costs are passed on to consumers in the form of higher premium loadings. Given this, in a range of cases, it may be rational for consumers to forego catastrophe insurance (Kousky & Cooke, 2012). This section discusses the factors that may lead utility-maximising agents to reduce their demand for climate-risk insurance. Such "rational" barriers include: charity hazard, considerations connected to the affordability of insurance instruments, risk aversion, ambiguity aversion and loss aversion.

4.1.2.1 Charity hazard

The terms charity hazard (Browne & Hoyt, 2000), or Samaritan's dilemma (Buchanan, 1975; Raschky et al., 2013), refer to the phenomenon for which the (anticipation or expectation of) external assistance by a third party crowds out individual incentives to undertake self-protection measures. Expected social support reduces risk perception, potentially making agents less likely to adopt protective measures, including seeking insurance coverage (Babcicky & Seebauer, 2017). As shown in Chapter 3.2.4, governments in several European countries provide compensation to households and businesses following a climatic event. While this allows the affected populations to rebuild their damaged assets and recover to the pre-event conditions, it comes with a number of downsides. Governments acting as "insurers of last resort" reduce the demand for private (commercial) climate risk insurance (Raschky et al., 2013). This leads insurance companies to have to raise insurance premiums in order to guarantee profitability, which, however, further reduces the attractiveness of insurance policies and risks exacerbating affordability issues (Tesselaar et al., 2022). In certain cases, governmental relief goes in direct competition with private insurance coverage. For example, in Austria governmental relief is precluded to households holding insurance coverage, which, coupled with the restrictive policy conditions, make the insureds feeling worse-off than non-insureds, thus reinforcing charity hazard (Holub & Fuchs, 2009; Porrini & Schwarze, 2014).

---

[12] This finding, however, should not be taken as a definite proof of the "puzzle", since it could simply be a result of underlying differences between the two countries, such as the levels of structural flood protections, risk preferences or cultural and social norms.

Despite the well-established consensus that governmental relief can crowd out incentives to privately insure, still relatively few studies exist that empirically test the existence of a charity hazard (Raschky & Weck-Hannemann, 2007). Andor et al. (2020) find that households living in areas at high flood risk have lower uptake of flood insurance if they expect that the government will provide damage compensation. Also, Miglietta et al. (2020) show that governmental relief has a negative effect on the uptake of insurance among Italian farmers. While the paper does not specify the exact hazards covered by the policies, crop insurance in Italy typically covers against rain and hail damages. Research from the US does not find evidence of charity hazard as regards household add-on wind coverage (Petrolia et al., 2015); mixed findings are reported for household flood insurance (Davlasheridze & Miao, 2019; Landry et al., 2021; Petrolia et al., 2013); while charity hazard is present for agricultural crop insurance (Deryugina & Kirwan, 2018).

A number of studies use surveys and experiments to investigate the impact of governmental relief on the intentions to purchase insurance coverage or agents' stated willingness to pay (WTP). Research from the Netherlands demonstrates that governmental compensation reduces both households' demand (Botzen et al., 2009b; Botzen & Van Den Bergh, 2012b; Seifert et al., 2013) and WTP (Botzen & Van Den Bergh, 2012a; Seifert et al., 2013) for flood coverage. Similar results have been found for a sample of Austrian and German households and businesses threatened by flooding (Raschky et al., 2013); although Seifert et al. (2013) do not find evidence of charity hazard among households in Germany. Anecdotal evidence of charity hazard exists also for household flood insurance in the Czech Republic (Andráško et al., 2020). For the agricultural sector, Liesivaara & Myyrä (2017) report that state aid can generate charity hazard, especially for crops presenting low expected indemnity. The effect, however, results mainly in a reduction in the WTP for deductibles, while it does not seem to have an impact on insurance premiums.

Some authors have also assessed the expected effect of charity hazard through theoretical models. Brunette et al. (2013) test the predictions of a model of insurance demand under ambiguity with a sample of French households and find that government compensation through a fixed public support scheme significantly reduces the WTP for insurance. However, introducing ambiguity in the compensation increases the WTP compared to certain or risky compensation schemes. A similar finding is corroborated by results from Raschky et al. (2013) who suggest that certainty of compensation exacerbates charity hazard. On the other hand, with a game-theoretic analysis, Li et al. (2023) show that it is only excessive governmental relief that produces charity hazard, whereas a rational and regulated allocation of governmental funds can actually benefit the insurance market.

Finally, governmental compensation has been shown to also reduce the propensity to undertake flood mitigation measures among German households (Osberghaus, 2015). However, the effect is limited to tenants with high education and high risk aversion, who probably understand that property owners are the main beneficiaries of enhanced flood protection (Penning-Rowsell & Pardoe, 2012), who are also responsible for seeking flood insurance for the property. Andor et al. (2020) also did not find evidence of charity hazard on the implementation of non-financial flood protection measures among German households.

4.1.2.2 Affordability

Affordability refers to the ability of prospective policyholders – being them households, businesses, or public administrations – to purchase insurance coverage against climatic hazards given their budget constraints. Market-based insurance coverage against climatic events can generate affordability issues (Schäfer et al., 2019). This is due to the fat-tailed and dependent nature of such events, that requires insurance companies to increase capital reserves and seek reinsurance to ensure solvency, which in turn increases the cost of insurance policies and can make the price of insurance exceed what people are willing or able to pay (Kousky, 2019; Kousky & Cooke, 2012).

Income levels are an important factor in explaining differences in insurance penetration across countries (R. L. Carter & Dickinson, 1992; Enz, 2000; Outreville, 2011; Surminski, 2014). Also, within countries, income has been found to be a key determinant of insurance demand. The social status of residents influences the spatial variability of flood insurance in Slovakia (Solín et al., 2018). Rufat et al. (2024) show that higher-income households are more likely to purchase flood insurance in France, and a similar positive relationship has been uncovered in the US (Bradt et al., 2021). Considering the agricultural sector, Menapace et al. (2016) find that income increases hail insurance uptake among Italian farmers. Binswanger-Mkhize (2012) says that poorer farmers may lack the financial resources to purchase insurance, but he also suggests that wealthier farmers may forego coverage since they already have adequate insurance through income diversification and social networks.

Despite the general positive relation between income levels and insurance demand, the matter of affordability is more complex (Saenz, 2009). Indeed, there is not even a unique definition of (un)affordability. For example, Hudson (2018) investigates how three definitions of unaffordability – based on household expenditure cap, on residual income and on housing costs – lead to considerably different results in terms of projected unaffordability rates and flood risk adaptation. However, the common denominator to all definitions of (un)affordability is the reference to the cost of insurance, namely the insurance premium.

Reviewing how German households and businesses adapted their flood preparedness strategies after the 2002 and 2006 flood events along the Elbe River, Kreibich et al. (2011) find that both groups reduced uptake of flood insurance after the 2002 flood. The authors advance as a possible explanation the increase in premiums that followed the event. Indeed, several studies find the demand for insurance to be reasonably price elastic (Cole et al., 2013; Dercon et al., 2019; Giné et al., 2010; Hill et al., 2019; Karlan et al., 2014). Similarly, Gizzi et al. (2016) attribute the reluctance of Italian homeowners to purchase flood insurance to a combination of high premiums, low indemnity limits and significant levels of deduction. An analysis conducted in the US shows that higher insurance premiums will likely lead insured businesses located in floodplains to raise prices (Frazier et al., 2020). This can reduce their competitiveness, and potentially lead to more severe social effects if the loss of competitiveness forces them to relocate.

Affordability issues are of particular concern when premiums are risk-based (Hudson, 2018; Hudson et al., 2016; Seifert-Dähnn, 2018), also because oftentimes those located in the areas at highest climatic risk are also the more socially vulnerable (Sayers et al., 2018). Some studies in Italy and the Netherlands investigate the viability of risk-based premiums in relation to households' WTP and the consequent effect they would have on insurance demand. In both countries the average annual WTP for flood insurance is around €250 (Botzen & Van Den Bergh, 2012a; Roder et al., 2019).[13] Despite these similarities, the conclusion in terms of affordability are diametrically

[13] A recent report by EIOPA shows that the majority of surveyed respondents from four member states (MS), are willing to pay less than €30 per month (corresponding to a yearly expenditure of €360) for insurance against natural catastrophes (EIOPA, 2024). A study considering insurance protection against climate-

opposite. Paudel et al. (2013) use Bayesian inference and Monte Carlo simulations to estimate flood insurance premiums for 53 dyke ring areas in the Netherlands and find that they are below the average annual WTP, meaning risk-based pricing would be sustainable. However, the authors admit that actual premiums in practice would likely be higher since the model does not include administrative costs and a profit margin for insurers. A study in the Veneto Region in Italy, on the other hand, estimates that risk-based premiums could exceed €800 a year, which largely exceeds households' WTP (Roder et al., 2019). Such high premiums are a result of a combination of high flood risk, relatively low levels of flood protection, and low penetration. But the outcomes suggest that even quadrupling protection standards would make premiums acceptable only for a quarter of the respondents. Conversely, making flood insurance compulsory for all households in Veneto, would allow a dramatic decrease in insurance premiums (between €26 and €40 per year), which would make it palatable to more than 90% of the respondents.

Another crucial element is the effect that climate change will have on the affordability of insurance. All the studies investigating this relation focus on flood risk. The aforementioned paper by Paul Hudson (2018) projects risk-based insurance premiums to grow by an average of 120% by 2080 in Europe, with the majority of this growth being due to socioeconomic development rather than worsened climatic conditions. The different definitions of affordability yield considerably different results in terms of unaffordability rates and their spatial distribution, although these appear to be rather stable over time and across risk scenarios for a given definition. The author concludes by recommending the adoption of the "residual income" definition for affordability considerations, since it is less sensitive to the threshold choice, it is strongly focused on low-income households, and it is easier to integrate into pre-existing policies. Tesselaar, Botzen & Aerts (2020) confirm a steep increase in insurance premiums towards 2080 accompanied by a significant impact of capital market conditions, which can cause considerable changes in the unaffordability of, and the demand for, flood insurance, potentially leading some households to forego insurance coverage altogether and rely on government compensation or private savings. In particular, unaffordability is found to increase especially for households who already faced affordability problems. In a related study, Tesselaar, Botzen, Haer, et al. (2020) find that the unaffordability of household flood insurance in Europe increases with climate change. Simulations show that under a high-climate change scenario penetration rates decline to less than 5% in 2080 in several regions, where insurance uptake almost disappears.

In order to reduce the unaffordability of climate insurance under climate change and risk-based pricing, scholars have advanced various forms of subsidisation (Kunreuther, 2021). However, without interventions to reduce the level of risk, these are likely to put a higher financial burden on governments given the projected patterns of future unaffordability (Tesselaar, Botzen, & Aerts, 2020). Making insurance compulsory does not solve affordability problems by itself, it is even likely to increase unaffordability without a certain degree of subsidisation (Tesselaar, Botzen, & Aerts, 2020; Tesselaar, Botzen, Haer, et al., 2020). And it also does not guarantee higher penetration, since, if insurance is perceived to be too expensive, people are not likely to purchase it even if mandatory (Savitt, 2017). In addition, compulsory schemes risk weakening the risk-signalling ability of insurance (Roder et al., 2019), while subsidisation blunts incentives for risk reduction

related extreme weather events (floods, droughts and heatwaves) reports an average annual WTP of Italian households just greater than €140 (Ivčević et al., 2021).

Funded by the European Union

(OECD, 2021), so comprehensive risk management and reduction are paramount to ensure extensive and affordable coverage in the future.

4.1.2.3 Risk aversion and loss aversion

In the economic literature, individuals are believed to prefer situations of certainty to those of uncertainty, even though the two present the same expected payoff, or as Jan Werner puts it, "an agent is risk averse if she or he is unwilling to take any actuarially fair (i.e., zero expectation) gamble when starting from a position of no risk" (Werner, 2009, p. 1). Purchasing insurance is an example of an economic decision under uncertainty (Surminski, 2014), and factors such as income, price and attitudes toward risk are key determinants to this decision (Schlesinger, 2013).

Since insurance allows policyholders to protect themselves from the occurrence of an uncertain future loss in exchange for a certain smaller premium, risk aversion should increase the demand (and WTP) for insurance (Kunreuther & Pauly, 2004; Robinson & Botzen, 2018). However, Papon (2008) finds that risk-averse, utility-maximising agents would never choose to partially insure, opting for either full or no insurance, which is contrary to EUT. The literature on insurance against climate risk also fails to detect such a clear-cut relation as EUT would imply, and a much more nuanced effect emerges.

A number of studies do report a positive impact of risk-aversion on climate insurance uptake. First of all, looking at the supply of insurance, Bernard et al. (2020) demonstrate that when risks are correlated, as is the case for climate events, the optimal strategy for insurers is to restrict the offer to the more risk-averse policyholders. Botzen and Van Den Bergh (2012a) find that flood insurance coverage is more valuable for risk-averse households in the Netherlands, and Botzen and Van Den Bergh (2012b) highlight that risk-seeking households have a lower WTP for flood insurance. In addition, assuming compulsory flood insurance, Mol et al. (2020b) show that risk aversion can also increase investments in damage-reduction measures. A couple of studies in the US find risk aversion to positively affect the demand for flood (Petrolia et al., 2013) and wind (Petrolia et al., 2015) insurance. However, in both instances, this is only the case when risk aversion is elicited over the loss domain, while no relationship emerges when it is computed for the gain domain. In the agricultural sector, Menapace et al. (2016), Santeramo (2019) and Giampietri et al. (2020) report that risk aversion increases the likelihood of Italian farmers purchasing crop insurance. And Gómez-Limón & Granado-Díaz (2023) show that more risk-averse farmers would pay a higher premium for drought index insurance in Spain. This is particularly relevant, since a recent literature review reveals that most European farmers are risk averse (Iyer et al., 2020).[14] A similar positive effect on agricultural insurance has been detected also outside Europe, with risk aversion enhancing the demand for index-based insurance in Ethiopia (Belissa et al., 2020), and reducing the aversion to probabilistic insurance in Guatemala (McIntosh et al., 2019).

However, there are also several papers that highlight the presence of a negative, rather than positive, impact of risk aversion on climate risk insurance. The already mentioned study by Osberghaus (2015) reveals that charity hazard is limited to the subgroup of risk-averse and

[14] The authors, however, warn against the definitive validity and generalisability of this finding, claiming that the concept of risk aversion is necessarily a relative one, likely to be context- and circumstance-specific, which makes it challenging to aggregate farmers' risk preferences across large geographical regions. Moreover, this result is based on a counting principle and not on a statistical analysis of the underlying estimates (Iyer et al., 2020).

educated tenants, suggesting that, at least for them, risk aversion would lead to lower flood insurance demand when governmental relief is available. Most of the evidence of a negative impact, however, comes from the agricultural sector. Platteau et al. (2017) report that the demand for index-based and microinsurance seems to be negatively correlated with risk aversion. From a survey among German farmers, Meraner & Finger (2019) find that risk aversion reduces the probability of farmers to adopt off-farm risk management strategies, including the uptake of crop insurance and futures, while it increases preferences for on-farm strategies. The authors argue that such a negative relation could be explained by a low degree of trust in financial institutions, which makes them lean toward on-farm strategies to diversify risk. Van Winsen et al. (2016) also detect a negative relationship between the risk aversion of Belgian farmers and their propensity to adopt off-farm risk-management strategies. In a study in Bangladesh, Hill et al. (2019) show that more risk-averse farmers have a lower demand for drought index insurance than those less sensitive to risk. In this context, offering a rebate on the insurance contract (in the form of a partial refund towards the end of the contract) seems to counteract this effect.[15] In fact, if policyholders are worried that they might not receive payouts (either because of the absence of loss events or due to basis risk), the option of a refund gives them the assurance that they will receive some financial recompense. A similar reasoning could be applied to forms of ecosystem-based insurance. For instance, an experimental investigation of farmers' willingness to accept a nature-based solution for climate adaptation reveals that those who are more concerned about the risk of insufficient repayment of the contract (i.e., who are more risk averse), are less likely to accept it (Zandersen et al., 2021).

These reasonings are also akin to the phenomenon of loss aversion. Tversky & Kahneman (1991) demonstrate that individuals are more sensitive to losses than to equally sized gains. Given that insurance contracts entail a series of certain losses – i.e., the insurance premiums – and a non-guaranteed gain – i.e., the payout –, loss aversion could have a negative impact on the demand for insurance. Indeed, Lampe & Würtenberger (2020), using experimental data from (Cole et al., 2013), find that loss aversion reduces the demand for rain index insurance among Indian farmers. In addition, Liu et al. (2023), in their investigation of a new weather index insurance product for blueberry growers in Canada, states that loss aversion has a negative impact on farmer's demand for weather index insurance.

Finally, two studies find no relation between risk aversion and flood insurance uptake in Finland (Väisänen et al., 2016) and the US (Landry et al., 2021).

4.1.2.4 Ambiguity aversion

In his seminal work, Elsberg (1961) demonstrates that agents prefer situations where the probability of occurrence of a certain event are known, a phenomenon which is referred to as ambiguity aversion. This has important consequences on the demand for insurance, and in particular for coverage against climate-related losses. On the one hand, prospective policyholders do not know if and when a climate event will take place nor the extent of damage they will suffer, and insurance reduces the ambiguity connected to the future economic situation by guaranteeing a certain level of compensation should a loss occur. As such, ambiguity aversion should have a positive effect on the demand for insurance. On the other hand, there are several factors that could make insurance policies not to perform as expected (Peter & Ying, 2020), thus making

[15] The effect, however, disappears when the estimation model simultaneously controls for hyperbolic discounting (Hill et al., 2019).

Funded by the European Union

policyholders unsure as to whether they will actually receive compensation. In this sense, ambiguity aversion is likely to reduce the demand for insurance.

Theoretical studies seem to corroborate the existence of a positive relationship between ambiguity aversion and insurance demand. Brunette et al. (2013) demonstrate that ambiguity-averse agents buy more insurance than ambiguity-neutral ones, that making public support contingent on insurance coverage reinforces this effect, and that over-insurance is optimal for ambiguity-averse agents when the price of insurance is subsidised. In the experimental investigation that followed, the authors find that, regardless of the policy instrument, the WTP to be fully insured relative to the expected loss are significantly higher in the ambiguity treatment compared to the risk treatment, suggesting that individuals are ambiguity-averse in the loss domain for low-probability events. These findings are in line with what is reported by Berger and Bosetti (2020, p. 634), who state that "recent theoretical developments suggest that exhibiting [diminishing absolute ambiguity aversion] in the presence of ambiguity will lead to (1) an increase in the insurance coverage rate, (2) raise the optimal level of [self-insurance], and (3) favor a higher optimal level of [self-protection]". Conversely, in a theoretical analysis of insurance non-performance, Peter & Ying (2020) show that ambiguity aversion lowers the optimal demand for insurance.

Experimental evidence also returns mixed outcomes. In a threshold public good game among students in the UK, Le Roux (2020) observes a positive relationship between ambiguity aversion and the decision to purchase insurance against climate catastrophes. On the other hand, several studies find ambiguity aversion decreases farmers' demand for weather index insurance in developing countries (Belissa et al., 2020; Bryan, 2010; McIntosh et al., 2019), often as a result of the unknown probability of receiving a payout of such contracts (basis risk). Finally, Osberghaus & Reif (2021) show that ambiguous (non-guaranteed full compensation) or certain (guaranteed partial compensation) governmental relief have no effect on insurance decisions.

Overall, the academic literature does not provide a clear picture of the relationship between attitudes toward ambiguity and demand for climate risk insurance. Theoretical and experimental studies offer support to the existence of both a positive (ambiguity aversion fosters demand) and a negative (ambiguity aversion hampers demand) relation. Empirical evidence is still limited, and almost no on-the-field investigations focus on developed countries.

4.1.3 "Irrational" barriers

"Irrational" barriers have to do with biases, heuristics and mental shortcuts that agents adopt in their decision-making processes and that might lead to suboptimal outcomes. These include status quo bias, availability bias, herding, mental accounting, and a mismatch between the probability of event and the policyholders' threshold level of concern.

4.1.3.1 Status quo bias

The status quo bias refers to a reluctance of agents to change and a tendency to stick to the status quo, even in situations in which switching and moving away from the status quo would lead to a better situation. Such a phenomenon is of potentially great relevance in the context of climate insurance, since, as it has been shown in Chapter 3, the average penetration rate is still fairly low, even among developed European countries. Hence, if holding insurance coverage against climate risk is the exception rather than the norm, agents who display a status quo bias will opt to remain under- or uninsured, despite the several advantages provided by climate risk insurance.

In a recent experiment among households in New Zealand and Australia to investigate their choices over catastrophic natural hazards insurance, Dudek et al. (2021) find that the decision to hold insurance coverage in the current period is positively affected by previous period's choices. Namely, if a respondent was (was not) insured in previous periods, they are more (less) likely to choose insurance in the current period. The authors attribute this effect to respondents either being very consistent with their insurance choices or being affected by a status quo bias.

Two additional experimental studies investigate the effect of status quo bias not as a cause of underinsurance, but as a potential driver for sustained insurance uptake. Kunreuther et al. (2021) and Robinson et al. (2021) evaluate whether making coverage against natural and climatic hazard as a default in insurance products, as opposed to an optional add-in coverage, incentivises uptake. In the first study, Kunreuther and co-authors show that, in an hypothetical insurance scheme against seismic risk in Canada, being assigned to an opt-out default significantly increases the take up of earthquake coverage with respect to being assigned to an opt-in default (Kunreuther et al., 2021). In the second study, Robinson and colleagues find that a similar opt-out default increases the likelihood of insuring against flooding in the Netherlands but not in the UK (Robinson et al., 2021). Looking at these effects more in depth, the authors find that risk preferences don't affect the impact of the default option in the Netherlands; whereas in the UK, the opt-out default incentivised uptake for risk-averse individuals, but the effect decreases with the level of risk tolerance to the point where the opt-out condition could even backfire and decrease flood insurance demand relative to an opt-in scheme. Hence, both these studies suggest that the status quo bias could also operate in favour of climate risk insurance diffusion, although results from the United Kingdom caution that this effect might be context-dependent and possibly vary with other individual characteristics. Yet, the body of research examining the presence of a status quo bias for insurance purchase decisions remains relatively small, so further investigation of this phenomenon is warranted.

4.1.3.2 Availability bias

Tversky & Kahneman (1973) show that people often tend to make decisions or evaluate the likelihood of an event happening based on the salience of said event and their ability to recall similar experiences happening in the past. This type of mental shortcut is referred to as availability bias/heuristic, and it can lead to a limited uptake of insurance coverage against climatic events for two reasons. First, severe climatic events are LPHI events, and as such they tend to happen rather infrequently over the lifespan of an individual. This implies that most people have limited direct experience with such events, and this can affect the probability they attach to their occurrence and in turn their willingness to take out insurance to protect against them (Holzheu & Turner, 2018). Second, if people have not taken out insurance in the past, they might lack experience with the product itself and might fail to view and properly evaluate it as a viable option to cope with climate-related risk.[16]

In a study on flood risk perception among New York City residents, Botzen et al. (2015) find that previous experience of flooding is a significant determinant of individuals' (mis-)evaluation of flood risk, in support of the availability heuristic. Specifically, having been flooded more often in the past leads to an overestimation of the probability of flooding, while not experiencing flood damage contributes to underestimation.

[16] This effect also presents connections with the status quo bias and mental accounting.

This effect has been found to translate to insurance uptake. In a multinational investigation of country-wide NATCAT insurance diffusion, Holzeu & Turner (2018) show that more recent losses have a strong positive effect on insurance penetration, while more distant losses have a more contained impact, which the authors say could be testament of availability bias. A number of studies also find evidence of a positive impact of past experience with climate-related events on insurance uptake. Petrolia et al. (2013) find that each additional flood event directly experienced in the past increases the probability of holding flood insurance by 11.4%. According to the authors, this effect could be consistent with updating by Bayes's law (experience with flooding can increase subjective probability estimates leading to higher flood insurance demand) or with availability bias (increased experience with flooding may render available information that increases subjective probability of flooding and augments flood insurance demand). Atreya et al. (2015) confirm the results of Holzeu & Turner (2018) at the micro level for households in Georgia (US). Flood damage increases demand for flood insurance, however the effect is statistically significant for damage suffered over the past three years, while damage suffered more in the past does not bear any impact on present flood insurance decisions. Conversely, in an experimental analysis of insurance uptake against LPHI events, Papon (2008) reports that it is more faraway loss experience to affect insurance decisions, while more recent losses have no effect. Andor et al. (2020) show that having experienced flood in the past increases the probability of German households to own flood insurance. If the flood event did not cause personal damage the likelihood increases by roughly 3 percentage points, while in case respondents suffered personal damage it is almost 6 percentage points higher. These effects, however, disappear when the implementation of non-financial protection measures is included in the estimation, likely as a result of the high correlation between flood experience and non-financial protection measures. Hudson et al. (2022) also confirm that having been flooded before increases the probability that households and businesses undertake flood insurance in Germany. Frigo and Venturini (2024) detect a positive correlation between experience with previous climate-related damages and the decision of Italian SMEs to hold insurance coverage against climate risks.

It is not only the direct experience with climate events and losses that matters. In fact, Seebauer & Babcicky (2020) reveal that both personal and vicarious experience affect the decision to undertake insurance. While Gallagher (2014) demonstrates that also having access to the same flood information as the affected communities through TV news stimulates insurance take-up.

A couple of studies uncover a negative relationship between experience and insurance. In a lab experiment with students at a German university and an online experiment with Austrian households, Osberghaus & Reif (2021) report that having experienced flood losses in the past has an adverse effect on insurance decisions, with insured subjects being prone to forego insurance coverage after experiencing damage. With a similar combination of laboratory and online experiments with subjects from Australia and New Zealand, Dudek et al. (2021) also reveal that respondents tend to decline insurance take-up if they experienced a disaster in a previous period. Both studies attribute the negative effect to the so-called gambler's fallacy (Tune, 1964). This phenomenon originates from people relying on the law of small numbers to draw conclusions on the probability of an event, which leads them to assume that the occurrence of an event reduces the likelihood of future occurrences, essentially implying that event occurrences are determined as extractions without replacement. Given the nature of climatic hazards as low-probability (high-impact) events, if agents behave according to the gambler's fallacy after they experience one such event they are led to believe that the odds of another event taking place are extremely small, which makes insurance coverage an unnecessary expenditure.

Finally, Petrolia et al. (2015) and Rufat et al. (2024) find that past experience does not bear any effect on the uptake of flood insurance in France and wind coverage in the US, respectively.

Regarding the second channel through which availability bias can affect the uptake of climate risk insurance, very few studies have been conducted. Moreover, the analysis of the effect of past take-up on current diffusion present methodological limitations and can offer only anecdotal indication of a potential availability bias, since it is difficult to disentangle the effect of the experience with the insurance product itself (the availability bias component) from those of other factors that might be driving the demand for insurance.

As mentioned in the previous section, Dudek et al. (2021) find that past insurance uptake is an important determinant of present insurance purchasing decisions. The authors attribute this effect to a manifestation of the status quo bias, but it could also be evidence of subjects exhibiting the availability heuristic. Similarly, Santeramo (2019) estimates a positive and significant relationship between past experience with crop insurance and the decision of Italian farmers to buy insurance coverage. The analysis highlights that direct experience increases the likelihood of farmers to buy (again) crop insurance by 10% with respect to previously uninsured farmers, whereas indirect experience (expressed by the sum of other farmers in the same regions who held insurance in the past) has no impact. The effect is stronger for transitory (i.e., deriving from the year immediately prior) than for permanent (i.e., deriving from any past year) experience. Cai & Song (2017) find that playing an experimental insurance game increases actual insurance take-up rates among Chinese farmers. The effect is sizable, since the 9.1 percentage point increase corresponds to a 46% increase relative to the baseline level. The authors also show that the main explanatory factor for the observed effect is the exposure to hypothetical disasters, which gives subjects a reference estimate of their probability and potential losses and a rule of thumb to follow for real-life decisions. Finally, Wang et al. (2012) reveal that both disaster and insurance experience have a positive impact on the willingness to buy natural catastrophe insurance. These findings yield support to both possible sources of availability bias.

4.1.3.3 Herding

“Individuals’ choices are often influenced by other people's behavior, especially under conditions of uncertainty” (Kunreuther, 2021, p. 322). In the context of climate insurance, this implies that agents’ decision to purchase insurance coverage depends on the degree to which other agents in their social network have or have not purchased it. In a situation of low baseline diffusion of climate insurance, such a herding mechanism can reinforce the protection gap.

While a couple of papers fail to detect a significant effect of social networks and social norms on risk mitigation decisions and flood insurance demand (Harries, 2012; Poussin et al., 2014), several studies do find support for the presence of such an effect. In one of the first assessments of the relevance of social connections and social norms for insurance purchase decisions, Kunreuther et al. (1978) find that homeowners in flood- and earthquake-prone areas prioritised discussions with friends and neighbours over considerations of the likelihood and consequences of a future disaster for their choice to purchase insurance coverage against those hazards.

In a series of studies, Alex Y. Lo investigates the impact of social norms on the demand for household flood insurance. In particular, it is found that individuals are more likely to insure themselves against flooding if they expect that people similar to them (e.g., neighbours) or from intimate social circles (e.g., relatives and friends) will do the same action or will approve their choice (Lo, 2013a). Also, the beliefs that family or friends “want me to buy insurance”, or that “other people would buy insurance”, have a positive effect on both the take-up of flood insurance as well as belief that insuring is important (Lo, 2013b). In addition, Lo & Chan (2017), in a survey on the intention to adopt flood prevention measures, including insurance, among British households, argue that community engagement and trusted social networks can enhance the motivation to prepare against flooding and the adverse impacts of climate change.

More recently, Mol et al (2020a), in an experimental analysis of investment in self-insurance and insurance purchase to cope with flood risk, find that social norms have a positive effect on both the WTP for and the level of coverage of flood insurance. The authors also detect a positive impact on the decision to invest in self-insurance, which is mainly driven by cautious individuals perceiving this measure as more effective. However, they caution that this could potentially be due to subjects answering consistently with the chosen investment level in the experiment, since the social norms question was only part of the survey at the end of the experiment Mol et al (2020a). Finally, in a survey on insurance coverage among American households, Zhang et al. (2022) find that a stronger social norm for insurance uptake – i.e., people thinking that their relatives believe they should purchase flood insurance – has a positive impact on the probability to purchase both flood and wind insurance, as well as a negative effect on the probability of being uninsured.

This calls for the importance to reinforce social networks and engagement toward climate risk protection and prevention. For instance, Kunreuther (2021) argues that flood “protection could become a social norm if homeowners that adopt protective measures are given a seal of approval based on a certified inspection”, which may induce others to follow suit. However, Robinson & Botzen (2022) reveal that nudging individuals toward a social norm of greater protection and insurance coverage is only effective if individuals’ personal beliefs align with the norm to begin with, or if they trust the source of information. Hence, figures such as environmental risk managers and community leaders can play a key role in strengthening the social networks and engagement with local communities (Lo & Chan, 2017), to ensure all community members share the same view over the social norms.

4.1.3.4 Mismatch between perceived probability and threshold level of concern

One of the reasons why agents do not insure against climatic hazards is that they perceive the likelihood of these events happening to be too low – i.e., below their threshold level of concern – to invest resources in purchasing insurance coverage (Charpentier, 2008; Kousky & Kunreuther, 2017; Kunreuther, 2021; Kunreuther et al., 1978; Kunreuther & Pauly, 2004). A number of studies have found that insurance demand for low-probability events often follows a bi-modal distribution, with individuals opting for either full or no insurance (McClelland et al., 1993; Papon, 2008), with the latter being attributed to agents following a threshold level of concern model (Kunreuther, 2021). Indeed, anecdotal evidence seems to suggest that this might be the case (Kunreuther & Pauly, 2004; Slovic et al., 1977).

A study conducted among households in the US to elicit their flood risk and damage perceptions and compare them to experts’ estimations reveals that subjects tend to overestimate the probability of tail (i.e., low probability) events but to underestimate their potential damage (Botzen et al., 2015). Among the causes for the underestimation of damages is the perception that the flood probability is below their threshold level of concern. Two papers from the Netherlands further investigate the factors influencing the threshold level of concern and how it impacts on flood insurance decisions. In particular, anticipated regret of not purchasing insurance and worry about flooding are negatively related to the threshold level of concern, while, surprisingly, education does not seem to affect it (Robinson & Botzen, 2018). The threshold level of concern is then found to lower the demand for flood insurance, especially for low-probability flood risks, with this effect acting through probability weighting rather than the curvature of the utility function (Robinson & Botzen, 2020). There also appears to be a negative correlation between the belief that flood probability is below one's threshold of concern and risk aversion. It is worth noting, however, that in the experiment conducted by Robinson & Botzen (2018), only 52 out of 1,041 subjects consistently choose "no insurance", and for the remaining 982 less than 7% present a threshold probability greater than or equal to 0.01. This means that the vast majority of individuals would be willing to purchase insurance coverage up to a 1-in-100-years flood. Conversely, in Robinson & Botzen (2020) most respondents believe that the flood probability is too low to be concerned about, with the authors arguing that this is likely a result of a high level of trust in the structural defences and the Dutch flood risk management. Kunreuther (2021) suggests that stretching the time horizon and re-framing the way in which event probabilities are communicated can reduce the likelihood of individuals assessing them as below their threshold level of concern.

4.1.4 Other personal and social factors affecting insurance demand

4.1.4.1 Demographics

The demographic characteristics of potential policyholders are important determinants of the decision to purchase climate insurance, in particular age and education. Several studies find that older and more educated individuals are generally more likely to have insurance (among others Atreya et al., 2015; Botzen et al., 2019; Bradt et al., 2021; Rufat et al., 2024). However, some papers reveal a negative impact of either age (Väisänen et al., 2016), or education (Menapace et al., 2016), or both (Andor et al., 2020; Meraner & Finger, 2019). The analysis of Meraner and Finger (2019) shows a nonlinear relationship between farmers' age and their preferences over risk management practices. In fact, younger farmers tend to opt for on-farm agricultural strategies, middle-aged farmers rely on off-farm strategies (e.g., crop insurance and other financial risk-transfer mechanisms), while older farmers seem to prefer on-farm activities not directly related to agriculture as solutions to diversify and manage risk.

An aspect related to education is financial literacy, which can be summarised as people's knowledge of financial products (including insurance), their characteristics and their functioning (e.g., the laws of probability). Indeed, Platteau et al. (2017) suggest that education should not be assumed as a proxy for financial literacy, and cite various studies that have found no correlation between the two in the context of insurance. Several authors claim that limited financial literacy or a lack of understanding of insurance products are important factors that reduce the uptake of insurance (Surminski, 2014; Surminski et al., 2016; Surminski & Oramas-Dorta, 2014). While this issue is likely to be particularly severe in the global south (Kraehnert et al., 2021), the literature has documented the presence of an effect also in developed economies. For instance, Menapace et al. (2016) find that financial and risk literacy increase the probability to purchase hail insurance among Italian farmers; while Meraner & Finger (2019) show that risk literacy and a better understanding of numbers and probabilities increase the probability to adopt off-farm risk management strategies in Germany. In a study in India, Cole et al. (2013) reveal that it is the knowledge, or lack thereof, of the probabilistic concept to correlate with insurance demand, while financial literacy per se has no effect. Yet, despite the evidence in support of the relevance of financial, risk and probabilistic literacy for the diffusion of insurance, trainings to improve said literacy have not been very effective (J. Cai & Song, 2017; Platteau et al., 2017).

Some authors have also suggested that insureds might have an imperfect knowledge of their policies, which could offer an additional explanation to the limited diffusion of coverage against climate risks. In particular, it is argued that some households may incorrectly assume that certain hazards (like flooding, wind or hail) are included in their policy when in fact they are not (Holzheu & Turner, 2018; Kousky & Kunreuther, 2017), given that coverage against climatic hazards is offered as an odd-on option in most standard policies.

Another important element is the ownership or tenancy status, with home and business owners being more likely to purchase insurance (Hudson et al., 2022; Rufat et al., 2024). This can be due to national legislations making the owners those legally responsible for insuring the property (while tenants are responsible for content insurance); but possibly also the result of a principal-agent problem, where no such legislation is in place. Also, Petrolia et al. (2015) find that households living in a condominium are less likely to purchase insurance than those living in a single-family home. Since the authors do not investigate ownership status, this could result from condominiums having higher tenancy rates; but also from the fact that in a condominium there is a lower marginal utility of insuring a single apartment/property, while the entire building should be insured instead. Findings from the agricultural sector, on the other hand, seem to suggest that tenancy has a positive impact on insurance. In fact, Meraner & Finger (2019) find that farmers with a greater portion of rented land are more likely to adopt off-farm risk management strategies compared to on-farm non-agriculture ones. They say that such a result confirms previous evidence (Mishra & El-Osta, 2002; Velandia et al., 2009), and that the reason could be that these farmers might have a greater need to share the risk with third parties.

4.1.4.2 Attribution of responsibility

A possible reason why agents do not seek insurance coverage against climate-related risk is that they believe it is someone else’s responsibility to ensure they are protected (usually the government or local administrations). For example, Cornia et al. (2016) claim that in countries like Austria, France, Germany or Sweden there is the belief that the authorities have to take care of citizens’ safety. While this might seem similar to charity hazard, there is an important distinction. In the case of charity hazard, the anticipation of an external relief removes the individual incentive to purchase insurance. In this sense, the agents “rationally” decide not to invest resources in insurance because they know, or they believe, that they will receive compensation anyway. Conversely, in this instance, the mental predisposition of agents leads them to believe that it is not their duty to protect themselves, and they do not even take into account the possibility of purchasing insurance.

This phenomenon is investigated primarily in the context risk preparedness and protections more broadly (e.g., Andráško et al., 2020; Harvatt et al., 2011; Roder et al., 2019; Scolobig et al., 2012; Terpstra & Gutteling, 2008), while evidence of the impact on the demand for insurance is scant. Among those studies that relate to insurance, Ivčević et al. (2021) report that the refusal to invest in home insurance in Sardinia (IT) is partially due to belief that the state should pay for damages (12.5% of those that the authors say express a “protest vote”). In addition, Hudson et al. (2022), studying the flood-protection decisions of German households and businesses, find that the self-perceived belief that government’s actions reduce the need to adapt has a negative impact on business' take-up of flood insurance. Whereas, the self-perceived responsibility to adapt has no impact on insurance uptake for both households and business.

4.1.4.3 Trust

Several authors have suggested that a lack of trust in financial institutions, insurance companies and insurance products are important determinants of the decision not to purchase coverage (H. Cai et al., 2015; Cole et al., 2013; Giné et al., 2010; Karlan et al., 2014; Platteau et al., 2017). While the issue of trust is likely to be more severe in developing countries, where, as mentioned above, there is less familiarity with financial products in general, this factor can also be at play in developed economies, especially if they are characterised by a low insurance penetration.

Numerous studies, for instance, relate the limited uptake of climate insurance in Italy to trust issues (among other things). So, Cesari & D'Aurizio (2019) claim (as reported by Frigo & Venturini (2024)) that one of the motivations explaining the low penetration of coverage in the country is a perceived lack of clarity and transparency of insurance contracts, which can thus generate mistrust in insurance policies and providers. Similarly, Ivčević et al. (2021) document that among the reasons for refusing to invest in home flood insurance, 20% of subjects mention the distrust in insurance. Conversely, a feeling of trust in financial intermediaries has been shown to increase the willingness to undertake multiperil crop insurance and to participate in an income stabilisation tool that compensate member farmers who suffer extraordinary losses (Giampietri et al., 2020). The authors also find that the effect of trust is stronger if farmers had previously adopted (subsidised) risk management tools, suggesting that the feeling of trust is reinforced by the quality of past experience. The importance of trust in the financial intermediary has been documented also in the Netherlands, another country where the penetration of climate (flood) risk insurance is extremely low. In fact, a nudge to leverage social factors for improved flood insurance take-up was found to be ineffective, unless households trusted the source of information, which in the study were insurance agents. The level of trust of households in insurance agents was also found to have a positive impact on insurance demand (Robinson & Botzen, 2022). Conversely, in the US, where the insurance market is much more well-established, Petrolia et al. (2015) find no effect of perceived insurer credibility on the uptake of wind coverage. This seems to suggest that building confidence in insurers and their products can prove particularly beneficial in those markets where there is currently low penetration and experience with said products. Whereas in those markets where the insurance industry has already a consolidated role this is not as much of a necessity, perhaps because the baseline level of trust is already fairly high.

4.1.4.4 Fatalism and wishful thinking

Two rather opposite mentalities can have a negative impact on the decision to purchase climate insurance: fatalism and wishful thinking. Fatalism refers to the belief that an event and its consequences are predetermined and inevitable, and there is nothing that can be done to prevent them. This attitude can also be associated with having an "external locus of control" (Rotter, 1966), which means that the consequences of an event and the power to influence them are external to the individual. Wishful thinking, on the other hand, relates to an optimistic or even naive attitude, which leads people to dismiss the possibility that something bad will happen. The former can crowd out individuals' incentive to self-protect, as they believe there is nothing they can do in that sense. The latter essentially removes negative events from their consideration sets, which is tantamount to reducing their perceived probability of occurrence to zero.

Funded by
the European Union

In the academic literature, Terpstra & Gutteling (2008) report that when people perceive to have less control over their personal safety during floods, then they are more likely to attribute the responsibility for protection and preparedness to the government. Bubeck et al. (2012) mention that, among the factors affecting the decision to uptake flood risk protection measures, fatalism has a negative effect. Likewise, a sense of impossibility to do anything against floods is brought up as a common reason by Czech households for not having any strategy to protect against flood risk (Andráško et al., 2020). A couple of studies have also demonstrated that fatalism negatively affects the demand for household flood insurance in the Netherlands (Botzen & Van Den Bergh, 2012a; Robinson & Botzen, 2020). In particular, Robinson & Botzen (2020) find that individuals with an internal locus of control assign larger weights to more severe floods in their insurance decision problem, and that they also tend to be more risk averse/less risk seeking. Extrapolating in light of what said above and the findings on risk aversion, this suggests that having an external locus of control reduces the importance given to severe events and decreases the degree of risk aversion, both of which undermine the propensity to seek insurance coverage.[17] Other countries where there is a diffused fatalistic mentality are France, Hungary and Italy, whereas in Austria, Germany and Sweden people believe that it is possible to cope with and minimise the consequences of natural disasters (Cornia et al., 2016).

While the impact of wishful thinking has received less attention, Meraner & Finger (2019) find that more optimistic farmers tend to rely less on off-farm risk coping strategies. Also, Cesari & D'Aurizio (2019) mention that overconfidence is one of the potential determinants for the low penetration of climate risk insurance in Italy (as reported by Frigo & Venutirni (2024)).

4.1.4.5 Substitutability with other risk protection measures

Finally, it has been argued that insurance and other mitigation or risk protection measures can be viewed as substituted by agents (Kousky & Kunreuther, 2017; Surminski, 2014), which implies that the presence of these measures would undermine the demand for climate insurance. However, most of the literature fail to find evidence in support of substitutability (Atreya et al., 2015; Hudson et al., 2017; Hudson & Thieken, 2022; Kousky, 2019), with several studies actually finding evidence of complementarity or advantageous selection between insurance and private risk reduction measures (Botzen et al., 2019; Ivčević et al., 2021; Mol, Botzen, & Blasch, 2020a; Rufat et al., 2024). Elements of substitutability are reported with respect to private savings (Holzheu & Turner, 2018) and federal mitigation grants (Petrolia et al., 2015).

4.2 Supply-side barriers

The factors reported in this section relate to frictions in the supply of insurance products that lead insurers to limit the offer of coverage, charge higher premiums, or to limitations connected to specific characteristics of insurance policies that reduce their attractiveness for consumers.

4.2.1 Insurability

In order for a risk to be considered insurable, a number of requirements must be met (Charpentier, 2008; GFIA, 2023; OECD, 2021). These include: (i) the randomness of the occurrence of the specific event; (ii) the ability to determine the probability of occurrence; (iii) the ability to determine the average frequency and severity of an event (requires a sufficient number past occurrences to predict losses); (iv) the fact that risks should be pooled so that the law of large numbers applies

[17] The authors say that they cannot distinguish whether the effect of the locus of control on flood insurance demand acts through probability weighting or outcome valuation (Robinson & Botzen, 2020).

(losses/claims are diversifiable, independent and identically distributed); (v) the possible maximum loss should not be huge with respect to the insurer's solvency; (vi) there should not be significant informational asymmetries, moral hazard and adverse selection; (vii) there should be an insurance market (i.e., an insurer willing to supply coverage and an insured willing to demand it), so that an equilibrium price (premium) can arise; (viii) the feasibility of the equilibrium price, i.e., insurance premiums are substantially less than the insured amount. If all of these conditions are met, a risk is considered insurable. However, it could still not be profitable to do so. Insurance companies will offer coverage if the costs of marketing and issuing policies are sufficiently low to make a positive profit based on the number of policies that are expected to be sold at the (optimal) insurance premium (Grossi et al., 2005).

Natural disasters and climate change pose threats to insurability (Grossi et al., 2005; J. Lamond & Penning-Rowsell, 2014; Savitt, 2017; Schäfer et al., 2019). Firstly, the uncertainty regarding their occurrence and magnitude limits the ability of insurers to accurately quantify potential losses (criterion (iii); Grossi et al., 2005; Kron et al., 2019; J. Lamond & Penning-Rowsell, 2014). This can be particularly problematic for certain hazards and activities (e.g., drought and grassland production; Vroege & Finger, 2020). In addition, changing climate conditions imply that loss estimation based on historical data is less reliable (Savitt, 2017). Second, climate-related loss events tend to be spatially correlated, with a large number of claims clustered in specific areas (Grossi et al., 2005; Kousky, 2019; Kunreuther & Michel-Kerjan, 2013; J. Lamond & Penning-Rowsell, 2014). For instance, Kron (2009) and Kron et al. (2019) state that "properties affected by flooding are more or less always the same and only these will seek flood insurance, whereas those not affected won't" (adverse selection, criterion (vi)).[18] This also reduces the scope for diversification (criterion (iv); Charpentier, 2008; Kousky & Cooke, 2012). As a result, certain risks might be considered outright uninsurable (Schäfer et al., 2019), or, for those that are insured, insurance companies might ask premiums that are unattractive or unaffordable for most potential policyholders (Kron, 2009; Kron et al., 2019; J. Lamond & Penning-Rowsell, 2014). However, as noted by EIOPA (2023b) large climate-related disasters display weak correlation across EU MSs and across time. Third, extreme climatic events tend to have a distribution that is characterised by "fat-tails", meaning that there is a higher probability that catastrophic events will occur, which could threaten the solvency of insurers (criterion (v)). Born & Klimaszewski-Blettner (2013) claim that the withdrawal of insurers from the market is more a result of the severity of events impacting their ability to bear risk, than of their frequency (the authors also report that this is particularly an issue for household insurance, while it is not the case for business coverage). In Europe, it is estimated that the potential losses from flood events could exceed 2% of the national GDP in countries like Czech Republic, Poland and The Netherlands, and that the magnitude of the hazard relative to the size of the country and the population might prevent commercial insurers from providing coverage (Bouwer et al., 2007). This issue is further aggravated by the spatial correlation of losses, which further inhibits the ability to supply insurance coverage. For instance, studying the distribution of storm losses in the US, Conte & Kelly (2018) find that the distribution is indeed fat-tailed, and that this is given by the distribution of coastal properties rather than by the distribution of wind speed.

These issues are further aggravated by climate change, which is expected to increase the frequency and intensity of climate-related loss events (i.e., to increase the probability mass in the

[18] Kron (2009) specifies that this is not the case for (pluvial) flash flooding, which has much lower correlation thus making diversification and setting an affordable premium possible.

tail of the distribution). For instance, using data from the Munich Re NatCatSERVICE, Hoeppe (2016) highlights that the number of loss relevant weather extremes has increased in the period 1980-2014, claiming that such increase is partially driven by global warming. In an investigation of the projected impacts of climate change on flooding in Europe, Alfieri et al. (2015) estimate that the socio-economic impact of river floods would increase, on average, by 220% in 2080 relative to 1990's levels; and that flood damage is projected to increase to €20-40 billions in 2050 and €30-100 billions in 2080. Also, Lung et al. (2013) project heat stress, flood risk and wildfire risk to increase considerably in many parts of Europe due to climate change. Nevertheless, some expect that climate-related events will remain insurable in the next decades as long as so called non-linear "tipping points" of climate change are not reached (Hoeppe, 2016). Indeed, Botzen & Van Den Bergh (2012a) suggest that offering flood insurance in the Netherlands will be profitable if climate change results in a moderate increase in flood probabilities, but not if there is an extreme rise in flood probabilities. On the other hand, Ulbrich et al. (2013) reveal that the cumulative effects of storm damage could pose severe threats to insurers' solvency.

Despite the fact that climate change can affect the insurability of future climate-related losses, it appears that insurance companies usually do not consider future climatic conditions in their actuarial models. To give a simplified representation of how insurers price climate risk, catastrophe models present four main components: (i) hazards, i.e., the geo-physical properties of the event; (ii) inventory, namely the properties and assets at risk and their characteristics; (iii) vulnerability, i.e., the susceptibility of the properties and asset to the hazard; (iv) the resulting loss (Grossi et al., 2005).

In a review of climate risk pricing, Gray (2021) claims that traditional models were based on historical data and the assumption of stationarity of climate events, which ensures that reliable predictions can be drawn from past observations. This approach, however, does not consider the possibility that future distributions might be different, which in turn would make the estimations unreliable. The industry tried to move beyond this approach by incorporating expert opinions to select and weight factors that predict the occurrence of events (the so-called "Delphi-method"), in an attempt to forecast future hazardous events and losses. While these models proved effective at predicting (hurricane) losses, many questioned their validity due to a lack of clear rules to source and test the experts' opinions. As a result, primary insurers seem to have reverted back to the traditional approach based on long-term historical data, and "current efforts [are focusing] on reanalysis and bootstrapping of the decadal cyclone and sea-surface temperature data sets, rather than actually dealing with questions of climate change (Bonazzi et al., 2014; Caron et al., 2018)" (Gray, 2021, p. 213). However, forecast-based models are adopted by reinsurers, so they still affect insurance prices indirectly. From the review conducted by Ingel et al. (forthcoming) within this project, it emerges that the majority of actuarial risk models are still backward-looking.

Therefore, it would be advisable to integrate future climate conditions into loss modelling (Mills, 2012), as this would reduce the risk that policies are mis-priced. However, the adoption of climate models to loss estimations presents a number of limitations which reduce the scope for actuarial applications. Climate projections are typically based on General Circulation Models (GCMs) or Regional Climate Models (RCMs). However, there is considerable uncertainty connected with these models, which increases with the time horizon, and that results in estimates being highly variable and often biased (Kourtis & Tsihrintzis, 2021; Sunyer et al., 2012). Therefore, in order to produce usable estimates, appropriate bias-correction and downscaling techniques must be applied. Yet, with downscaling to appropriate spatial scales the forecasts become less precise (J.

Lamond & Penning-Rowsell, 2014). Moreover, their applicability to impact assessment is usually limited to a single process (e.g., a single flood type between coastal, fluvial and pluvial), which can lead to erroneous estimates in large-scale assessments for regions dominated by a different process (e.g., European projections of future river flooding usually yield implausible results for the Netherlands (De Moel et al., 2015)). In order to produce accurate impact assessments, Kourtis & Tsihrintzis (2021) recommend using an ensemble approach where several GCMs, RCMs and bias-correction methods are employed, as this allows for the uncertainties of each approach to be controlled for. Such an approach is data and computationally intensive, and requires considerable expertise and resources, which might significantly hamper the ability of insurance companies, especially smaller and more resource-constrained ones, to adopt forward-looking actuarial models. In addition, their usefulness might be region-, hazard- and/or sector-specific. For instance, using climate change projections for the Netherlands in 2050, based on an ensemble of GCMs, Botzen & Bouwer (2016) estimate a marginally small increase in hailstorm damage, mainly restricted to summer months, which could be addressed via standard practices (e.g., limiting coverage, increasing premiums, and purchasing additional reinsurance). Hence, in this case, developing a policy that covers for hail damage considering future climate conditions might not be profitable. However, further research is needed that investigates insurers' awareness of and appetite for forward-looking approaches.

4.2.2 Cost of capital

As seen above, natural hazards often violate some of the key principles of insurability, which makes insurers unwilling to offer coverage for such events. When insurance companies do decide to provide coverage, they typically do so for a higher price point than other lines of business, since insuring climate-related risk, which is often fat-tailed and dependent, is extremely expensive (Kousky & Cooke, 2012; Louaas & Picard, 2021). One of the reasons for this expensiveness is that NATCAT and severe climatic events have the potential to generate extremely large losses which require insurance companies to hold large capital reserves to cover them (OECD, 2021). For other lines of business, insurance premiums collected in a year are often enough to cover claims in that year. For severe climatic events, however, premiums are usually not enough, and in order to guarantee the payments of claims and ensure their solvency, insurance companies have to collect additional capital from other sources, such as reinsurers[19] and financial markets (Kousky, 2019). This capital comes at a cost, which is passed on to consumers in the form of higher premium loadings[20] (Kousky & Cooke, 2012), which reduces penetration, in turn increasing the need to rely on external sources of capital.

There are several factors that contribute to this extra cost of capital. First of all, in recent years there has been an increase in the value of property at risk, due to more development in risk-prone areas (Hoeppe, 2016). For instance, Jongman et al. (2014) report that, in the Netherlands, the ratio between property value in flood-prone areas to the total value was more than 25% in 2012, while it was less than 20% in 1960, and this trend is more pronounced for residential properties, which, as we have seen in Chapter 3, generally tend to have lower take-up rates of flood

[19] Reinsurers are insurers of insurance companies. These are very large companies that operate on a global scale and are thus able to diversify across multiple locations, customers and risks. The most important reinsurance companies are Munich RE and Swiss Re.

[20] The premium loading is the non-risk-related component of the premium. A premium which only reflects the underlying level of risk is said to be 'actuarially fair'. Usually, insurance companies add a positive loading factor to the actuarially fair premium in order to ensure profitability.

Funded by
the European Union

insurance. Similar patterns have been evidenced in the US, where the "fat-tailness" of hurricane damage is due to the sorting of properties in coastal areas (Conte & Kelly, 2018). This leads to greater exposure and increases in expected payouts, requiring insurers to hold more capital.

Relying on external capital entails issues costs and underwriting costs which are not present if insurance companies could use exclusively their internal resources, and asymmetric information further adds to this toll (Kunreuther & Pauly, 2004). In addition, extreme events generate negative capital shocks, which lower the availability of capital for both insurance and reinsurance, and can lead to so-called "hard" markets where the supply of (re)insurance is scarce and expensive (Kousky, 2017; Kousky & Kunreuther, 2017; Kunreuther & Michel-Kerjan, 2013). These shocks have been found to propagate across regions due to the interconnectedness of global financial markets, so, for instance, a particularly severe hurricane season in the US can lead to insurance companies in Europe facing less favourable reinsurance conditions which are then passed on to final consumers (Tesselaar, Botzen, & Aerts, 2020; von Dahlen & von Peter, 2012). Because of this, reinsurance has been shown to be cyclical, with reinsurance prices being driven by similar factors as primary insurance markets (Meier & François Outreville, 2006).[21] Capital availability is thus a key determinant of the price of (re)insurance (Tesselaar, Botzen, & Aerts, 2020).

There are then a number of other elements that lead to frictions in the supply of and demand for reinsurance. These include the market power of reinsurers, which allows them to set higher loading factors; inefficiencies in the corporate form of reinsurance companies; agency issues that distort managers' decisions; the crowding-out effect of third parties' interventions that substitute for (re)insurance; and a degraded market generated by moral hazard and adverse selection (Froot, 2001). One particularly relevant managerial distortion is the tendency to adopt a safety-first decisional approach,[22] which focuses on minimising the probability of insolvency rather than on maximising profits. This affects the types of policies that are offered and leads to overcharging certain risks while undercharging others (Kousky & Kunreuther, 2017; Kunreuther & Pauly, 2004).

In a recent analysis, Tesselaar, Botzen & Aerts (2020) estimate the projected evolution of flood (re)insurance prices across Europe under a changing climate. The study finds that a greater average and variance of flood risk is expected toward the end of the century, which will lead to higher and more volatile insurance premiums as a result of global reinsurance and capital market conditions, with these effects being particularly pronounced under a severe climate change scenario (RCP8.5-SSP5). The authors report, citing evidence from the OECD (2018), that the finding of greater volatility in the reinsurance market seems contrary to the current state of the said market, which is the result of financial policies to maintain low interest rates and the absence of large catastrophes in the period 2011–2017. The predicted impact of capital market conditions for reinsurers, however, can have severe effects on the unaffordability of flood coverage, since

[21] The demand for capital increases after extreme events, since resources are needed to rebuild (Meier & François Outreville, 2006). Investors demand higher prices which increase reinsurance premiums (Froot, 2001). As the return of capital increases, however, more capital is supplied which brings its price down and allows reinsures to lower their premiums.

[22] Citing the work of James Stone (1973), Grossi et al. (2005) report that insurers aim to satisfy a survival constraint, which leads them to choose a portfolio of risks, and relative prices, that minimise the expected probability of insolvency. Being T the total potential loss the insurer could have to repay, n the number of policies, z the insurance premium, and A the current insurer's surplus, the survival constraint is satisfied if: $\Pr[T > ((n * z) + A)] < P$, where P is a probability of insolvency deemed acceptable by the insurer.

primary insurers have to raise premium loadings, thus potentially aggravating the insurance protection gap and forcing agents to rely on government compensation or private savings.

Various authors have discussed possible approaches to reduce frictions connected to the cost of capital. Kousky & Cooke (2012) say that insurance companies could utilise tax-deferred catastrophe reserves. These are trusts or separate accounts where insurers allocate catastrophe funds tax free, which can only be accessed for claims payment. Alternative ways in which insurance companies can enlarge their capital reserves and establish additional (financial) capacities include captives, sidecars and industry loss warranties (Charpentier, 2008). Kousky (2019), citing a report from the US Office of Management and Budget (OMB, 2016), states that, despite the evidence suggesting a limited effectiveness of premium discounts to secure cost-effective investments in mitigation, these could operate at the level of reinsurance, allowing for risk-reduction investments to be more than paid for by the lower reinsurance premiums. Lastly, some studies claim that public insurers (Buzzacchi & Turati, 2014) or insurance pools (Louaas & Picard, 2021; OECD, 2021) are better equipped than individual insurance companies to deal with the costs of sourcing sufficient capital resources.

4.2.3 Asymmetric information

Insurance companies generally hold less information than policyholders on their underlying level of risk and cannot adequately monitor their behaviour or risk-reduction efforts. This informational asymmetry leads to two phenomena that threaten insurability: moral hazard and adverse selection.

4.2.3.1 Moral hazard

According to Stiglitz (1983, p. 6) “the more and better insurance that is provided against some contingency, the less incentive individuals have to avoid the insured event, because the less they bear the full consequence of their actions”. In order to cover themselves against the heightened risk level that such a moral hazard generates, insurance companies are induced to charge higher premiums and introduce policy conditions such as deductibles and coverage limits (Kraehnert et al., 2021). While the evidence presented in section 4.1.4.5 shows that, in the majority of cases, agents do not treat climate insurance and protection measures as substitutes, the studies discussed in that section investigate whether having protection measures in place reduces the likelihood of seeking insurance coverage. The phenomenon of moral hazard analysed here considers the opposite effect, namely whether having insurance crowds out incentives to undertake risk-reduction measures.

Theoretical studies confirm the detrimental effect of moral hazards. In an analysis of optimal insurance contracts, Winter (2013) demonstrates that moral hazard reduces the optimal amount of insurance coverage. Similarly, Buzzacchi & Turati (2014) show that this phenomenon affects local administrations as well and not just private entities. In fact, the presence of moral hazard, even with actuarially fair premiums, makes foregoing voluntary insurance the optimal choice of local administrations; while, in the presence of a mandatory level of coverage, the higher premium charged by the insurer to cover from moral hazard leads to a sub-optimal level of precautionary investments by local administrations (thus fostering moral hazard). Moreover, Quaas & Baumgärtner (2008) demonstrate that financial insurance and natural insurance (provided by biodiversity) are substitutes: the availability of the former reduces the demand for the latter, leading to lower ecosystem quality.

Results from empirical and experimental studies on the presence of moral hazards, on the other hand, are mixed. In a series of experiments framed in an insurance setting, in which participants had to decide whether or not to provide self-protection for agricultural activities, Biener & Eling (2016) find that, in line with moral hazard, effort for self-protection decreases when insurance coverage is higher and payoffs are less state-dependent. In an experimental investigation on investments in flood protection measures, Mol, Botzen & Blasch (2020b) show that when insurance is available participants invest significantly less in damage-reduction, irrespective of the level of deductibles. However, this effect is mostly present for high-probability (15%) flooding, while in low-probability scenarios (3%) there is no moral hazard, except for very small deductibles (5%). This suggests that moral hazard might be less of an issue for LPHI events. Consistent with this hypothesis, several studies detect a positive effect of flood insurance uptake on risk-reduction measures in Germany (Hudson & Berghäuser, 2023; Osberghaus, 2015), the US (Shao et al., 2019), and Austria, Romania and the UK (Hanger et al., 2018). It is worth noting that the studies that reveal a positive relationship are mostly based on cross-sectional surveys, whereas those that do find evidence in support of moral hazard rely on experimental approaches, which are better suited to estimate causal effects and should thus offer more reliable conclusions. The exception is the paper by Hudson & Berghäuser (2023) which uses panel data derived from a longitudinal survey, and still detects a positive effect.

4.2.3.2 Adverse selection

In the context of natural and climate-related hazards, adverse selection occurs when only the agents at high(er) risk seek coverage, while those at low(er) or no risk do not. This increases the exposure of insurance companies, which respond by limiting coverage or raising premiums (Holub & Fuchs, 2009). The effect of which would be to push away "good risk" and leave only "bad risk", a situation akin to Akerlof's "market for lemons" (Akerlof, 1970).

A study from the US finds that flood insurance uptake is higher for both locations with greater potential hazard (i.e., coastal tracts and tracts with a greater share of their surface area covered by water bodies) and properties with a greater probability of getting flooded (measured by the First Street Foundation flood factor), thus showing evidence of adverse selection (Bradt et al., 2021). In addition, a report by Headwaters Economics on fire risk suggests that insurance policies are unlikely to deter agents from building or relocating in high-risk areas (Headwaters Economics, 2016). In Europe, Hudson et al. (2017) find that adverse selection could be present in the German household flood insurance market. In fact, their analysis reveals that insured households score significantly worse than uninsured ones on several flood hazard indicators (e.g., water levels) during the Elbe and Danube flood events occurring between 2002 and 2006. Moreover, in their discussion of the Austrian climate insurance market, Holub & Fuchs (2009) state that adverse selection is one of the main reasons for the limited penetration of private climate-risk insurance in the country. Conversely, Frigo & Venturini (2024), considering the diffusion of natural hazards insurance among Italian SMEs, do not detect any correlation between the factories being located in a high-risk area and insurance take-up.

4.3 Additional factors and considerations

4.3.1 The role of data in adaptation promoting indemnity insurance portfolios

The EU acknowledges shortcomings in the availability, access and quality of damage impact data with respect to closing the so-called insurance gap as part of the climate change protection gap

(European Commission, 2021). The availability, accessibility, quality, and sharing of climate change related risk data is for several reasons important for climate adaptation planning and implementation, including the insurance industry. Firstly, there is the *enablement* of risk sharing services. Equally important is *equitable access* to risk data for different market actors. For both aspects applies that both *more and better organised collaboration* as well as *generation and uptake of innovations* can ameliorate the shortcomings. All these three domains will be discussed below. However, some of the identified aspects are also relevant in other sections of this report, notably regarding innovation (Chapter 5.3) and collaboration (Chapter 5.4).

4.3.1.1 Data availability

Companies offering indemnity insurance know current hazard risk levels from their own claim statistics, possibly complemented with some socioeconomic contextual information. The challenge is that climate change is affecting these historic risk levels, whereas other factors such as demographic and socioeconomic developments, and the presence and effectiveness of prevention and protection measures, can also appreciably impact on the eventual damage risk levels (O'Neill et al., 2022). Neumayer & Barthel (2011) show for fairly aggregate spatial scales that land use changes in storm prone and/or flood prone areas (e.g. Florida, various European river valleys) have exacerbated damage results by expanding the manmade capital stock especially in high exposure areas. In terms of projections, Perrels et al. (2022) show for fluvial and coastal flooding risks in Finland up to 2070 that the socioeconomic drivers have often more impact on expected damage value than hydro-meteorological factors. All in all, this means that adequate incorporation of climate change effects into the risk data portfolio on which indemnity insurance are based goes well beyond geophysical data on observed and projected climate change, and should also include observed and projected socioeconomic and demographic changes, as well as realised and planned adaptation measures.

Furthermore, hitherto negligible hazard risks may start to grow to levels that require response (O'Neill et al., 2022), thereby opening demand for new insurance coverage, and by extension for new integrated risk data. Examples of these are climate change enhanced biotic risks (Venäläinen et al., 2020) with impacts on agriculture, forestry, and human health.

For riverine and coastal flooding risks, drought risks, extreme precipitation risks, and wildfire risks the current and projected risk levels in Europe data are available at quite high levels of spatial resolution.[23] For other climate change enhanced hazards, and generally for impacts on the manmade environment and costs at high(er) spatial resolutions, such a degree of unification and standardisation does not exist, even though the JRC Disaster Risk Management Knowledge Centre Data Hub provides a broader portfolio of risk data.[24]

Spekkers et al. (2015) illustrate for intense rainfall events that combined multi-source hazard, exposure and damage data enable an crucially better decomposition of damage cost driving factors by hazard features, and quality of publicly and privately owned attributes such as sewer system and roofs, thereby enabling a more effective insurance product design in conjunction with possible actions in the public domain. For the insurance market, in conjunction with broader adaptation planning, it is important that such multi-factor risk data are easy to find and to integrate

[23] See, for example, Copernicus Climate Data Store C3S, Copernicus Land Monitoring Service CLMS, Copernicus Emergency Management Service CEMS, EEA ClimateADAPT portals

[24] More information available here: https://drmkc.jrc.ec.europa.eu/risk-data-hub/#/

Funded by the European Union

or already organised in an integrated manner in order to keep information cost manageable. In an assessment of obstacles to uptake of climate information services by the finance sector, including insurance, Hamaker-Taylor et al. (2018) point out that shortcomings in findability and data portfolio transparency, inclusion of non-climate data, and climate change impact data were obstacles to uptake.

There have been some attempts to create integrated natural hazard datasets with both geophysical and socioeconomic data, such as the EU LODE project (e.g., Faiella et al., 2022), but to limited avail. Creation of unified standardised impact and cost data across scales appears to entail more collaborative complexities and will be discussed in Chapter 5.5.2 on data sharing issues.

Furthermore, it requires several domains of advanced expertise, and thereby resources, to derive applicable risk information for insurance purposes from combinations of extracted data sets. This means that regardless of the free availability of these data the beneficial use of these may entail a threshold effect in favour of larger and better resourced user organisations. Hence the use of (public) climate change information platforms and brokers, such as OASIS Hub, could be promoted employing a merit good motive.[25]

Harrison et al. (2022), referring to New Zealand's Hazard Management organisational structure, argue that natural hazard data management has already evolved significantly in technical terms, but often lacks a *governance layer* which takes care of strategic coordination and development, and assignment of data stewardship, with the latter meaning developing general methods for acquisition, storage, aggregation, identification, and procedures for data release and use. The need for better overall governance of data collection, processing and dispatch seems to equally apply climate change adaptation related risk data.

4.3.1.2 Data sharing

The data market for adaptation planning and implementation and for indemnity insurance is a complex field of public, private and to some extent third-sector actors, while the number of drivers for producing and using such data (i.e resilience management, climate adaptation, climate mitigation, sustainable development goals) has been expanding in the last 15 years, inviting a proliferating number of national and international actors from public administration, research, private consultancy, insurance, infrastructure, and non-governmental organisations (NGOs) to chip in. In Perrels (2018) this is summarised as follows (Figure 4.1).

Considering the observations above by Harrison et al and the findings of Hamaker in the EU-MACS project it is worth noting that the EU-MARCO project proposed a Climate Services Observatory for Europe as a means to keep oversight, coordinate, and promote transparency and accessibility for such data (Perrels et al., 2020). There have been and are similar bodies for energy efficiency and the building stock in Europe.

[25] More information available here: https://oasishub.co/

Funded by the European Union

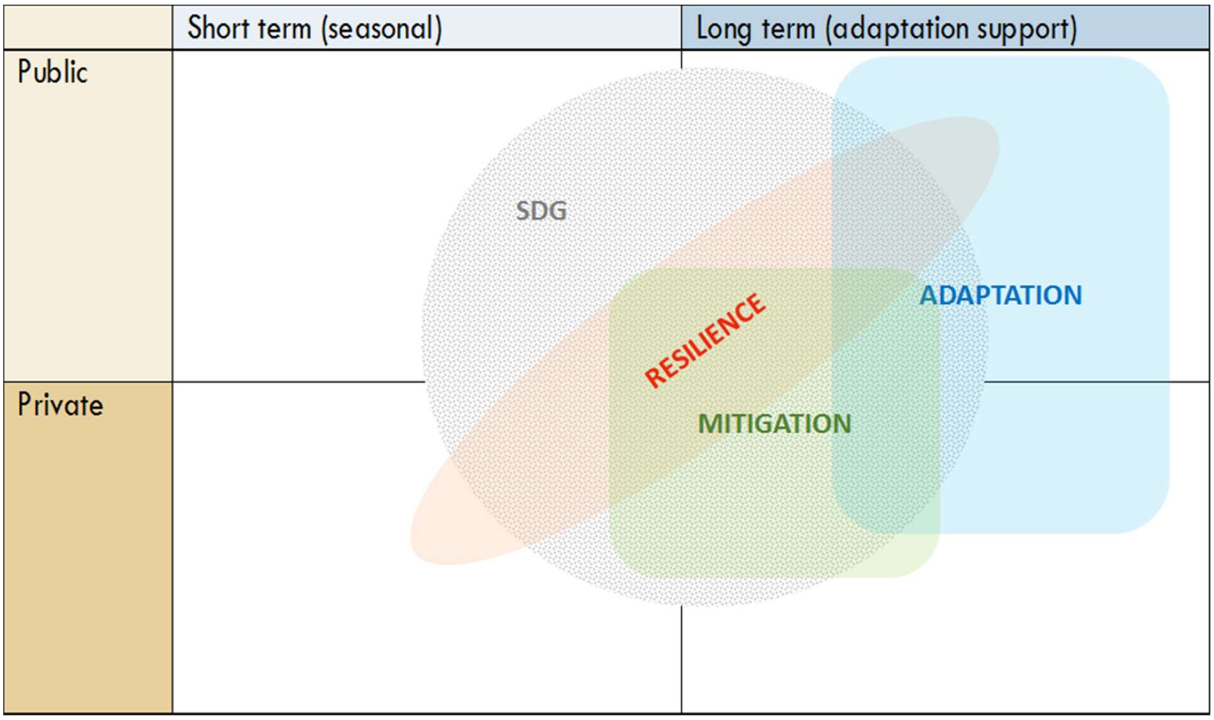

Figure 4.1: Main drivers underpinning interest for climate (risk data) services by time and funding perspective (Source: Perrels (2018))

A more direct hands-on approach has been pursued in Norway. Thomassen & Hauge (2022) report on the establishment of the Norwegian Hazard Damage Knowledge Bank, which is a collaboration of the Norwegian local and regional authorities and the Norwegian insurance industry, with the Department of Emergency Management (DSB) and the sector organisation Finance Norway as key organisations (Figure 4.2).

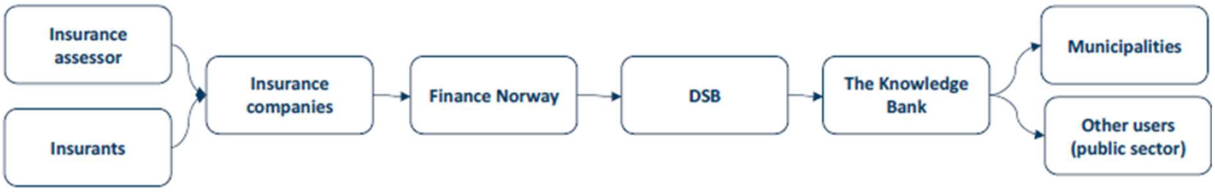

Figure 4.2: Overview of the flow of insurance loss data from the reporting of damage events to the end users, being local authorities (Source: Thomassen and Hauge (2022))

The Knowledge Bank operates under a statute agreed between DSB and Finance Norway after consultation of the information providing and information using organisations. It took nine years to move from setting up a pilot to regular operation (since 2023). Important challenges were the confidentially handling of data as well as standardisation requirements regarding data formats and included variables throughout the system, and the creation of smoothly working interfaces for data submission and data retrieval. The Norwegian experience illustrates that an integrated risk data system can be established, but such initiatives could benefit from national and EU regulation that could shorten the preparation times. The example also gives rise to new questions, such as about the ability to expand the user community and/or data supply community.

The data system is (so far) specifically meant for local authorities to design and implement their adaptation plans (including natural hazard risk management), which refer both to adaptation of the entire community and the municipality's more direct responsibility for public assets. It encompasses standardised damage information (by claim) from the insurance companies, weather data, land use data, elevation data, etc.

An entirely different way of overcoming barriers regarding integrated multi-factor risk data is by focusing on (selective) open access of data collections distributed over different organisations through the so-called open insurance approach. Open insurance has been so far concentrating on the customer side (Standaert & Muylle, 2022), profiling claims, customers, areas by insurance product, which in turn can be used for added services (application programming interfaces, APIs) from third parties, but could also empower customers to compare products via APIs. In principle, various insurance companies could voluntarily agree on mutual openness of (a part of) their claim data and design or approve APIs that can seek and compare these data, and merge with other data such as weather observations. This may reduce product development cost and may add precision to estimated damage functions and responsiveness functions, while it may also help to better match the product portfolio with the most suitable client base. It should however be emphasised that the open insurance concept entails risks regarding infringement of data confidentiality and the GDPR rules. It is also important to have clear rules and independent oversight about use and re-use rights of data and spin-offs of these rights. This includes co-sharing of designated benefit generation. The attraction of the open insurance concept lies in its potential that it may help to overcome very complex coordination problems in more traditional collaborative structures, such as illustrated in the Norwegian case and in the article by Harrison et al. (2022). Even though open insurance may still seem a relatively small phenomenon it is gaining rapidly popularity also among established insurance companies as can for example be seen in the membership of the Open Insurance Network.[26]

4.3.2 Justice

One theme that has frequently surfaced in the discussion so far, and that will emerge several times also in the next chapter, is that of the fairness and justice of climate risk insurance. Climatic hazards and the adverse consequences of climate change are deemed to affect more severely less developed countries and vulnerable social groups, which are less capable to put in place measures to reduce or transfer risk (IPCC, 2022). Indeed, most of the arguments about the affordability of insurance revolves around low-income households, which could be forced to forego insurance coverage and resort to self-protection or external assistance (see, for instance, Lucas & Booth, 2020; Schäfer et al., 2019; Walker & Burningham, 2011). The concept of justice is therefore central in the debates on national risk management regimes, and it is likely to become even more important as climatic and socioeconomic changes make the distribution of resources and vulnerabilities more uneven (Kaufmann et al., 2018). There is not, however, a common view of what justice is or looks like in the context of climate adaptation and/or climate insurance (T. Thaler & Hartmann, 2016).

In a utilitarian perspective (Mill, 1863; Sidgwick, 1874), justice (or a just distribution) means employing the society's resources in the way that offers the highest benefit for the lowest cost. Such an approach, however, risks disregarding certain areas or constituencies simply in light of their low exposure, irrespective of their (potentially high) vulnerability. Conversely, a rawlsian interpretation of justice (Rawls, 1971) posits that resources should be invested to provide the greatest benefit to the most vulnerable. At the opposite side of the spectrum, a libertarian

[26] More information available here: https://openinsurance.io/

perspective (e.g., Hayek, 1960) does not envisage any need for redistribution since, with an argument reminiscent of Adam Smith's invisible hand, a just distribution can be achieved through the independent just actions of individuals (Davoudi & Brooks, 2012). If pushed to the extremes, this school of thought can lead to an elitist interpretation of justice, advocating that self-protection should be a responsibility of the individuals and that redistribution (for example through premium subsidisations) is unjust insofar as it takes away rightfully entitled holdings (Nozick, 1974). In a review of different approaches to risk management across various European countries, Thaler & Hartmann (2016) report that the Anglo-Saxon approach to justice (e.g., in the UK) focuses primarily on utilitarianism, accompanied by a ‘privatisation’ of responsibility, while in continental Europe (e.g., Austria and Germany) there is an emphasis on social justice, with the state being expected to care for the citizens and the allocation protection measures which follows the rawlsian principle.

Insurance has its own interpretations of justice, fairness and solidarity. First of all, insurance should not be interpreted as an instrument of social policy (J. O’Neill & O’Neill, 2012). Second, insurance is also not about spontaneous reciprocity and joint responsibility (Lehtonen & Liukko, 2011); it is about sharing collective risk for one’s own individual benefit. Nevertheless, insurance can still embed some elements of solidarity and fairness. O’Neill & O’Neill (2012) report three different concepts of fairness. In addition, Lehtonen & Liukko (2011) discuss three types of solidarity, which, in some cases, refer directly to a specific concept of fairness, albeit not in all. The first is the principle of actuarial fairness, which is achieved through the payment of premiums reflective of risk. This is the central concept in modern commercial insurance schemes (Frezal & Barry, 2020), in good part resulting from the increase complexity and technologization of the insurance industry allowed by new data collection and analysis tools, which enable an ever greater individualisation of risk (Barry, 2020; Lucas & Booth, 2020). This relates to ‘chance solidarity’, which involves sharing the costs of future damage without considerations about responsibility for events and without knowing who will suffer from the consequences. In this context, insureds participate in the risk pool with a share that equals their individual likelihood of causing damage to the whole risk pool, and equality is achieved by guaranteeing that the ratio between the probability of an accident and the premium is the same for everyone (Lehtonen & Liukko, 2011). The second type of fairness is a ‘choice-sensitive’ fairness, according to which policyholders should be responsible for the risks they take voluntarily. Even though this seems a sensible principle, according to O’Neill & O’Neill (2012), choice sensitivity is often related to luck-egalitarianism, and in certain contexts and domains it risks leading to ethically questionable outcomes. The third type of fairness aligns with the principles of social justice, and prescribes that insurance should be offered independently of risks and choices. This relates to the other two types of solidarity discussed by Lehtonen & Liukko (2011), namely ‘subsidizing risk solidarity’ and ‘subsidizing income solidarity’. Both entail helping those in greater need by less strictly following risk classifications and premiums progressions, with the latter being more focused on low-income groups.

Based on these definitions, there remain significant differences in viewpoints regarding the type of fairness and solidarity a just insurance scheme should present. For instance, while Lehtonen & Liukko (2011) maintain that having risk-reflective premiums is important to ensure the economic stability of insurers, and thus the supply of coverage, they also state that agents should not be deemed responsible for risks that they are not responsible for, and so these should not be reflected into insurance premiums. The authors thus seem to align with a choice sensitive type of fairness.

O'Neill & O'Neill (2012), on the other hand, advocate for insurance to be fully solidaristic. In fact, the authors contend that insurance is a gateway social good which ensures access to other essential elements of a worthwhile life and, as such, its provision should be granted to everyone. As a result, premiums should be reflective of the ability to pay or the value insured, not of the level of risk. In this perspective, insurance should pursue a rawlsian view of justice. Support in favour of a solidaristic principle is expressed also by Duus-Otterström & Jagers (2011) and Frezal & Barry (2020). In particular, the former claim that justice in adaptation should entail four principles. (i) Wealthier agents should take on a greater burden of adaptation. (ii) Those with more contributory responsibility should take on a greater burden of adaptation. (iii) There exists a threshold of ability to pay below which one is exempted from contributions to adaptation. (iv) There is no threshold of contributory responsibility below which one is exempted from contributions to adaptation. This would translate into a system in which the richer the agents are and the more they contribute to hazard (e.g., by being at higher risk) the more they should pay. Conversely, if agents are very poor, they are exempted from paying; whereas if someone contributed nothing to the current risk level, they are still entitled to pay something. In insurance terms, this calls for pure cross-subsidisation of premiums from high-income to low-income agents, even if the former have no risk. Of an opposite opinion is Penning-Rowsell (2015) who, discussing the flood insurance system in the UK, claims that the subsidisation of high-risk policies by low-risk ones or taxpayers money is 'unfairness piled on unfairness'. He adds that the introduction of Flood Re only worsens this situation by subsidizing even those living in very valuable properties. According to the author, such a system does not align with either an egalitarian, utilitarian or rawlsian definition of fairness. Finally, by reviewing the debate on insurance solidarity and the changes and opportunities opened by new technologies, Barry (2020) reports that while fairness seems to have been reduced to an algorithmic calculation of individual scores, these might lead to more equitable pricing; that subsidisation of high-risk agents from low-risk ones is not socially equitable; and that fairness should be "behavior-based" (i.e., choice-sensitive). Ultimately, the definition of what justice and fairness mean in the context of (climate) insurance depends on the social preferences for equity and redistribution. In any case, an insurance scheme should, at a minimum, avoid exacerbating pre-existing vulnerabilities.

In any case, most of the reviewed literature seems to believe that the climate insurance systems currently in place in various countries are not particularly just or fair. From their own review of the literature, Kraehnert et al. (2021) highlight that the redistribution effects of climate insurance are uncertain. Comparing market-based insurance systems to public ones, Lamond (2014) reports that while the former presents many advantages, these are, in some sense, offset by the lack of a mandate to protect the most vulnerable. Market-based systems actually appear more expensive for low-income households. The same view is held also by Lucas & Booth (2020), who state that market-based systems are more likely to leave the most vulnerable unprotected. These authors suggest that hybrid schemes (namely PPPs; Lamond, 2014), or collective and solidaristic schemes (like takaful or solidarity funds; Lucas & Booth, 2020) could overcome such an issue. Duus-Otterström & Jagers (2011) take a step further, and claim that global social insurance would be more efficient in addressing climate change mitigation, calling for a system where governments come together to pool risk and resources to compensate those most vulnerable. However, such a system is unlikely to be created, since richer and less vulnerable countries would be better off without pooling risk with poorer ones. In addition, the authors also say that such a system is in many ways inferior to a system of pure mitigation or prevention.

Moving on to specific national systems and case studies, Kousky (2019) reports the results of the research conducted by Peacock & Girar (1997) in the US after Hurricane Andrew, who found that african americans and hispanics were less likely than whites to have insurance. In addition, even after controlling for income and damage levels, their insurance did not provide enough compensation to cover the costs of repairs, which was due to these ethnic groups being less likely than whites to have coverage from big insurance companies.

Several authors have criticised the UK flood insurance system, both pre- (C. Johnson et al., 2007; J. O'Neill & O'Neill, 2012; Walker & Burningham, 2011) and post-Flood Re (O'Hare et al., 2016; Penning-Rowsell, 2015; Sayers et al., 2018). Johnson et al. (2007) claim that insurance does not fit the equality or vulnerability criteria of decision fairness set out by DEFRA, and that uninsurance, either due to withdrawing flood coverage or increasing premiums, creates social inequality. Walker & Burningham (2011) also report that the pre-Flood Re system was characterised by significant inequalities and injustice, with around half of the households in the lowest income decile not having contents insurance. This often couples with high crime rates in the areas where these households reside, which are going to bring premiums even higher, further exacerbating to unaffordability and injustice. O'Neill & O'Neill (2012) add that purely market-based and risk-reflective premiums would lead to maladaptation and social segregations, since insurance rates would drive the demand for and value of properties, with low-risk areas having high property value and low premiums, while high-risk areas having low property value and high premium. The less well-off would thus be unable to afford housing in low-risk areas and would end up being segregated in high-risk locations. But here, they would face difficulties in obtaining coverage, either because the premiums are unaffordable or because insurance companies consider the property uninsurable. The maladaptive potential of climate insurance scheme is highlighted also by O'Hare et al. (2016), as a byproduct of a 'return to the status-quo' mindset, which prioritises rebuilding and reconstruction, instead of a proactive approach centred around 'building-back-better'. Finally, both Penning-Rowsell (2015) and Sayers et al. (2018) criticise the subsidisation regime created by Flood Re. The former, as already mentioned, condemns the fact that high-value properties end up being subsidised. The latter highlight the lack of transparency of the system, since policyholders do not know if their premium is subsidised or not. And they also stress that "in high risk areas, it is unclear whether Flood-Re is successful in improving insurance uptake in the most vulnerable neighbourhoods and it does nothing to assist the uninsured" (Sayers et al., 2018, p. 345).

Penning-Rowsell (2015), however, claims that public or state-backed systems, as those present in France and the US, are the worst at dealing with climate change and the exacerbation of risk it entails, advocating the superiority of fully market-based or PPP schemes. Upon reviewing the French system, Charpentier et al. (2022) suggest that its flat premium structure is effective in areas prone to river flooding, where it ensures affordability for low-income households who are not able to relocate. But it is not in areas affected by coastal flooding, which usually have higher property value, so that the current premium is effectively subsidising the wealthier population. However, the authors' analysis also reveals that, in light of the very wide coverage of the French system, premium segmentation would not offer a meaningful improvement, as it would do little to encourage prevention, it would have no impact on settlement patterns, and would risk leaving the most socio-economically vulnerable excluded. A critical view of the current US system, and especially of the NFIP, is held also by Frazier et al. (2020), who state that changes in floodplains and reforms of flood insurance premiums would not only affect vulnerable groups (like the elderly, racial and ethnic minorities, and low-income households), but would also impact businesses and potentially lead them to close or move outside floodplains, with further knock-on effect on the affected communities.

Despite such critiques, there is also evidence that commercial insurance can improve social welfare, especially where central governments have soft budget constraints which would limit their ability to act as primary insurers (Buzzacchi & Turati, 2014). In addition, index-based insurance can offer additional opportunities for improvement, since it has been documented to have welfare-enhancing effects, particularly in less-developed countries (Kraehnert et al., 2021).

In light of all of the above, it appears necessary that climate risk management strategies embed clear social justice principles and criteria (T. Thaler et al., 2018). This could be facilitated by strengthening collaborative and participatory processes (Paauw et al., 2024; T. Thaler et al., 2018) and using capacity building tools that respond to the needs of the most vulnerable groups (Schäfer et al., 2019). We thus conclude this discussion reporting seven pro-poor principles for climate risk insurance outlined by Schäfer et al. (2016; as reported by Schäfer et al., 2019). (i) Solutions to protect the poor from extreme weather events must be tailored to local needs and conditions. In addition, insurance must be embedded in comprehensive risk management strategies that improve resilience. (ii) Reliable coverage that is valuable to the insured is crucial for the take-up. (iii) Affordability of insurance coverage for poor and vulnerable groups must be increased. (iv) Efficient and cost-effective delivery channels, aligned with the local context, are key for reaching scale. (v) Participation, transparency and accountability of insurance schemes help create trust. (vi) Safeguarding economic, social and ecological sustainability is crucial for long-term success of insurance schemes. (vii) An enabling environment that accommodates and fosters pro-poor insurance solutions should be built.

5 Innovations

This chapter reports discussion and insights, sourced from the academic literature and insurance industry reports, regarding potential innovations that could help closing the IPG. In particular, we consider new product characteristics that improve the efficiency, attractiveness and affordability of classic indemnity insurance policies (Chapter 5.1). Then, we then introduce new, non-indemnity insurance products, like parametric insurance, as well as alternative forms of risk transfer (Chapter 5.2). Subsequently, innovations in data collection and analysis are reviewed, which can be applied to both indemnity and parametric insurance products (Chapter 5.3). Finally, we conclude with the potential for increased multi-actors collaborative efforts, which would allow for insurance to act as a resilience-building tool (Chapter 5.4).

5.1 Product characteristics innovations

This section presents the main findings from the last fifteen years of research on new and alternative ways to design insurance policies, and which, scholars argue, would help stimulate the uptake of climate insurance while addressing affordability and risk-reduction objectives. The product characteristics innovation considered include: multi-year contracts (Chapter 5.1.1), bundling of climate-risk coverage (Chapter 5.1.2), opt-out contracts (Chapter 5.1.3), and various forms of premium reductions (Chapter 5.1.4).

5.1.1 Multi-year contracts

It has been advocated that long-term or multi-year policies could represent a promising improvement to climate insurance schemes and would help closing the climate insurance protection gap (Kleindorfer et al., 2012; Kunreuther, 2008; Kunreuther & Michel-Kerjan, 2013; Michel-Kerjan & Kunreuther, 2011). These types of contracts can address some of the demand- and supply-side barriers that limit the diffusion of climate and NATCAT insurance. On the demand side, multi-year contracts with fixed premiums reduce uncertainties due to potential premium increases or withdrawal of coverage, which is attractive for risk-averse consumers (Dudek et al., 2021; Kleindorfer et al., 2012; T. Liu et al., 2022). Since the policy needs to be renewed less frequently, it entails lower transaction costs (Kleindorfer et al., 2012). Moreover, long-term insurance policies can reduce the tendency of agents to cancel their insurance after not experiencing a claim for a few years, especially if they are attached to the property rather than the property owner (Kunreuther, 2021). On the supply side, multi-year policies reduce the variance of losses, acting as a de-facto tool for diversification (Kunreuther & Michel-Kerjan, 2013; T. Liu et al., 2022). In addition, they could attract agents with diverse preferences who might not otherwise insure, thereby increasing diversification.(Dudek et al., 2021). In turn, these could lower the cost of reinsurance (Dudek et al., 2021). Moreover, multi-year policies could reduce moral hazard issues (Winter, 2013), for instance because insurers would have a greater incentive to inspect properties over time (Kunreuther & Michel-Kerjan, 2013). Finally, long-term contracts have the potential to incentivise investments in adaptation and risk-reduction (Dudek et al., 2021; Kunreuther & Michel-Kerjan, 2013), benefiting policyholders (via lowered premiums), insurers (via lower exposure), and public administrations (via reduced need for ex-post relief) alike.

Several empirical and experimental studies suggest that multi-year policies would increase the demand for climate insurance. Papon (2008) shows that longer contracts increase the demand and the level of coverage for insurance against LPHI events. Kleindorfer et al. (2012), Kunreuther & Michel-Kerjan (2015) and Dudek et al. (2021) find that, when offered both a 1-year or 2-years climate-risk insurance, the majority of households prefer the latter, even when this is relatively more expensive and priced above the actuarially-fair premium. In a discrete choice experiment (DCE) among Dutch households, Botzen et al. (2013) reveal that offering 5-years or 10-years contracts would increase consumers' utility with respect to an annual policy. However, as the length increases even further, the effect would backfire, and a 15-years contract would reduce utility. In another DCE with European farmers, Doherty et al. (2021) find a statistically significant preference for longer flood insurance coverage. This effect is mostly produced by farmers who already have crop insurance; while previously uninsured farmers dislike longer contracts.[27] In addition, the increase in WTP connected to long-term policies appears to be relatively small (ca. 10%). Finally, a methodological study on the feasibility and attractiveness of a multi-year index-based drought insurance concludes that the proposed insurance scheme can be a valuable tool for managing the financial risks associated with hydrological droughts, particularly for policies targeting more severe and prolonged events (Guzmán et al., 2020).

Despite the predicted advantages and the evidence showing higher potential demand with multi-years contracts, these policies are still not widely adopted in the climate insurance market (Botzen et al. 2013). Maynard and Ranger (2012) mention that such policies present a number of disadvantages compared to single-year ones. These include higher premiums, lower flexibility for policyholders and insurers, and a less efficient use of capital. Many of the empirical studies discussed above do indeed consider the possibility that the multi-year policy sells for a higher price, but, as already mentioned, they do not find this to render them unattractive. In addition, while being locked into an insurance contract for a long(er) period could certainly disincentivise some potential policyholders, it can also contrast some potential biases that lead insureds to cancel their policies (Kunreuther, 2021). On the other hand, limiting the ability of insurers to renegotiate contract terms exacerbates the potential impacts of mispricing policies, which might make these options highly unattractive for insurance companies. Hence, some authors advocate for designing multi-year contracts with variable premiums that can be adjusted as new information on the nature of risk becomes available (Goss, R. and O'Neill, D. (2010) Long-term retail general insurance: The potential for long-term home insurance contracts in the context of flood risk, ABI Research Paper No. 21, London) Kunreuther et al. (2009, At War with the Weather: Managing Large-scale Risks in a New Era of Catastrophes). However, there are technical and methodological challenges to this strategy. Modelling the premiums of long-term (5-, 10- and 15-years) flood insurance contracts under four climate and socio-economic change scenarios for the Netherlands, Aerts and Botzen (2011) reveal several obstacles. The estimation results show that there would be an incentive for both insurers and insureds to opt for the shorter option. In particular, insurance companies would not accept to lock themselves into very long contracts given the variability generated by climate and socio-economic change and would need to conduct periodic renegotiations (as suggested above). However, the study suggests that this would be impractical since these changes have a region-specific component which is further influenced by national and local adaptation interventions. Beyond the uncertainties connected to climatic conditions, Kunreuther and Michel-Kerjan (2013) also mention considerations regarding the (future) cost of capital and concerns about the financial solvency of insurers over a long(er) period.

[27] This result could be a byproduct of other factors, such as risk preferences, attitudes toward insurance products, or other farmers' characteristics.

5.1.2 Bundling

Another approach that is often regarded as a promising solution to incentivise the diffusion of coverage against climate and natural hazards is bundling (Holzheu & Turner, 2018; Keskitalo et al., 2014; Kousky & Kunreuther, 2017; Kunreuther, 2018). In this report, we consider bundling in two ways: (i) combining multiple climate-related risks into a single insurance product; (ii) linking climate-risk insurance to other products. In this second case, climate coverage can be bundled to other insurance products (such as fire insurance, general house insurance or life insurance), to credit products (for example making it a prerequisite for mortgage), or to other salient products (such as production inputs, or making it a prerequisite to receive agricultural subsidies).

Offering multi-peril insurance can address adverse selection by pooling policyholders affected by different types of hazards, thus ensuring greater diversifications (Kron, 2009; Kron et al., 2019; Kunreuther & Michel-Kerjan, 2013). However, it would be advisable that in such bundled policies individual risks are priced separately according to the specific level of risk (Kron et al., 2019), for example through zoning and then assigning a flat rate within a given risk zone (Kron, 2009). Such policies also reduce transaction costs for both insurers and policyholders. Insurers do not have to design and advertise multiple products, and they can avoid the costly and time-consuming process of determining the cause of damage (Kunreuther & Michel-Kerjan, 2013). Likewise policyholders do not have to seek information for several distinct policies. Moreover a bundled product reduces ambiguity regarding the effective coverage (Kunreuther & Michel-Kerjan, 2013) and can reduce delays with claims' settlements (Kunreuther & Pauly, 2004). In addition, bundling would limit the distortions generated by the threshold level on concern heuristic. The combined probability that one among several hazards occurs is greater than the individual probability that the single events will occur, and thus it is more likely that said combined probability exceeds the threshold level (Kunreuther & Pauly, 2004). Regarding the other type of bundling, linking climate coverage to other, more salient products can also limit adverse selection issues and enhance insurability (Tesselaar, Botzen, Haer, et al., 2020), reduce insurers' distribution and underwriting costs (Holzheu & Turner, 2018), and increase client value (Schäfer et al., 2019).

The literature has also evidenced some limitations and shortcomings of bundled insurance. Bundling is more challenging when there is high variation in risk across regions (Holzheu & Turner, 2018) and socio-economic groups. On top of that, even though pooling multiple hazards in a single policy increases the degree diversification and should thus reduce insolvency concerns, if hazards are highly correlated this beneficial effect is greatly diminished (Kunreuther & Pauly, 2004). Luckily, in Europe, severe climatic events display weak correlation across MSs and across time (EIOPA, 2023b). Certain regulations, such as those on maximum premiums, could further reduce the propensity of insurers to offer bundled policies (Kunreuther & Pauly, 2004). Moreover, bundling shrouds the true cost of risk (Surminski, 2018), which could reduce the incentive to invest in risk-reduction measures (J. Lamond & Penning-Rowsell, 2014). Finally, consumers could still decide to forego climate coverage once the product they are attached to is no longer in place (e.g., after paying off the mortgage; Holzheu & Turner, 2018). In light of these limitations, regulators and public administrations should act as facilitators, enacting measures that encourage bundling (Kunreuther & Pauly, 2004) while also fostering its effectiveness.

Already two decades ago, Kunreuther & Pauly (2004) called for further empirical research to better understand the relationship between bundling and purchase behaviour. However, to this day, there is minimal empirical evidence on the effectiveness of bundling. Some studies that review various national climate insurance systems highlight that in those countries where climate coverage is bundled with fire or general house insurance, penetration rates are generally higher (Bouwer et al., 2007; Surminski, 2018). A feature that is also confirmed in this report (see Chapter 3). Analysing penetration rates worldwide, Holzheu & Turner (2018) find a positive correlation between mortgage and climate insurance. In addition, modelling the evolution of flood insurance under changing climatic conditions and with various policy measures, Tesselaar, Botzen, Haer, et al. (2020) claim that making coverage a prerequisite for obtaining a mortgage leads to higher penetration rates. Neither of these papers, however, is able to estimate a causal relationship. Tesselaar and co-authors do not even explicitly test the effect of bundling, instead they consider a semi-voluntary system which, they say, in reality is often achieved by linking insurance to mortgage. Therefore, more research is indeed needed in the future to investigates the (causal) effect of either type of bundling on the demand for climate risk insurance as well as the willingness of insurers to offer multi-hazard policies.

5.1.3 Opt-out contracts

In most market-based insurance systems, coverage against climatic and natural hazards is offered as an additional component that policyholders can decide to include to their policy for an extra premium. An alternative way of framing insurance policies would be to have climate coverage included as a default, and then policyholders can choose to remove it and pay a lower premium. As Kunreuther et al. (2021) mention, neoclassical economic theory would prescribe that these two framings would lead to the same insurance decision. However, agents do not always behave rationally (in an economic sense), and research from several fields has demonstrated that different defaults can lead to different choices (R. H. Thaler & Sustein, 2008). In particular, since, as discussed in Chapter 4.1.3.1, people often fall prey of a status quo bias, it is argued that providing climate and natural hazard coverage as a default component of insurance policies, from which policyholders have to opt-out of, could promote higher penetration and help closing the climate insurance protection gap (Holzheu & Turner, 2018; Kunreuther, 2015; J. Lamond & Penning-Rowsell, 2014). Several authors (Holzheu & Turner, 2018; Kunreuther et al., 2021; Robinson et al., 2021) report that such an approach has proven to be successful in other lines of insurance (such as health, life and automobile) and intertemporal decisions (like retirement savings plans). However, evidence of its effectiveness for climate insurance uptake is still limited (Kunreuther, 2015).

Analysing the performance of various types of insurance systems, Lamond & Penning-Roswell (2014) claim that when flood insurance is included by default in general property insurance, penetration rates are higher, and the beneficial effect is particularly strong when there is also a connection with mortgages.[28] The authors report that, in those schemes where flood coverage is included as a default, premiums are generally not risk-based and there is a high degree of cross-subsidisation, which enhances affordability but limits risk-reduction. Their paper, however, does not statistically test the difference with respect to systems where flood coverage is offered as a voluntary add-on component, it simply presents an overview of the various national systems that fall in each category, discussing their characteristics and their overall performance over a number of criteria. Conversely, two recent studies (Kunreuther et al., 2021; Robinson et al., 2021) conduct

[28] The authors refer to a system in which flood insurance is included by default in property insurance as bundled. However, since they draw comparisons with systems in which it is available as an add-on component, we believe it is more appropriate to discuss their findings here rather than in the section dedicated to bundling.

experimental investigations that put in direct contrast the effect of opt-out and opt-in contracts on insurance demand.

In an experiment among Canadian households, Kunreuther et al. (2021) study how different default options affect the decision to purchase seismic coverage. Participants are randomly assigned to either a control version where coverage against seismic risk is offered as an opt-in component (baseline), or to a treatment version where it is included by default and individuals have to opt-out of it. The results show that 58% of participants in the opt-out version (N = 1,260) eventually take-up seismic coverage, as opposed to 47% in the opt-in condition (N=1,140). Logistic estimations reveal that the odds ratio for the opt-out variable is 1.64 (significant at the 1% level), which implies that, when seismic coverage is included by default and participants have to opt-out of it, take-up rates are 64% higher than when it is an add-on component. The effect is particularly pronounced in the case of a market-based system with relatively small deductibles (Can$15-50,000), which represents the status quo in Canada. Whereas it is less pronounced under a public-private risk pool, and it is insignificant with a high deductible (Can$100,000).

A positive effect of opt-out contracts has been found also for household flood insurance in the Netherlands. Robinson et al. (2021) conduct an experiment with respondents from the Netherlands and the UK (separate versions), where participants are randomly assigned to a control version in which flood coverage is offered as an additional component to a fire and burglary insurance policy, or to a treatment version where the policy includes fire, burglary and flood coverage by default and people can choose to remove the latter. The results show that offering flood coverage as a default opt-out component has a statistically positive effect in the Netherlands, where take-up rates increase by 17-18% compared to the opt-in case. Conversely, in the UK the aggregate effect is insignificant, and it appears that an opt-out default would even reduce uptake for high levels of risk tolerance (low risk aversion) or among households who have been flooded in the past. Decomposing the positive effect in the Dutch sample, the authors reveal that around two-thirds of the increase in flood insurance demand is a direct effect of the opt-out default; while one-third comes from an indirect effect, mostly through a (potential) sense of regret from having decided to remove flood coverage if a flood event where to happen.

In light of this evidence, it would appear that offering climate and natural hazard coverage as a default component in insurance policies would stimulate take-up, especially in market-based systems that are currently characterised by low penetration rates, which is the case in many European countries. However, in other contexts the effect could be considerably more contained or even counterproductive, depending on the features of the system and on the preferences of the policyholders. Therefore, while opt-out contracts remain a promising solution to close the climate insurance protection gap, more research should be conducted to provide a more precise answer as to when they are expected to be effective and to what extent.

5.1.4 Premium reductions

Various ways to reduce premiums exist. Among these, this section investigates the following: premium discounts, (publicly) subsidised premiums, and means-tested vouchers combined with long-term loans.

5.1.4.1 Discounts

Insurance companies could offer premium discounts to incentivise policyholders to implement risk-reduction measures (Botzen et al., 2009a; Holub & Fuchs, 2009; Hudson et al., 2020;

Kraehnert et al., 2021; Paudel, 2012; Tesselaar, Botzen, Haer, et al., 2020). This would decrease insurers' risk exposure, allowing them to set lower premium loadings, also thanks to a reduction in the cost for reinsurance (Kousky, 2019), thus further increasing affordability. Premium discounts should be designed through sound techniques and in such a way as to limit distortions (Schäfer et al., 2019). For insurance, Herweijer et al. (2009) state that they should be based on a quantification of their expected risk-reduction impact, by embedding specific building code standards or risk mitigation measures in actuarial catastrophe risk models.

Despite several insurance companies offering premium discounts to incentivise risk-reduction, Kousky (2019) highlights that evidence of their effectiveness at stimulating both insurance uptake and investments in mitigation is scarce. Upon reviewing the US National Flood Insurance Program (NFIP), Paudel (2012) reports that the Program's premium discount scheme is successful in incentivising flood mitigation for new buildings but not for existing ones. Most of the evidence of the effectiveness of premium discounts comes from experimental or modelling studies.

Considering the demand for flood reduction measures (which the authors refer to a self-insurance) in a lab-in-the-field experiment with Dutch homeowners living in floodplains, Mol et al. (2020a) find that a premium discount increases investments in self-insurance, irrespective of whether the underlying insurance system is private (voluntary, market-based) or public (mandatory). Conversely, modelling the evolution[29] of flood insurance uptake and investments in flood mitigation measures across Europe, Haer et al. (2019) estimate that premium discounts do not increase the demand for voluntary insurance. A positive effect is observed when insurance is mandatory, and premium discounts lead to 38% more risk reduction compared to a situation with no discounts. Finally, Hill et al. (2019) investigate the demand for drought index insurance among farmers in Bangladesh. The authors assess the effectiveness of two forms of price reductions, namely premium discounts and rebates, at incentivising uptake. Their results reveal that discounts are significantly more successful than rebates in stimulating both the decision to purchase insurance and the units purchased. Additional estimations suggest that rebates might be more effective at dealing with distortions generated by hyperbolic discounting and risk aversion, however the effects disappear when the other measure is controlled for (i.e., when risk aversion is included in the regression model for hyperbolic discounting and vice versa).

In any case, Kousky (2019) suggests that insurance markets might not be suitable to incentivise investments in risk reduction and mitigation measures, which would inevitably limit the effectiveness of insurance premium discounts. In soft markets, where premiums are low(er) the savings entailed by the discount might not be sizable enough to justify investing in risk reduction (Dixon et al., 2017). On the other hand, in hard markets, the premiums might be so high that there is no demand for insurance to begin with (which is what happens in the analysis of Haer et al. (2019)). In addition, if insurers believe that premiums are already low enough (or too low due to specific regulations) they will not be inclined to offer discounts (Herweijer et al., 2009).

5.1.4.2 Subsidies

Public administrations can decide to subsidised premiums in order to incentivise uptake, especially for lower-income households, thus alleviating the unaffordability issue and improving the solidarity

[29] The analysis considers various types of households and government's adaptive behaviour, for the period 2010-2080, under the Representative Concentration Pathway 8.5 (RPC 8.5) and Shared Socioeconomic Pathway 5 (SSP 5).

of the insurance system (Kraehnert et al., 2021; Li et al., 2023; Paudel et al., 2015; Sheehan et al., 2023; Surminski et al., 2016; Surminski, 2018). When such premium subsidisation is enacted, Kunreuther (2021) claims that the financial assistance should come from public finances and not through cross-subsidisation from other policyholders, since insurance premiums should remain risk-based. In addition, subsidies should not be provided to households that decide to relocate to high-risk areas (Kunreuther, 2021)[30], and they should still aim to incentivise risk-reduction as well as boost the local economy (Sheehan et al., 2023). In fact, several authors warn that public premium subsidies could undermine the incentives to mitigate risk (Herweijer et al., 2009; Kraehnert et al., 2021; Surminski et al., 2016), which would exacerbate moral hazard issues. Subsidised premiums in an PPP or fully public insurance system also deplete the finances of the insurer(s), meaning that there might be the need to resort to public funds to pay claims or provide disaster relief (Herweijer et al., 2009), which increases the burden on taxpayers. Moreover, the presence of a public premium subsidy would also crowd out the incentives of insurance companies to innovate and improve their products (Vroege & Finger, 2020), since they could rely on governments to make insurance policies affordable and acceptable for prospective policyholders. In light of these limitations, some authors argue that funds could be better spent on other adaptation measures than on insurance (Surminski et al., 2016).

Premium subsidies are particularly relevant in the European agricultural sector. In fact, the CAP includes subsidies to insurance premiums among the risk management tools to address the volatility in the sector and help farmers stabilise their income (European Commission, 2023). Support for insurance premium is adopted in Croatia, Germany, Greece, Latvia, the Netherlands, Portugal and Slovakia; whereas Bulgaria, France, Hungary, Italy, Lithuania, Poland and Romania use a combination of insurance premium support and mutual funds or other risk management tools. For instance, Italy will establish four risk management interventions worth almost €3 billion which aim to help farmers to better face growing climatic adversities through subsidised insurances and other tools (European Commission, 2023). Also, in a review of the Spanish agricultural insurance market, Garrido and Zilbermann (2008) claim that premium subsidies are the main driver for the demand for crop insurance (as reported in Liesivaara & Myyrä (2017)). The use of subsidised premiums, however, entails also certain requirements in terms of insurance policy design, such as the fact that they have to include a deductible of at least 30% (Liesivaara & Myyrä, 2017), which might have consequences on insurance demand.

Empirical studies mostly find support in favour of the positive effect of subsidised premiums on the demand for climate-risk insurance. In a DCE with Finnish farmers, Liesivaara & Myyrä (2017) show that the demand for crop insurance can be influenced by introducing insurance premium subsidies. However, the results highlight that farmers appear to treat premium subsidies and governmental relief as substitutes, so that if relief is present, the amount of subsidy should increase to incentivise insurance uptake. Indeed, farmers who state that the government should not compensate yield losses are more likely to buy crop insurance products. Hence, the authors suggest that governments should either provide premium subsidies or ex-post compensation, but not both, since otherwise the burden on public finances would increase exponentially. Evidence of the effectiveness of premium subsidies in the agricultural sector is provided also by Bulte et al. (2020). In a study involving farmers from Kenya, the authors show that a short-term subsidy increases long-term demand for insurance, as well as the demand for complementary inputs such

[30] This is, for example, the case in the UK, where houses built in floodplains after 2009, the year when the flood maps were first published, are not covered under Flood Re.

as fertiliser, machinery, hired labour and land. Finally, in their investigation of future penetration and affordability of flood insurance in Europe, Tesselaar et al. (2020) predict that the highest reduction in unaffordability will be achieved with a premium cap, a measure which has a similar underlying scope as a subsidy. The authors also suggest that, with mandatory flood insurance, to alleviate unaffordability for low-income households, the government could provide a subsidy to either policyholders (to allow them to cover the unaffordable part of the premium) or to insurers (to compensate them for setting premiums below the profit-maximisation level). The same subsidy to insurance companies could theoretically be enacted also in the presence of a premium cap, hence why the affinity of the two. In contrast to these findings, in an experimental investigation with households in Australia and New Zealand, Dudek et al. (2021) fail to detect a statistically significant effect of premium subsidies on NATCAT insurance take-up.

The key message that emerges from the literature presented above is that while premium subsidies are likely to be an effective tool to reduce unaffordability of climate insurance and incentivise the take-up among resource-constrained groups, they should be carefully designed in order to avoid distortions and exacerbate moral hazard issues. The intervention detailed in the next section should address these concerns.

5.1.4.3 Means-tests vouchers and long-term loans

One way to de facto subsidise insurance premiums for low-income, households which limits potential distortions and improves, rather than reduces, the incentives to invest in risk-reduction measures is to use means-tested vouchers in combination with (long-term) loans to finance mitigation investments (Dixon et al., 2017; Hudson et al., 2016; Kousky & Kunreuther, 2014, 2017; Kraehnert et al., 2021; Kunreuther, 2008; Michel-Kerjan & Kunreuther, 2011; Miller et al., 2019; Tesselaar, Botzen, Haer, et al., 2020). The rationale would be to provide lower-income households with a voucher that covers the unaffordable part of the insurance premium (Hudson, 2018; Tesselaar, Botzen, Haer, et al., 2020). This would act as a premium subsidy, but it would be specifically directed at those most in need and it would only cover the part of the premium which is beyond the household's financial possibilities. Its design and quantification would therefore depend on the specific definition of (un)affordability that is employed.[31] However, these vouchers would still impose a substantial burden on public finances since, by themselves, they do not address the underlying problem of high or increasing climate-related risk, and they still risk incentivising development or relocation in high-risk areas (Hudson, 2018). Therefore, they should be complemented with appropriate measures that make them contingent on undertaking risk-reduction investments (Kousky et al., 2021). Hence, long-term loans at advantageous interest rates to invest in mitigation would alleviate moral hazards concerns and generate significant savings for both policyholders and public administrations (Kunreuther, 2021). By tying them the the means-tested vouchers, they would provide triple dividends: (i) they would allow households to pay a lower premium because of the voucher; (ii) they would reduce the total amount of the premium thanks to the mitigation measures implemented, which improve their risk status in actuarial calculations; (iii) they would decrease the burden on the government since the voucher has to cover a smaller unaffordable part of a smaller premium.

Some studies have investigated the performance of these two measures individually. Hudson et al. (2016) conduct a modelling exercise to investigate the effectiveness of a means-tested voucher

[31] See Hudson (2018) for a discussion of various definitions of (un)affordability and their relevance for future insurance demand.

Funded by the European Union

to cope with the unaffordability of households flood insurance in France and Germany, and analyse how the relative costs may evolve with future socio-economic development and climate change. While this voucher alone is not conditional on mitigation investments, the authors designed a scheme where the percentage of the insurance premium that the voucher covers falls by five percentage points every year and ceases to exist after twenty years to limit distortions as much as possible. Moreover, only households present at the beginning of the program are considered eligible for the voucher. The model also includes premium discounts for flood mitigation, but this is offered by the insurance provider and is not financed through a dedicated loan program. The results highlight that the voucher would cost more in France than in Germany (about four times as much), that the cost would increase over time in both countries due to socio-economic and climatic change, and that the rate of increase would be steeper in France. However, the voucher is cost-effective in both countries: the net present value (NPV) of the costs of providing the voucher is smaller than the net present value of the benefits of additional mitigation, and their ratio declines over time. In addition, the voucher would actually be more beneficial in France, despite the higher total cost. In an investigation of the effectiveness of a means-tested program to replace the current NFIP subsidy scheme in New York city, Miller et al. (2019) estimate that the new approach would reduce the burden on federal budget (hence on taxpayers) by ca. $183 million. On the other hand, Mol, Botzen & Blasch (2020b) experimentally test whether loans stimulate investments in flood mitigation measures. Their findings suggest that such a measure is not effective at incentivising risk-reduction. Both when the loan is provided by itself and when it is coupled with a premium discount for risk-reduction, the effect is statistically indistinguishable from zero. In the latter case, the coefficient of the interaction between loan and discount is even negative, suggesting that the loan would reduce investments in risk-reduction when a premium discount is offered. The authors, however, warn that a lab experiment might not be best suited to test the effectiveness of a loan, and recommend that future research adopts field experiments instead.

Assessment of the performance of the combined voucher-loan approach is only considered for specific case study areas in the US under the NFIP. Kousky & Kunreuther (2014) estimate that, in Ocean County (NJ), a program that combines vouchers and mitigation loans would yield savings of close to $80 million over a twenty-years period, and greater than $100 million for loans longer than twenty years, compared to a situation with just the voucher (subsidy). For Charleston County (SC), Zhao et al. (2016) show that a voucher program with mitigation requirements could reduce government expenditure by more than half in comparison to a scheme with no such requirements. The effectiveness of the combined program changes depending on risk zones and elevation costs. In high-risk zones (V Zone), the voucher-loan combination is always less expensive, and can produce cost savings for the public administration greater than 60% when mitigation costs are low. In low-risk areas (A Zone), the combined program is preferable only when mitigation costs are low. Han & Peng (2019) test the performance of a scheme analogous to the one proposed by Kousky & Kunreuther (2014)[32] in Miami-Dade County (FL). The results suggest that the voucher-loan combination would: (i) increase the number of loss-reducing measures installed; (ii) reduce the number of insurance policies in total but increase it within the flood zones; and, (iii) reduce the cost of adaptation and of insurance for households. Overall, the measure would reduce the average flood risk with respect to the default (current NFIP scheme) and increase the benefit-cost ratio of adaptation. Finally, Xian et al. (2017) use a combined voucher-loan scheme to determine

[32] A low-interest loan with 3% interest rate for 30 years is given to households and homeowners pay at most 5% of their income in their adaptation.

optimal property elevation levels based on estimates of the NFIP risk-based premiums. The rationale behind their study is that the cost-effectiveness of a voucher program can be improved when houses are elevated to their optimal level rather than other levels, since the voucher cost would be lower. Their estimates for Ortley Beach (NJ) reveal that almost $2 million (NPV) could be saved in voucher costs over a thirty-years period if houses are elevated to their optimal elevation levels compared to the minimum requirement of one foot above base flood elevation. The authors also point out that the voucher cost "varies with the loan length and loan interest rate, suggesting that the government should specify reasonable loan lengths and interest rates in the voucher program, considering both short- and long-term benefits and budget constraints" (Xian et al., 2017, p. 73).

Despite the estimates from the academic literature providing overwhelming support to the effectiveness of combining means-tested voucher with long-term mitigation loans, Kousky (2019) reports that few such loan schemes have been developed in practice and, at least in the US, none of them appears to be successful, with low participation rates and difficulties to scale. As Dixon et al. (2017) suggests, such schemes might not be attractive as a result of the current level of flood insurance premiums under NFIP and flood maps, but that this issue could be eliminated with revised maps and premiums that are more reflective of risk. Therefore, future research should try to move away from modelling exercises and empirically test the performance of these schemes on the field, as suggested by Mol, Botzen & Blasch (2020b). These types of investigations, however, require considerably more time and financial resources, and necessitate the cooperation with public administrations and insurance providers, which makes them much more challenging to conduct.

5.2 Innovative insurance and risk-transfer products

This section discusses alternative typologies of risk-sharing products, different from indemnity-based insurance. These include: parametric insurance (Chapter 5.2.1), insurance-linked securities (Chapter 5.2.2), microinsurance (5.2.3), takaful (Chapter 5.2.4), insuretech (Chapter 5.2.5), decentralised insurance solutions (Chapter 5.2.6), and insurance of ecosystem services (Chapter 5.2.7).

5.2.1 Parametric (index-based) insurance

Parametric or Index-based insurance is a type of insurance contract where payouts are triggered by predefined parameters or indexes rather than actual losses. This modern method sets the stage for the trading of weather as a commodity, similar to stock indices, currencies and interest rates, providing coverage on the basis of pre-established weather indices, such as temperature, rainfall heaviness or wind speed. The coverage reimbursement is activated when the predefined weather index reaches a specified threshold, revealing that catastrophic conditions represent serious issues for clients. Since payments are triggered by objective weather conditions, oftentimes measured by independent third parties, this type of products is particularly effective at reducing among all moral hazard and adverse selection problems (Goodwin, 2001).

In terms of weather indices, there are different typologies of indexes-based insurance. The most common known are weather derivatives and weather-index insurances.

The term of weather derivatives emerged in the late 1990s, as individuals found out the potential to measure and index weather data, such as seasonal temperatures, and attribute financial values to these indices. When sellers engage in weather derivatives, they stand to profit if a specific weather-event occurs before the contract expires. Conversely, in case of unexpected or adverse weather, the seller compensates the buyer as per the agreed-upon terms. Weather index-related financial derivatives are structured on the basis of specific weather events rather than the damages resulting from those events (Pu et al., 2018). In this context, weather derivatives offer a distinct form of risk management, where companies and/or individuals use them to protect against weather-related losses. In light of this, weather derivatives take the form of the classical derivatives instruments present in the financial industry, such as futures, forwards, options and swaps. The main difference with respect to the regular ones relies on the fact that the underlying assets are linked with weather conditions or parameters, such as heating degree days, cooling degree days, daily rainfall/snowfall in mm or inches in particular place, or, alternatively, through wind speed in kilometres per hours (km/h)(Bianconi, 2020).

On the same logic, but unlike weather derivatives which are financial contracts used mainly for hedging purposes which may not involve insurance companies, weather-index insurances provide coverage on the basis of pre-established weather indices, such as temperature, rainfall heaviness or wind speed. In this context, crop insurance also represents a type of parametric tools that uses weather data, such as temperature, precipitation or growing degree days. This instrument is commonly used in the agricultural sector, and farmers receive compensation to offset their losses if weather conditions fluctuate far from historical averages or predetermined thresholds. However, there are types of insurance that also use some predetermined indices, but not related to weather data but instead they rely on different indicators such as agricultural yields, commodity prices, or economic indicators, to determine payouts. If the value of the index plunges beneath a certain threshold, policyholders are able to get a payout regardless of their actual losses.

Unlike traditional insurance products, index-based insurance offers a distinct form of risk management, where companies and/or individuals use it to protect against weather-related losses. These sorts of instruments provide several benefits to investors. Regarding to weather indexes insurance, one of those is that since they are not strictly correlated with stock market indexes, investors are able to better diversify their portfolio and reduce their risk on investments (Brockett et al., 2005; Ender & Zhang, 2015; Musshoff et al., 2011; Yang et al., 2011). Doing so, index insurance spreads risk across a wide area or multiple policyholders, such as farmers in a region, lowering the impact of localised losses. This diversification minimises the risk for individual policyholders by distributing potential losses more broadly. Secondly, as already mentioned, index-based insurance wipes out the effects of adverse selection and moral hazards, since insureds' behaviours are not tied to the insurance payment. This means that the payout is based solely on predefined weather conditions being met, rather than on the individual decisions/actions or behaviour of the insured parties (Gronberg & Neilson, 2007), in turn increasing transparency (Gatzert & Kellner, 2011). Not only, because the index is standardised and straightforward to measure, it can lower transaction and administration costs for all parties involved in the insurance contract. This is the result of the rapid payouts based on objective triggers, which reduces administrative burden and processing time, providing immediate liquidity to policyholders and reducing the potential risks associated with subjective loss assessments (Fisher et al., 2019).

Nevertheless, the most challenging issue for index insurance parametric is caused by the basis risk, which occurs in the case of an imperfect hedge, i.e., when the hedge could not cover losses (M. Carter et al., 2015). More specifically, basis risk arises in parametric insurance when there is a mismatch between the predetermined parameters which triggers the payout and the actual loss suffered by the insured party (Vroege & Finger, 2020). This poses several problems, mainly for the effectiveness and credibility of parametric index insurance. First, basis risk causes a problem of limited coverage. This situation materialised mainly when triggers are not accurate, i.e parameters employed to identify payouts do not accurately reflect the actual losses incurred by the policyholder. In other words, if the trigger parameter is too narrow, it may fail to capture certain types of losses. This means that losses are not fully compensated because of the discrepancy between the trigger event and the insured risk, leaving room to a potential financial exposure from the policyholders side (Gatzert & Kellner, 2011), resulting in under compensation. In this way, policyholders may lose confidence to rely on index insurance parametric tools if they perceive the basis risk may be too high (Clarke, 2016; Platteau et al., 2017). Hence, the uncertainty linked to basis risk can undermine the trust in the insurance products from those potential buyers who believe that the triggers may not faithfully represent their specifics on risk exposures (McIntosh et al., 2019; Sheehan et al., 2023). One effective approach to mitigate basis risk in parametric insurance involves meticulously choosing indices that closely align with the insured party's specific risks (Schäfer et al., 2019) . Achieving this requires precise weather data collection and accurate measurement of trigger parameters. By meticulously selecting diversified indices, where the sensitivity of individual fluctuations is minimised, and ensuring the accuracy of data collection (Fisher et al., 2019), insurers can reduce susceptibility to manipulation or distortion (X. Liu et al., 2023). This may involve knowledge of risk modelling techniques estimation, which facilitates the assessment of the potential impact of basis risk and then correcting the trajectory of the insurance premiums accordingly. Another solution to mitigate basis risk is to introduce innovative contract designs, such as double trigger approaches or layered coverage, thereby providing alternative triggers or combining multiple triggers for payouts (Vroege et al., 2019). This would help to ensure that payouts are more closely aligned with real losses. This is coherent with Carter et al. (2015), who focus on the potential of index-based insurance to address basis risk, utilise risk layering, and advance research on factors influencing behaviour towards risk and insurance. They emphasise the need for further exploration into these determinants to enhance the effectiveness of index-based insurance.

Additionally, index insurance also plays a pivotal role in helping to bridge the IPG. On one side, they provide coverage for risks that are typically excluded from traditional insurance policies, especially in areas prone to natural disasters where traditional insurance may be inadequate. Not only, index insurance's efficient claims processing and reduced administrative expenses allow insurers to cover risks previously considered uninsurable or financially unviable (Barnett & Mahul, 2007).

Despite all this, index insurances present some limitations. For example, despite recent technological advancements in data collection, such as remote sensing systems (see Chapter 5.3.1), the availability of quality data and accurate definition of triggering events remains a limit to the use of parametric insurance (Clement et al., 2018). Additionally, expanding index insurance to a larger scale could present additional challenges. Indeed, efforts to enhance index insurance might not adequately tackle the affordability concerns of small-scale farmers or effectively compete with self-insurance practices among more affluent farmers (Binswanger-Mkhize, 2012). Lastly, the penetration of index-based insurance, if not subsidised, could be low because of high prices (Surminski, 2014), deterring potential buyers, especially in lower-income countries, suggesting a need for innovative approaches to make insurance more accessible and affordable (Clarke, 2016). Overall, although these instruments represent valid tools to adapt to climate

Funded by
the European Union

change, they are still subject to high start-up costs where initial expenses for implementing could be significant, reducing their effective utilisation (Collier et al., 2009).

The bulk of empirical research on index-based insurance predominantly centres on less developed countries and small-holder farmers (M. Carter et al., 2017; Fisher et al., 2019; Surminski & Oramas-Dorta, 2014). For example, cocoa farmers in Ghana benefited from weather index insurance due to other factors such as age, gender, education level, awareness, and access to finance, influencing in turn insurance adoption and cocoa output (Agbenyo et al., 2024). In West Africa Sahel, where hypothetical drought and flood index insurance contracts have been proposed. The author concludes that the utility and affordability of such index based insurance contracts may vary over time and space (Siebert, 2016).

Surprisingly, studies examining its applicability in developed economies are remarkably sparse. However, remarkable exceptions exist, such as research conducted in Australia, where the adoption of rainfall index insurance has demonstrated benefits for policyholders during periods of excessive rainfall (Kath et al., 2018). In Finland, in terms of agricultural index-based contracts, farmers garnered a greater willingness-to pay with respect to indemnity insurance policies (Liesivaara & Myyrä, 2017). Also, a survey among Finnish farmers conducted within the PIISA project reveals that, while a large majority of respondents agrees that new and innovative insurance products are needed to manage weather risks in agriculture, one third of farmers are not interested on parametric insurance and one third sees basis risk as a major challenge for parametric products (Eerola et al., Forthcoming). Similarly, Liu et al. (2023) shed light on the use of index insurance uptake among blueberry pickers in Canada, suggesting that farmers' willingness to pay for weather-indexed insurance remains insufficient without significant subsidies, indicating a need for further research and policy interventions to address basis risk and loss aversion concerns.

To conclude, given the growing interest in weather-index insurance programs, important concerns should be considered. Policymakers must recognize that factors beyond mere economics shape the adoption of index insurance programs, especially in the agriculture sector. According to Patt et al. (2009), trust in both the insurance product and organisations management is often seen as a paramount, surpassing economic incentives in determining demand. Engaging with communities then is indispensable, not just for research, but also for fostering comprehension and confidence in these programs. As such, policymakers should prioritise efforts to replicate community engagement initiatives and employ tools such as field games to bolster trust in index insurance programs. Carter et al.(2017) instead advocates for some initiatives' advancements to enhance index insurance, such as contract design, technology integration, quality benchmarks, marketing strategies, and subsidy distribution.

5.2.2 Insurance-linked securities

Insurance-Linked Securities (ILS) are financial instruments commonly used in the insurance industry. They are primarily designed to transfer risk from issuers, such as insurance companies or governments, to investors in the capital markets. Specifically, they serve as a mechanism for raising funds to cover losses resulting from specific catastrophic events. Through this mechanism, ILS facilitate risk transfer by shifting the financial burden of catastrophic events from issuers to investors. ILS act as a financial tool for managing exposure to catastrophic risks, rather than directly contributing to risk reduction or resilience building. Investors in ILS assume the risk of catastrophic events and, in return, receive potential returns in the form of coupon payments or premiums. The returns on ILS are tied to the occurrence and severity of predefined events, with higher-risk bonds potentially offering higher returns. Moreover, sourcing capital from the global financial market increases the diversification of which, as mentioned in Chapter 4.2.1, has a positive effect on the insurability of catastrophic losses. On top of that, global investors are more risk neutral than (smaller) national agents, which further adds to the diversification potential and enhances the solvency of insurance companies.

5.2.2.1 Catastrophe bonds

Catastrophe bonds (CAT bonds) are debt securities issued by insurance or reinsurance companies to transfer specific catastrophic risks to investors in the capital markets. By issuing CAT bonds, insurers can access additional capital beyond traditional reinsurance markets, increasing their capacity to cover potential losses and in turn preventing potential operational impairments leading to insolvency. The literature emphasises that CAT bonds play a crucial role in enhancing resilience to natural disasters by providing an effective mechanism for transferring and managing catastrophic risks in financial markets (Herweijer et al., 2009). Indeed, the ultimate goal of CAT bonds is to provide a means for transferring risks associated with natural disasters to bond investors (Cummins & Barrieu, 2013; Polacek, 2018). CAT bonds also serve as a financial instrument that pays out to the issuer when predefined disaster risks, such as hurricanes, earthquakes, floods, or other catastrophic events, occur (Polacek, 2018). In this context, if the predefined catastrophic event occurs, investors may lose their principal or interest payments, providing capital to cover the insurer's losses, protecting their balance sheets. CAT bonds offer a mechanism for diversifying risk and increasing the capacity to absorb losses from such events, particularly for insurers and reinsurers (Herweijer et al., 2009). In this way, CAT bonds are structured to provide risk transfer through various trigger mechanisms, including parametric triggers, indemnity triggers, or market index triggers. According to Polacek (2018), parametric triggers, in particular, are highlighted for their ability to offer quick access to insurance protection and disaster funds without the need for extensive loss assessments, making them especially suitable for governments and other entities seeking rapid financial assistance after a catastrophe. This is also confirmed by Götze & Gürtler (2022), who reveal that CAT bonds may add value to insurers' risk management strategies and potentially substitute for reinsurance. Using data from the US, the authors find that such added value emerges mainly for non-indemnity bonds. Parametric CAT bonds are to be preferred to standard reinsurance in cases of high reinsurer default risk, low basis risk and in high-risk layers. Furthermore, CAT bonds are designed to be collateralized, meaning that the funds necessary to cover potential payouts are held in reserve, thereby eliminating counterparty risk. This collateralization ensures that bondholders receive timely and full repayment of their principal and interest, even in the event of a triggering catastrophe (Polacek, 2018).

The CAT bond market promotes price discovery and transparency, encouraging competition and innovation in risk transfer mechanisms, thus enhancing market efficiency. Indeed, they represent a complementary approach to risk financing that supplement traditional insurance and reinsurance products, thereby contributing to the overall stability of the insurance industry and facilitating rapid recovery after catastrophic events (Michel-Kerjan & Morlaye, 2008).

Although CAT bonds offer investors an appealing opportunity to diversify their portfolios because of high-yielding assets that are not correlated with traditional market movements, investment managers are still reluctant to engage with these products mainly due to behavioural biases. According to Bantwal and Kunreuther (2000), investors may compare their limited knowledge of catastrophic risk modelling to their expertise in other markets. Indeed, concerns over catastrophic losses and perceived superior knowledge of insurers may hinder investor participation (Fox & Tversky, 1995). Along this line, high spreads suggest underlying issues such as ambiguity aversion and myopic loss aversion (Fox & Tversky, 1995). In this context, standardising terms and reducing pricing uncertainty could alleviate investor reluctance and increase demand for CAT bonds, ultimately leading to lower prices and market development (Cummins, 2008). In this way, governments and regulatory bodies should make some efforts to increase public awareness and understanding of CAT bonds that can help promote investor confidence and facilitate market growth. Not only, in order to address barriers to market development and enhance the resilience of communities to catastrophic events, they could incentivize insurers to issue CAT bonds by providing regulatory relief or tax incentives, encouraging greater participation into the market.

Overall, CAT bonds pose certain challenges but also offer solutions to some issues. Regarding the insurance protection gap, CAT bonds increase the insurance industry's capacity to handle catastrophic risks, potentially reducing the gap by providing coverage for events that were previously uninsured or underinsured. The advancement of CAT bonds stimulates innovation in risk transfer solutions, resulting in the development of new products and mechanisms that address changing risks and vulnerabilities. These bonds attract investments from institutional investors willing to take on catastrophic risks, fostering collaboration between the insurance sector and financial markets to tackle the protection gap. Policymakers must establish clear and robust regulatory frameworks to govern the issuance and trading of CAT bonds, ensuring the protection of investors and the integrity of the market.

5.2.2.2 Resilience bonds

Unlike ILS, resilience bonds (RBs) primarily finance projects and initiative aimed at enhancing resilience to natural disasters and climate change. Despite both being financial instruments related to managing risks associated with natural disasters and climate change, they raise capital to invest in measures that reduce vulnerability and mitigate the impact of disasters, rather than transferring risk. Indeed, RBs finance projects designed to decrease the probability and severity of future disasters. These operations financed work in the logic of infrastructure improvements, ecosystem restoration, early warning systems, and community resilience programs, actively cooperating to develop resilience and reduce vulnerabilities. Overall, these projects aim to generate financial returns alongside positive social or environmental impacts, attracting a diverse range of investors, including those interested in socially responsible investments and sustainable development.

5.2.3 Microinsurance

Microinsurance typically provides coverage to low-income individuals and communities through simplified polices with lower premiums. In most of the cases, low-income individuals and communities are indeed often excluded from traditional insurance markets due to affordability constraints (see, for example, Lucas & Booth, 2020; Schäfer et al., 2019; Walker & Burningham, 2011). In this way, microinsurance products help the industry by extending coverage to underserved populations, by offering simplified policies with lower premiums and tailored coverage, addressing specific needs of marginal and vulnerable groups, as well as reducing the protection gap and promoting financial inclusion (Schuster, 2021). However, microinsurance products present some challenges. According to Platteau et al. (2017), despite its affordability, individuals who are more risk-averse may be less inclined to purchase microinsurance. This is because, even with low premiums, microinsurance is subject not only to price sensitivity but also to various demand barriers factors, such as lack of trust due to information asymmetries (Biener & Eling, 2012). Furthermore, the lack of understanding of the product is identified as a barrier to microinsurance uptake (Nzembela & Mazambani, 2019). In this context, the study of Ginè et al. (2010) suggests investing in educational programs to increase awareness and understanding of microinsurance among populations, mainly for low-income individuals, which are the main target. The authors also propose combining microinsurance products with other financial services, such as short-term loans or interest rates contingent on weather outcomes. This integration aims to alleviate credit constraints and enhance the affordability of microinsurance for policyholders. Overall, policymakers may need to implement regulatory frameworks and incentives to encourage the development of microinsurance markets, taking into consideration various demand-side barrier factors such as price sensitivity, liquidity constraints, and lack of trust or understanding. In primis, policymakers should proceed with innovative strategies, such as integrating microinsurance with other financial services and/or making efforts to increase financial literacy and awareness, in order to overcome these barriers and improve access to risk protection for low-income households (Frazier et al., 2020). Secondly, through innovative distribution channels such as mobile technology and community-based organisations, microinsurance enhances accessibility and awareness, increasing insurance uptake among vulnerable groups and narrowing the protection gap. However, while digitalisation and smartphone integrations can offer several benefits, they may also come with trade-offs, and they could even backfire, since poorer social groups might not have access to them (Kraehnert et al., 2021).

5.2.4 Takaful

Takaful is a form of Islamic insurance that proceeds from the principle of mutual assistance and shared risk, in harmony with Islamic law (Shariah). Takaful helps the industry by providing Shariah-compliant insurance solutions to the Muslim community, extending the reach of insurance coverage and addressing specific religious and cultural preferences. Aligning with Islamic principles of fairness and solidarity (Maysami & Kwon, 1999), takaful operates in the logic of insurance protection gap by pooling resources and spreading risks among participants, providing an alternative risk-sharing mechanism for Muslim communities where conventional insurance may face cultural or religious barriers (Salman et al., 2019). A report of the Pew Research Center (2017), which is also cited by Eurostat,[33] estimates that in 2016 Muslims comprised, on average, 5% of the European population, with growth projections to more than 10% by 2050. Notably, among the countries with the highest shares of Muslim population, are some nations that are characterised by low insurance penetration rates, such as Austria, Bulgaria, Germany, Greece and Italy. Therefore, takaful products could represent a valuable option to closing the IPG, especially if worsening climatic conditions exacerbates migration patterns from Muslim countries toward Europe.

This ethical foundation distinguishes takaful from conventional insurance models, fostering not only a sense of community and social cohesion (Hassan & Salman, 2017) but also financial inclusion, by the participation from individuals who may have been underserved or marginalised by traditional insurance providers (Lucas & Booth, 2020). Indeed, Lucas and Booth (2020) suggest that a pure market approach to insurance may not be sufficient for effective climate adaptation, particularly for vulnerable populations. While risk-based pricing may incentivize adaptation among certain groups, it may also leave the most vulnerable individuals unprotected.

[33] See https://knowledge4policy.ec.europa.eu/dataset/ds00140_en

In this case, takaful intended as solidarity-based approaches has the potential to effectively address climate risks, particularly for those at the highest risk (Gor, 2013). In this context, takaful serves as a reminder of the underlying principles of solidarity and mutual support within insurance systems. rather than operating on a purely profit-driven basis.

Although takaful promotes social values, from another perspective takaful tools present some disadvantages. Firstly, takaful faces hurdles in ensuring Shariah compliance, which in turn increases operational costs and impedes innovation (Ahmed Salman, 2014). Second of all, lack of standardised regulations and low consumer awareness pose great challenges to its growth, as well as competition from conventional insurance (Abdou et al., 2014).

However, Evans et al. (2013) and Lucas (2018), advocate that relying solely on risk-based pricing may have limited effectiveness in incentivizing adaptation. A comprehensive approach that takes into account both economic incentives and social dynamics may be more successful in promoting behavioural changes conducive to climate adaptation. For this reason, policymakers may need to create a conducive regulatory environment for the development of Takaful markets, ensuring compliance with Shariah principles while also safeguarding consumer interests and financial stability.

5.2.5 Insurtech

Insurtech is a term often referred to the use of technology within the insurance industry, such as artificial intelligence, big data analytics, and blockchain, useful to innovate and enhance insurance processes and products. Insurtech leverages technological advancements mainly to enhance risk assessment, underwriting efficiency, and claims management (Lanfranchi & Grassi, 2022). Indeed, by automating processes and reducing operational costs (Lin & Chen, 2019). Insurtech solutions enable insurers to offer more affordable and accessible insurance products, expanding market reach and fostering customer engagement (Cappiello, 2018).

According to Vriens and De Moor (2020), insurtech initiatives are classified into two main groups: top-down and bottom-up. Top-down initiatives typically contemplate advanced technologies such as online platforms, artificial intelligence, and blockchain to compute ad-hoc risk profiles and offer highly differentiated premium levels. In contrast, bottom-up initiatives prioritise equality and inclusion and do not distinguish based on subjective risk profiles. They aim to keep premiums low and offer minimal support to everyone. From one side, top-down organisations risk losing the sense of solidarity and trust crucial for keeping moral hazard occurrences low as risk-sharing groups become abstract and anonymous. On the other hand, bottom-up organisations may face difficulties with adverse selection if they attract a high number of high-risk individuals.

The expansion of insurtech has faced several limitations over the last decade. Indeed, by nature, insurtech heavily relies on big data analytics (BDA) and artificial intelligence (AI) to compute accurate risk assessment and pricing (McFall et al., 2020). However, the rapid pace of technological developments may outpaces regulatory and legal responses, raising concerns about privacy, algorithmic bias, transparency, and explainability (Swedloff, 2014; Barocas & Selbst, 2016; Mullins et al., 2021). Specifically, the use of BDA and AI complicates the regulatory environment and may lead to unfair discrimination if not properly monitored (Hamilton, 2020). In light of this, regulators may face challenges in ensuring fairness (Hamilton, 2020) and consumer protection while allowing the insurance sector to benefit from digital innovations (Bernardino, 2020). In a nutshell, a significant challenge is related to regulatory compliance, as insurtech companies operate in highly regulated industries with different jurisdictions. Additionally, also data privacy and security represent an issue.

Despite the challenges, insurtech offers significant benefits, including efficiency gains, cost savings, and enhanced customer experience (Holland & Kavuri, 2023). Distributed ledger technologies (DLT) such as blockchain, present chances for real-time exposure assessments and fraud detection. These advancements may facilitate the development of new insurance solutions tailored to address specific risks and close the protection gap (for a more detailed discussion see Chapter 5.3.2). In terms of policy implications, policymakers may need to adapt legislative landscapes to assist the evolving framework of Insurtech initiatives, guaranteeing consumer protection, data privacy, and cybersecurity.

5.2.6 Decentralised insurance solutions

Decentralised insurance solutions (DIS) involve insurance systems and mechanisms that function without central authorities or intermediaries. In traditional insurance models, there are typically centralised entities such as insurance companies, brokers, or regulators that play a significant role in underwriting, distributing, and managing insurance products. Decentralised insurance solutions aim to disrupt this centralised model by leveraging technologies such as blockchain, smart contracts, and decentralised finance (DeFi) to create alternative, more transparent, and efficient insurance ecosystems (Norta et al., 2019). In this way, decentralised insurance platforms can streamline processes, minimise administrative expenses, eliminate intermediaries and make insurance products more cost-effective (Abdikerimova & Feng, 2022). This in turn can incentivize more individuals and businesses, mainly those which are positioned in remote or financially unserved areas, to purchase insurance coverage, thereby narrowing the IPG (Norta et al., 2019). Additionally, by utilising blockchain, DIS ensure transparency, security, and trust among participants (Omar et al., 2023). Then, through automated claims processing and transparent risk-sharing mechanisms, DIS improve the efficiency and integrity of insurance transactions, increasing confidence among users and encouraging broader participation in insurance markets (Jha et al., 2021). Other underlying technologies are the so-called smart contracts, which are self-executing agreements with the terms of the contract directly written into code. In this way, smart contracts automate insurance processes such as policy issuance, premium payments, and claims settlements without the need for intermediaries (Sheth & Subramanian, 2019). For these purposes, decentralised insurance solutions may also employ tokens and cryptocurrencies, incentivizing participation. In particular, tokenization facilitates liquidity within decentralised insurance markets. Lastly, decentralised insurance also enables P2P insurance, avoiding the necessity for traditional insurance firms and permits for direct interaction between insurance providers and policyholders.

Decentralised insurance solutions, however, encounter several limitations. One major challenge is regulatory uncertainty (Tjäder & Ulrich, 2023), as the legislative landscape for decentralised insurance is still evolving and could significantly differ across various jurisdictions. Additionally, due to the large volumes of transactions, scalability could represent another concern (Sohrabi & Tari, 2020). Moreover, smart contract vulnerabilities and security risks pose a significant challenge for the integrity and reliability of decentralised insurance protocols. To conclude, the adoption and trust of decentralised insurance solutions may be hindered by the unfamiliarity with the technologies of blockchain by the users (Bracci et al., 2021).

5.2.7 Insurance of ecosystem services

The concept of insurance of ecosystem services involves using insurance mechanisms to protect and restore natural ecosystems and the services they provide, such as water purification, flood regulation, and carbon sequestration. This approach incentivizes investments in nature-based solutions (NbS), promotes environmental conservation, and enhances resilience to climate change. By valuing and insuring ecosystem services, this approach contributes to closing the protection gap (Coughlan De Perez et al., 2016) and creates co-benefits for biodiversity, communities, and economies (Barreal et al., 2014).

The concept of insuring ecosystem services, which encompasses natural infrastructure and NbS, has gained prominence in environmental governance and policy discussions (Zandersen et al., 2021). By leveraging insurance mechanisms to protect and restore ecosystems, such as wetlands, forests, and coral reefs, this approach offers a multifaceted solution to address environmental challenges like flood risks, storm surges, and water scarcity. Studies such as Kousky and Light (2019) confirm the effectiveness of ecosystem-based insurance in promoting environmental conservation, enhancing resilience to climate change, and closing the protection gap.

Other studies highlight the potential for insurance premiums to be reduced over time through the implementation of NbS and community-based insurance schemes. For instance, integrating NbS measures such as levee setbacks can lead to lower premiums by providing ecological benefits such as improved biodiversity and water quality (Munich RE, 2021). Additionally, the integration of community-based catastrophe insurance (CBCI) with NbS can result in substantial premium reductions, benefiting both individual homeowners and the community as a whole, as discussed in the same study. Moreover, Reguero et al. (2020) indicate that insurance premium reductions in the first few years of implementing resilience insurance approaches could cover a significant portion of the initial restoration costs, thereby making insurance more affordable over time. More specifically, the authors investigate an initiative of a consortium of hotels in Mexico, which joined forces to finance a coral reef restoration program to protect against sea level rise. The consortium indeed found that the program's benefits in terms of storm surge reduction and insurance premiums reduction exceeded the restoration costs. Thus, incorporating NbS and community-based approaches into insurance strategies can lead to tangible benefits (Baumgärtner, 2007), enhancing affordability and participation in insurance schemes while promoting environmental conservation and resilience to climate change (López Gunn et al., 2021).

These results are supported by the research of Guzmán et al. (2020), who underscore the insurance value of biodiversity and ecosystem services, highlighting the importance of integrating nature-based approaches into insurance regulation and climate adaptation strategies. In terms of policy implications, collaboration between insurers, policymakers, conservation organisations, and communities is essential for developing innovative insurance products, assessing ecosystem risks, and establishing effective governance mechanisms for ecosystem services (Hahn et al., 2023).

Despite these benefits, insuring ecosystem services comes not without limitations. Indeed, Baumgärtner (2007) raises doubts about their implementation for several reasons. One of the difficulties is the complexity of measuring, quantifying and valuing ecosystem services. Moreover, the unpredictability deriving from climate change further adds complexity to evaluating the risk associated with the ongoing sustainability of ecosystem services. Lastly, regulatory barriers may hinder the effectiveness of insurance for ecosystem services and NbS. For a more detailed overview of the benefits and limitations of investing in NbS and nature-based insurance see the report published by the European Investment Bank (2023).

5.3 Data innovations

In the insurance landscape, cutting-edge technologies have revolutionised data collection. The transformative integration of advanced technologies is reshaping the insurance industry, with the aim of improving risk assessment and thereby providing accurate estimates of underwriting practices, delivering greater value to both insurers and policyholders alike. Additionally, innovative products take the lead stage in the insurance industry, not only bolstering customer satisfaction but also driving significant operational efficiencies, such as automating manual processes, streamlining data workflows, but also in reducing administrative costs, minimising errors, and increasing productivity (Njegomir & Rihter, 2012). Furthermore, through the use of modern solutions, insurers can identify suspicious patterns and anomalies indicative of fraudulent activity (L. Zhao, 2020).

To expedite the fortification of resilience and mitigation strategies among European citizens against climate-related natural catastrophes, Sheehan et al. (2023) argue for the necessity to depart from conventional insurance measures toward alternative approaches enabled by advanced technologies for macro/micro-level assessment together with machine learning and artificial intelligent (AI) analytics.

In this context, drone, satellite, and blockchain technologies are among the most important for the insurance industry's temporal monitoring of climate-related loss events for several reasons (Njegomir et al., 2021). These kinds of technologies offer real-time, high-resolution data, while blockchain ensures secure and transparent data management, enabling faster payments and precise compensation (Njegomir et al., 2021). Moreover, these tools streamline insurance processes, improving efficiency and accuracy in responding to climate-related natural catastrophes (Sheehan et al., 2023).

These instruments can enable automated payments based on real-time catastrophe monitoring data, streamline risk estimation and claims processing, and gather crucial hazard data (Benami et al., 2021). Moreover, micro-satellite-based remote sensing facilitates various insurance tasks, while advancements in catastrophe modelling, including AI and machine learning integration, enhance data refinement and coordination for more accurate risk assessment. Taking all these considerations into account, technologies' innovations indubitably bolster the insurance industry's ability to respond swiftly and effectively to dynamic risks and challenges, creating an opportunity to close the protection gap. This synergy fosters a stronger insurance ecosystem, adept at addressing shifting challenges and aiding communities impacted by natural disasters.

5.3.1 Remote sensing

Remote sensing data provide a holistic view of Earth's surface and atmosphere, offering insights not readily accessible through ground-level observations. Unlike ground-based data collection, remote sensing enables the observation of large geographic areas, facilitating broader insights into environmental phenomena and enhancing various applications such as environmental monitoring, disaster management, and urban planning. In this context, monitoring and weather technologies serve as pivotal components of remote sensing, each offering distinct advantages in observing Earth's surface and atmosphere. Two types of remote sensing technologies are investigated for application to climate risk assessment and insurance in this study: drone and satellite imageries. While the former offers a more localised perspective, navigating closer to the ground and providing detailed, micro-level data, the latter provides a macroscopic view from space, capturing vast geographical areas and enabling comprehensive observations of environmental phenomena.

5.3.1.1 Drone imagery

Drones, also known as unmanned aerial vehicles (UAVs), are aircraft that operate without the need of a human pilot onboard. They can either be controlled by human operators or fly autonomously based on pre-programmed instructions or built-in systems. They vary in size, shapes and purpose, ranging from consumer models for recreation to military scopes for surveillance, or alternatively they could be equipped with sensors, cameras and weaponry in order to span aerial agriculture, mapping, search and rescue, and environmental monitoring.

Drone imagery presents a transformative opportunity for the insurance industry, particularly in the realm of data collection (Kleinschroth et al., 2022). By leveraging drones to gather micro-level data, insurers can conduct more comprehensive assessments of risk associated with various properties and regions. Drones have become invaluable tools in assessing natural disasters, climate change impacts, and other hazards due to their ability to capture intricate images of properties and micro geographical features with high-resolution cameras (Sheehan et al., 2023). This results in more precise risk assessment, including identification of potential hazards, vulnerabilities, and environmental factors (Benami et al., 2021). This is due to their high-resolution imagery nature and real-time data, which allows a correct recognition of potential risks also in remote areas, increasing proactive mitigation strategies (Kucharczyk & Hugenholtz, 2021).

In the underwriting process, drone imagery implementation could provide valuable insights into properties and asset valuation (Koeva et al., 2021). This is because it allows an accurate assessment, through aerial imagery, of property conditions, in turn determining the appropriate coverage levels (Iwahashi et al., 2023). This means they serve as a tool for insurers to identify and assess risks that could have been overlooked or underestimated. Due to the sophisticated level of technology and imagery, drones could address all those emerging risks or niche market risks, offering coverage options tailored to evolving needs (Cotrufo et al., 2018).

Additionally, drones can be swiftly deployed to assess instantaneous damage and gather immediate critical information following natural disasters or other catastrophic events, adjusting payouts based on damage experienced (Schirrmann et al., 2016). Indeed, real-time aerial imagery allows insurers to assess the extent of damage across affected areas, prioritise response efforts in a more efficient and rapid way (Xiang & Tian, 2011), and allocate resources more effectively.

To further enhance this capability, insurers may consider two approaches. The first option involves having trained personnel accompany the drones to manually assess damage on-site, potentially offering a quicker response than manual evaluations alone. However, this method may still be subject to human limitations such as fatigue or safety concerns. Alternatively, insurers could explore the feasibility of implementing fixed, pre-determined docks scattered on the ground at optimal distances from one another. These docks would serve as launching and landing points for drones, allowing for systematic and automated damage assessment. While this approach offers scalability and reduces reliance on human resources, it requires significant upfront investment in infrastructure and may be subject to regulatory and logistical challenges.

Additionally, drones can play a pivotal role in expediting claims processing within the insurance industry (Agarwal et al., 2022). In the event of a claim, drones can be deployed swiftly to survey and document damage to properties and assets. Utilising high-quality aerial imagery, insurers can precisely assess the extent of damage, facilitating quicker claims processing and minimising disputes(Kleinschroth et al., 2022).

The damage assessment opportunities afforded by drones have been documented by several research studies. For example, Furlanetto et al. (2022), using UAV-mounted sensors and spectral analysis techniques, quantify hail damage in winter wheat crops, offering a precise method for estimating yield loss. These provide reliable tools to accurately assess crop damage, improving risk management and compensation strategies. Additionally, Furlanetto et al. (2023) explores hail damage estimation in maize using UAV and Sentinel-2 sensors, demonstrating accurate LAI (leaf area index) estimation and the effectiveness of NDVI-based parametric methods, offering reliable tools for assessing crop damage and improving risk management strategies. A related study explores the use of remote sensing, particularly in the near-infrared spectral region, to assess hail damage in winter wheat crops. By analysing absorbance features and developing a multispectral index, the research effectively maps and quantifies the damage, providing valuable insights for agricultural management (Furlanetto et al., 2024). Lastly, Longo et al. (2022), in a two-year experiment, integrated remote sensing and crop modelling as a reliable method for estimating hail damage in agriculture. This approach demonstrated a less labour-intensive and more accurate solution for the insurance market. Overall, research presented in these studies showcases the potential of UAV-mounted sensors, spectral analysis techniques, and remote sensing technologies to accurately quantify hail damage in agricultural crops. By leveraging these advancements, insurers can benefit from more precise and efficient methods for assessing crop damage, leading to improved risk management and compensation strategies (Benami et al., 2021). By reducing the time and costs associated with estimating losses, these innovative approaches have the potential to lower premiums for indemnity insurance products compared to current practices. This is achieved through the use of advanced technologies that offer timely and accurate assessments of damages, allowing insurers to better understand and mitigate risks associated with extreme weather events like hailstorms. Ultimately, the integration of remote sensing and modelling techniques not only enhances the resilience of the agricultural sector but also fosters more sustainable and cost-effective insurance practices.

Having said that, the employment of drone imagery into insurance considerations provides additional opportunities. One of these is the cost savings of property inspections, in the sense of maximising operational efficiency through drone technology while minimising expenses associated with traditional inspection methods (Seo et al., 2018). By eliminating the need for hand-operated inspection, drones not only enhance safety by reducing the risk of accidents and injuries for inspection personnel but also deliver substantial cost savings to insurers. This dual benefit is achieved through the efficiency and cost-effectiveness of drone technology (Kleinschroth et al., 2022). Insurers can modernise their operational processes by utilising drones for data collection and inspection tasks, which in turn reflects an improvement of profitability (A. Otto et al., 2018).

Finally, drone imagery serves as a tool for insurers to offer value-added services aimed at mitigating climate change risks, enhancing risk management strategies (Johnson et al., 2017). The enhanced data collection capability from drones enables insurers to offer tailored insurance products that closely align with the specific risks and needs associated with individual properties and assets. Moreover, insurers have the potential to develop new services by providing customised coverage options and pricing based on detailed risk profiles derived from aerial data (Njegomir et al., 2021). In this context, insurers could offer insightful proactive risk assessments and make some recommendations based on aerial data, acting as consultants in assisting both policyholder and local administrations, with the aim of minimising potential hazards and reducing the likelihood of claims.

Also, the streamlined approach not only accelerates the settlement process (Anh & Duc, 2024) but also enhances customer satisfaction by providing policyholders with prompt access to funds following a covered loss. By leveraging drone imagery for claims assessment, insurers can develop insurance products with expedited claims settlement processes, further enhancing the overall efficiency and responsiveness of their services.

In a nutshell, drone imagery plays a pivotal role in improving data collection in the realm of the insurance industry, by offering micro and up-to-date information about properties, assets, and environmental conditions.

5.3.1.2 Satellite imagery

While drones offer detailed data at a local level, satellite imagery provides broader coverage, spanning large geographical areas. Indeed, satellite remote sensing utilises satellite technology to gather Earth surface and atmospheric data, crucial for insurers in assessing natural and climate-related disaster risks. This technology provides insights into terrain, land use, and environmental conditions, aiding in quicker claims processing post-events like floods and wildfires. In doing so, satellite data enhances risk modelling, helping insurers manage climate-related risks effectively (Eltazarov et al., 2021). Ultimately, satellite remote sensing empowers insurance companies with informed decision-making, bolstering resilience and minimising financial losses from natural catastrophes (Nordmeyer & Musshoff, 2023).

Within the insurance industry, by collecting macro-level data through satellites and remote sensing, insurers can ensure an overall picture of information and risks associated on weather patterns, terrain features, vegetation, and land use, among other factors, anticipating potential losses, estimating fair insurance compensation (Wu et al., 2023) and reducing moral hazard (Vroege et al., 2019). Nowadays, satellite-derived imagery and remote sensing systems are increasingly employed in the insurance landscape, with the ultimate goal to generate essential input data for models (Carter et al., 2017), helping the production of decision-relevant outputs concerning natural disasters or climate-related events (Ruckelshaus et al., 2020). More precisely, satellite technologies play a crucial role in improving risk and loss estimation in the insurance industry, thus helping to address the climate insurance protection gap.

Wu et al. (2023) shows in their work that flood economic losses modelling presents an error rate of less than 10% when compared to the official data from the Henan Provincial Government, indicating highly accurate flood loss assessment results. In light of this, incorporating remote sensing pixels in the flood losses model enhances the accuracy of compensation estimation. From a risk assessment perspective, ongoing acquisition of detailed, high-resolution imagery and data remains essential (De Leeuw et al., 2014)l. Concisely, digitalized satellite technology enhances data accuracy, which in turn improves the precision of risk and loss estimation models (Brahm et al., 2019). This reduces the discrepancies in risk assessments and improves the reliability of loss estimation models.

Besides that, detailed and accurate data also affords the opportunity to develop tailored insurance products based on specific customer needs by the insurers. Specifically, satellite imagery and remote sensing data enable practitioners to conduct granular risk assessment (Rumson & Hallett, 2019), as well as to offer additional services and products such as customised coverage options and personalised pricing (Vroege et al., 2019). Such tailored insurance products and personalised services would also contribute to an enhanced customer experience.

Another benefit of utilising satellite imagery and remote sensing data is the ability to provide extensive coverage, mainly due to their higher spatial resolution (Furlanetto et al., 2023), which may not be evident at a smaller scale. The enhanced resolution of these technologies allows finer details and nuances across large geographical areas to be captured, which may not be discernible when observed at smaller scales. This facilitates more informed decision-making across various fields such as environmental management, disaster response, urban planning, and agricultural monitoring.

According to Vecere et al. (2021), the use of digitised aerial platforms also eliminates the need for local recording stations. Not only, but the use of satellite and remote sensing technologies offers several benefits also in terms of event monitoring, in which satellite-retrieved data allows users to obtain timely and real-time information. In light of this, real-time monitoring of climate events could constitute a form of risk mitigation measure, which enables insurers to promptly inform policyholders in the case of extreme hazards, aiding in reducing the likelihood and severity of losses, thus acting as a tamper-proof trigger.

This constant monitoring can, in turn, stimulate insurers to have a proactive approach to risk management (Nagendra et al., 2023). This is translated into foreseeing vulnerabilities and potential damages, addressing resources more efficiently to respond swiftly to emerging threats, as well as alleviating the impact and thereby reducing the insurance protection gap.

Lastly, satellite and remote sensing technologies offer a cost-effective data collection solution (Matese et al., 2015), which means that such technologies are able to gather information quickly and efficiently over large geographical areas at lower operational costs, compared to traditional ground-based methods that can be time-consuming and resource-intensive.

Overall, satellite and remote sensing technologies release high-quality, as well as standardised data with reliable resolution and coverage. This ensures a high level of accuracy and reliability, supporting insurers to make reasoned decisions on the basis of consistent and comparable information. Satellite imagery has the potential to stimulate several innovative applications, although the measurements remain unexplored in insurance design (Vroege et al., 2019). However, in line with Villarroya (2016), remote sensing and satellite imagery could be an efficient tool for evaluating growing conditions and crop drought, if more accurate measurements are available.

Despite all the positive effects, remote sensing (both satellite and drones technologies) in the insurance industry faces several challenges, including high setup and operational costs (De Leeuw et al., 2014), variable data accuracy, and dependence on weather conditions. Regulatory restrictions, such as airspace regulations and data privacy laws, further limit its use. In addition, interpreting remote sensing data requires expertise and may be subjective, leading to potential errors in risk assessment. Moreover, coverage limitations in remote or inaccessible areas makes it challenging to integrate data and add complexity (De Leeuw et al., 2014). Lastly, regular maintenance and calibration are also a concern, as well as security and ethical considerations around privacy and data misuse.

5.3.2 Blockchain

The Blockchain, often referred to as a "chain of blocks", harnesses the power of a network of computer nodes to safely handle and update a ledger of data and information. More specifically, blockchain functions act as a decentralised database security, which introduces a new level of transparency and secures a new method of conducting business transactions. Over the years, blockchain technology has had the potential to revolutionise the ordering process by removing intermediaries, allowing transactions and records to be authenticated, exchanged, and validated without reliance on a central authority.

Although distributed ledger technology had been around for quite some time, the term “blockchain” officially emerged on January 3, 2009, with the invention of Bitcoin. Since then, blockchain has evolved and demonstrated its potential in different economic sectors. For example, in the insurance industry, blockchain has served as a foundational technology, not only in transforming core business operations by addressing inherent inefficiencies but also significantly aiding data collection. Indeed, when implemented efficiently, blockchain processes can offer a holistic solution to various challenges.

For instance, Omar et al. (2023) lists some benefits of using blockchain technology in crop insurance, focusing primarily on transparency and trust among stakeholders and insurers. In addition to that, Demir et al. (2019), argue that blockchain's decentralised nature ensures clarity in transactions and data sharing, with the opportunity for all the actors within the insurance ecosystem to access a shared ledger, thus enhancing trust among stakeholders by allowing participants in the network. This transparency reduces the risk of data manipulation and fraud (Singer, 2019), as well as enabling traceability and accountability, where insurers can track the origin and movement of data (Loukil et al., 2021). Another advantage of blockchain is the integrity and security of collected data (Kar & Navin, 2021). Once entered into the blockchain, information becomes unchangeable and permanent, preserving the integrity of records and providing a tamper-proof and immutable ledger. This feature prevents unauthorised access to sensitive data and, at the same time, guarantees that information remains precise and trustworthy throughout its lifecycle (Shetty et al., 2022). In doing so, blockchain facilitates secure and efficient data sharing among insurers, reinsurers, brokers, and other parties involved in the insurance ecosystem(Kar & Navin, 2021). Because of the cryptographic methods to safeguard data and transactions, the blockchain process enables access to real-time data, which in turn enhances decision-making.

Additionally, by leveraging blockchain-enabled smart contracts, insurance companies could streamline claims processing, diminishing manual intervention and administrative tasks (at the same time reducing human error) improving efficiency throughout the insurance value chain (Shetty et al., 2022). In turn, this may lead to decreased insurance premiums and facilitate smoother interactions between insurers and their clients. Automating claims processing not only favours payments when certain predefined conditions are met, but also accelerates the claim settlements, simultaneously reducing the processing time, enhancing customer satisfaction and loyalty (Wang et al., 2023). This is coherent with Kostic and Sedej (2022), who state that by utilising blockchain coordination and reconciliation processes, delays and discrepancies are minimised, resulting in faster and more accurate transactions between insurance entities. Another benefit of implementing blockchain in the insurance industry is the reduction of transaction costs. Given the nature of automation, blockchain provides the elimination of third parties such as intermediaries, reducing operating expenses for insurers (Sun et al., 2020).

In a nutshell, blockchain technology plays a pivotal role in data collection within the insurance industry, offering value-added information and peculiarities such as integrity, transparency, and efficiency while fostering trust among stakeholders.

5.3.3 Artificial Intelligence

By amalgamating technologies such as drones, satellite/remote sensing, and blockchain, the insurance sector achieves enhanced efficiency and accuracy in data collection. At the core of this transformation lies Artificial Intelligence (AI), serving as a fundamental element in revolutionising how data is collected and utilised within the industry (Castillo et al., 2016; Cesarini et al., 2021). According to Eling et al. (2022), artificial intelligence emerges as a transformative force in the insurance business model, offering a series of opportunities such as cost reduction and generation of revenue. In particular, they stress the importance for continued research to equip both industry practitioners and academics into this burgeoning field. This emphasis is particularly crucial in addressing agricultural disaster scenarios, given the increasing reliance on machine learning and AI-driven methodologies, as reported by (Hu et al., 2023).

Generally speaking, there are numerous benefits in combining AI analytics with innovation in data collection in the insurance industry (Sheehan et al., 2023). For example, by leveraging drones and AI analytics, insurers can model predictive techniques to forecast potential risks and losses. Through past drone images empowered by AI, machine learning algorithms can identify trends and anticipate future events, proactively mitigating risks, capturing intricate details through high-resolution imagery (Ruckelshaus et al., 2020), and facilitating at the same time precise risk assessments and damage evaluations (Gradeci et al., 2019). Indeed, satellite and remote sensing technologies, further enhanced by AI, can automate the process of collecting, sorting, and analysing extensive datasets on environmental variables, weather patterns, and geographical terrain. This allows us to extrapolate actionable insights from this data, empowering insurers to forecast emerging risks and preempt potential losses, thereby facilitating efficient decision-making and tailored product development.

Regarding the blockchain technologies, the integration of AI ensures the integrity and security of data. In this way, insurers have the capability to securely manage and share data (Gradeci et al., 2019), effectively reducing the risk of fraud while promoting transparency throughout transactions. In this context, Mullins et al. (2021) advocate that to completely ensure the transparency of the process, the information content and logic of AI algorithms should be fully transferable and understandable by customers, in order to avoid asymmetric information. Hence, consensus for both transparency and explainability are necessary for trust among insurers and policyholders.

Overall, AI technologies, such as machine learning and natural language processing, together with high tech instruments such as drones, satellites and blockchain, improves the accuracy of data collection, ensuring that insurers have all the necessary support pro for a reliable risk assessment and underwriting process.

5.3.4 Cybersecurity

The increased use of detailed data by insurers underscores the critical importance of cybersecurity. With vast amounts of personal and financial data at stake, insurers must fortify defences against cyber threats to prevent unauthorised access or manipulation. Robust cybersecurity measures not only protect sensitive information but also bolster trust among policyholders. Additionally, addressing the cyber protection gap is essential, as it bridges the divide between escalating cyber risks and insufficient insurance coverage. Organisations like The Geneva Association (Schanz & Sommerrock, 2016) and GFIA (GFIA, 2023) emphasise the urgency of this issue to fortify the insurance sector against evolving cyber threats. By integrating advanced technologies and cybersecurity protocols into risk assessment and loss estimation processes, insurers can effectively identify and mitigate risks, bolstering their resilience in the face of emerging challenges. To date, cybersecurity remains a very sizable protection gap, likely bigger than the climate and NATCAT insurance one (GFIA, 2023).

5.4 Scope and significance of multi-actor collaboration in climate risk insurance

Multiple actors and stakeholders (e.g., academia, insurance industry, banking, governments, local authorities and communities) can collaborate in the development and provision of climate risk insurance to further enhance risk-reduction and adaptation to climate change (Herweijer et al., 2009; Hudson et al., 2020; Kunreuther, 2015; Seifert-Dähnn, 2018; Surminski et al., 2015; Surminski & Hudson, 2017). Such partnerships can be created by public and private entities, actors representing multiple different sectors, between insurance companies and with national insurance associations (see, for example, Glaas et al. 2017). Similar partnerships are not new around Europe, but their importance is emphasised by more frequent extreme weather events and other risks associated with the changing climate.

According to Surminski et al. (2015), Surminski and Hudson (2017), and Seifert-Dähnn (2018), there is a need for more collaborative arrangements and efforts across and within stakeholder groups to combat rising climate risks through insurance. Furthermore, Surminski (2014) summarises how insurance sector initiatives such as ClimateWise and the Munich Climate Insurance Initiative have identified PPPs as paramount in building resilience to climate impacts, as they enable the combined efforts of both public and private sector approaches. By helping to promote climate change adaptation at the societal level, the private insurance industry can also accumulate new business opportunities and reputational benefits, strengthening the business case behind leading adaptation action (Herweijer et al., 2009).

However, such cooperative efforts might be impeded by numerous barriers. According to Surminski et al. (2015), when managing certain risks, there is a clear lack of ownership when it comes to the responsibilities and coordination. For example in terms of flood risk management in the EU, the lack of central coordination impedes the creation of partnerships and modification of current risk management systems. This strengthens the sense of institutional deadlock, making it difficult to create change within current disaster insurance systems. Another potential challenge limiting coordination between multiple actors is represented by the use of ecosystem services in reducing risks on local or regional scales, despite property insurance being bought at the individual household or company level (Kousky & Light, 2019). As the premium reduction for just one property may not suffice in covering the ecosystem service costs entirely, different types of institutional arrangements are needed to encourage all property owners to participate in funding of the shared service. This could help overcome issues in public goods provisioning, such as free-riding. A great example of how such a limitation could be overcome is represented by the study conducted by Munich RE (2021), which shows that a levee setback program coupled with a community-based catastrophe insurance scheme would yield ecological benefits and ensure wide insurance penetration at affordable rates.

Though the importance of collaboration has been highlighted in the academic literature, its success is not guaranteed. Surminski and Hudson (2017) suggest that multi-sector partnerships might not be successful if stakeholders try to achieve too many goals with insurance functioning as the only instrument. Instead, insurance should be considered and applied as one of many other methods, whilst keeping in mind how it interacts with other instruments and the possibly conflicting priorities among stakeholders.

Other barriers which have been identified include the instability of political preferences (Surminski et al., 2015) and regulatory challenges, such as competition laws when it comes to collaboration between insurance companies (Glaas et al., 2017). Competition laws aim to regulate anti-competitive conduct, but with cross-sectoral topics such as climate change adaptation, cooperative approaches by insurers could be beneficial when promoting proactive adaptation measures. For instance, such partnerships would make it easier to combine information when analysing areas for new construction and their susceptibility to climate risks. For instance, Glaas et al. (2017) highlight that in Sweden the national competition law possibly obstructs cooperation between insurance companies. Even if similar competition laws are in place in other Nordic countries as well, such as Denmark and Norway, they have faced less issues. This is perhaps due to strong intra-sector cooperation facilitated by national insurance associations (NIAs). However, such intra-sector cooperation has been seen to only address certain issues without a systematic approach. In the case of Denmark, Norway, and Sweden, PPPs are highly dependent on the type of capacity and resources available by the NIAs (Glaas et al., 2017).

Studies by Glaas et al. (2017), Surminski and Hudson (2017), and Hudson et al. (2020) have shown that collaboration across and within sectors by different stakeholders is also challenged by the lack of proper communication channels, limited data and dissemination of information. Thus, the creation of additional channels for communication and interaction between insurers, regulators, politicians, and other stakeholders have been suggested (Seifert-Dähnn, 2018). According to Surminski et al. (2015), the EU could indirectly aid in the creation of PPPs by encouraging sharing of information and best practices, facilitating discussions, and when needed, functioning as a neutral party in case of a dispute between parties. In general, governments have been identified to have a major role in information provision and increasing general awareness of risk management, both homeowners and institutional stakeholders alike (Glaas et al., 2017).

Beside public actors, individual insurance companies, industry organisations, and other sector initiatives such as ClimateWise have taken a more active and public role in advocacy and outreach when it comes to climate change impacts and sharing of risk information and knowledge (Surminski, 2014). The data, technology, and analytics that insurance companies have available to them gives these companies the needed insight when advising vulnerable communities on climate risks (Munich RE, 2021). Furthermore, multiple insurers and reinsurers have sponsored research on the topic and participated in risk modelling exercises (Surminski, 2014), in addition to having shared information and educated their customers (both homeowners and businesses) in identifying climate risks and ways to reduce them (Herweijer et al., 2009). As argued by Herweijer et al. (2009), both insurers and reinsurers can develop a wide range of services which could help the public and private sector to adapt. Such services include risk assessments, identification of risk mitigation priorities and advising on risk transfer opportunities.

The incentives of insurance companies to be providers, rather than consumers, of information, however, are considerably hampered by free-riding issues. An insurer acting as a consultant to instruct potential policyholders on ways to reduce their risk and thus obtain better policy conditions, has no guarantee that said policyholders will eventually purchase coverage from them. There is thus the risk that a company provides a service, the benefits of which are ripped off by its competitors. This is a classic example of a free-riding problem that hinders the provision of public goods. And both information and risk reduction do present public goods characteristics. Therefore, insurance companies knowing that, on the one hand, there is the risk that competitors benefit from their activity of information provision, and, on the other, that they could try to benefit from the information provided to potential policyholders by their competitors, do not have any incentive to offer such a consultancy service. The result is that a good that would benefit the whole society, namely information and best practices on how to reduce risk, is not provided.[34] In a recent report, the European Investment Bank has highlighted how a similar issue also limits investments in nature-based solutions and the insurance value they provide (European Investment Bank., 2023). In light of such a market failure, the role of NIAs, regulators, as well as public administrations becomes even more crucial. NIAs would create an environment of reciprocal trust between member insurance companies that they would not try to free ride on other members' efforts, thus re-introducing private incentives for individual insurers to engage in consultancy and information provision activities. Moreover, reinsurers could also offer more advantageous reinsurance conditions to primary insurers that engage in said activities. Regulators and public administration, on the other hand, could set specific requirements that each insurer operating in the territory has to devote some efforts to providing information to potential policyholders on opportunities for risk mitigation (which is a typical command and control approach to solving market failures).

Collaborative structures in risk insurance offer additional benefits as well. For example, PPPs can help finance extreme losses whilst maintaining the solvency of the insurance industry (Hudson et al., 2020). PPPs might also encourage investment in risk mitigation measures, which would enhance affordability and increase insurance capacity in high-impact low-probability events (Kunreuther, 2015). Public insurance schemes are also of interest to insurers as the schemes face limited market competition (Seifert-Dähnn, 2018). The approaches of the private sector can be influenced through PPPs both through the setting of different priorities and the co-creation of actionable measures. Furthermore, multi-sector partnerships can potentially enhance the risk reduction capabilities of insurance schemes, which lowers the pressure on insurance mechanisms and improves affordability (Surminski & Hudson, 2017). Collaboration across stakeholders helps to adapt insurance arrangements to changing situations and improves acceptability across stakeholders and sectors (Hudson et al., 2020). For instance, when it comes to premium pricing in areas which are highly exposed to risks, issues surrounding trust and acceptability could be limited through constructive relationships (Herweijer et al., 2009).

[34] Policyholders would benefit from information on how to reduce their risk level thanks to the lower insurance premiums they would have to pay if they implemented such risk-reduction measures. Insurers would benefit from a lower exposure of their pool of insureds, which in turn alleviates solvency concerns and reduces the amount of capital they have to hold. Public administrations would benefit from the wider penetration of coverage against climate risks and the greater resilience of the society as a whole, which reduces the amount of resources they would have to dedicate to post-disaster compensation and that can instead be used for other activities.

Collaboration and cooperation in climate risk insurance can also provide the sector with some very concrete opportunities in furthering adaptation to climate change. In addition to overcoming aforementioned challenges when working with other stakeholders, strengthening multi-actor partnerships and cooperation can help develop and promote various solutions. These may include: (i) insurance products with a property level risk reduction component (Seifert-Dähnn, 2018); (ii) construction companies including protection measures in their projects and using insurance schemes with competitive terms as a marketable selling point (Seifert-Dähnn, 2018); and (iii) using long-term data possessed by insurance companies in the development of building codes and standards or zoning to enhance resilience to climate risks (Glaas et al., 2017; Herweijer et al., 2009). Overall, multi-actor collaboration in climate risk insurance can help create a multi-layered approach with defined risk responsibilities.

6 Conclusion

This report has reviewed the current state of the market for climate risk insurance, with a focus on European countries (EEA 30 plus the United Kingdom). It has also reviewed the literature investigating the drivers of the climate insurance protection gap and the opportunities for innovation. This was achieved by means of a systematic and AI-powered review of the academic literature, which was complemented with documents and reports from the insurance industry, national governments and the European Union, as well as with information provided by the EIOPA "Dashboard on insurance protection gap for natural catastrophes".

Chapter 3 presented a systematic assessment and mapping of the characteristics of the national climate insurance systems and the current insurance penetration rates. The analysis considers four types of hazards: coastal flooding, inland (i.e., fluvial and pluvial) flooding, wildfire, wind. And two sectors: businesses and households. A special attention has been given to the agricultural sector. While no specific penetration rates maps are reported for agriculture, the discussion focuses the legal and regulatory framework, with a particular attention to the recent Common Agricultural Policy and how countries incorporate it to support their national agricultural insurance schemes.

What emerges is that there is a considerable degree of variation across countries in terms of the characteristics of the national insurance schemes. Also the penetration rates present considerable differences between countries, for both hazards and sectors. Table 6.1 summarises the main outcomes emerging from the review of the literature on the characteristics of the national climate insurance systems and their performance in reaching high penetration rates.

The systems that currently reach higher penetration rates present one or more of these features. (i) They are characterised by a public involvement in the climate insurance system, either in the form of a PPP or a public insurer. (ii) They have some form of premium cross-subsidisation through fixed or flat rates. (iii) They have some requirements for the uptake of climate coverage, either as a specific legal prescription or by making climate insurance a prerequisite for other (more) salient products, like mortgage. (iv) They do not rely on ad-hoc governmental relief, but there are clear regulations and dedicated public funds for post-disaster compensation. The system that presents most of these features and currently performs best at achieving high take-up rates appears to be the Danish one. It is important to remember, however, that there is no one-size-fits-all solution. Different countries have different environmental, cultural and socioeconomic characteristics, and so each climate insurance system should develop to align with the needs of its specific national context. In addition, while flat/fixed rates appear to perform best, we maintain the conviction that premiums should be risk-based, with support to lower-income groups coming from public interventions and not cross-subsidisation from other policyholders. However, additional measures should accompany risk-based premiums to incentivize investments in risk reduction, integrating insurance in a holistic risk management framework.

Table 6.1: Summary of national climate insurance systems' characteristics

Feature	Results and considerations
Supply system and coverage requirements	Voluntary market-based systems do not have any requirement for coverage against natural hazards foreseen. The highest penetration rates are found in countries recurrently affected by large floods (e.g., Germany and Czech Republic), but this is at most 50%. In some market-based systems, mortgage lenders require coverage against certain climate hazards as a condition for underwriting. This creates a de facto mandatory condition for homeowners, which typically leads to higher penetration rates (e.g., Ireland, UK). In PPP systems, the state plays some form of active role in collaboration with the national insurance industry. The aim is typically to create a solidaristic and financially sustainable regime which achieved the widest rate of coverage (e.g., France). These usually present some form of mandatory requirements (e.g., Belgium) or surcharge on other insurance products (e.g., Spain). Finally, in some countries the state provides direct financial coverage against natural hazards. Public institutions can hold a monopoly on all (e.g., Iceland) or only extreme (e.g., Denmark) climate hazards, imposing a general legal requirement of underwriting to all asset owners in the countries. These systems are solidaristic, have high of penetration rate and are, for the moment, financially sustainable.
Premium structure	Risk-based premiums characterise most market-based systems. They reflect individual levels of climate risk, and, as such, they can act as a signalling tool for policyholders, incentivising investments private protection measures. However, they may bring issue of unaffordability in high-risk areas (e.g., Ireland), and their ability to stimulate investment in risk reduction is still limited (e.g., Italy). Flat rates (on asset value) or fixed fees are the typical solutions to apply the solidaristic principle. They entail cross-subsidisation (across geographic areas and/or policyholders), enhancing affordability. However, they require some forms of mandatory requirements to expand risk pools. In addition, they do not incentives private risk-reduction (which risks creating moral hazard), so they should be accompanied by complementary measures. Mixed systems, in the likes of France, Spain, Denmark and the UK seem better suited for enhancing take-up rates among households and businesses.
Reinsurance system	Most European systems are based commercial reinsurance and on the industry's ability to transfer risk to international capital markets. The state, if involved in the national climate insurance system, can provide reinsurance options (e.g., France, Spain) or act as a reinsurance monopolist (e.g. Belgium) at lower costs. The sole public entity not transferring risk is the Danish Storm Council.
Ex ante public guarantee	State guarantee brings the most advantages when put on the solvency of public (e.g., Denmark, Iceland) or PPP (e.g., France, Spain) entities. This is due to their ability to raise capital on the international financial market at

	advantageous rates. In the UK, public guarantee on extreme tail risk allows the system to be financially sustainable and generally affordable. The public guarantor role should not be limited (as in Italy), so as not to entail the risk of default for the industry in case of large events.
Ex post relief system	Ad hoc measures are the most counterproductive approach to manage relief and financial recovery, as they create structural charity hazards (e.g., Germany, Italy), impose ambiguity in the time and entity of aid the affected stakeholders will receive. They may cause low penetration rates, and can sometimes penalise households and businesses that signed up for private coverage (e.g., Slovenia). Most European countries have dedicated public funds for post-disaster compensation, financed through annual financial budgets. They can be administered nationally or locally, and are typically matched with strong checks on claims (e.g. Austria, Croatia). They bring more financial sustainability for the recovery after sizable catastrophes than ad hoc interventions. Some countries do not have public post-disaster public compensation (e.g., France, UK, or the Swiss cantons with public monopolies). The systems have typically reached high penetration rates and have a strong public involvement, which virtually removes the need for ex post public relief.

Chapter 4 presents the results of the literature review on the drivers of the climate insurance protection gap. Considerably more studies analyse demand-side factors (Chapter 4.1) than supply-side ones (Chapter 4.2). Also, the majority of the academic literature focuses on flood risk/insurance, while there is a considerably smaller representation of other hazards, with wind, storms and droughts being those more frequently considered. There is a similar disparity also for what concerns the countries investigated. In Europe, the countries that have received the most attention are Germany, the Netherlands, the UK, France and Italy. The same considerations apply also to Chapter 5, since the pool of documents is the same.

Table 6.2 and Table 6.3 summarise the main outcomes emerging from the review of the literature on demand-side and supply-side factors, respectively.

Chapter 4.3 also presents a discussion of data availability/sharing and fairness/justice issues. Regarding the former, what emerges is that data on the impact of climatic events is considerably less readily available than hazard data. This is often due to the additional costs connected to the collection and disclosure of this information, as well as to privacy reasons. Impact data also presents less standardisation in processing and representation practices. As regards the latter, there does not appear to be a unique view of what justice and fairness mean in the context of climate insurance. Nevertheless, most authors report that the present climate insurance regimes do not perform particularly well on the justice front. And this issue is likely going to be aggravated by climate change. Both these topics would benefit from a greater cooperation between the insurance sector, public administrations and other relevant stakeholders.

Table 6.2: Summary of demand-side drivers of IPG

Factor	Observed effect on uptake	Results and considerations
Imperfect information about risk	Negative	Several studies suggest that people tend to have a low perception of climatic and natural risks, despite living in risk-prone areas. Previous experience with risk and social capital are important determinants in shaping people's risk knowledge. Lower perceived risk decreases the demand for climate insurance.
Imperfect information about low-probability events	Negative	A few empirical and experimental studies have documented the presence of a "LPHI-HILP puzzle" for climate insurance uptake.
Charity hazard	Negative	While several papers find evidence of a negative effect of governmental compensation on the demand for climate insurance, the majority are experimental or theoretical analyses. There are few empirical studies based on real-world observational data.
Affordability	Negative	Both income and price are found to be important determinants of the decision to purchase climate insurance. Unaffordability issues are expected to become particularly relevant with risk-based pricing under climate change.
Risk aversion	Ambiguous	Most of the literature finds a positive effect (as expected). However, some studies also evidence a negative impact, primarily in the agriculture sector.
Ambiguity aversion	Ambiguous	Theoretical and experimental studies find mixed evidence. There is almost no empirical investigation using real-world observational data.
Status quo bias	As expected	Still underinvestigated. The phenomenon is mostly studied as a potential driver for greater uptake (see also Chapter 5.1.3). The results suggest that making climate coverage a default in insurance policies increases uptake.

Availability bias	As expected	Most of the studies focus on agents' experience with climate events and losses. The experience with (climate) insurance products is still underivestigated. The results suggest that agents with more experience have higher demand for climate coverage.
Herding	As expected	Still underinvestigated. The phenomenon is mostly studied in the context of positive impacts of social networks on climate insurance uptake.
Level of concern	As expected	Mostly experimental studies. Having a lower threshold level of concern reduces the demand for climate insurance.
Demographics	Ambiguous	Older and more educated individuals are generally more likely to have insurance. Some papers reveal a negative impact of either age, or education, or both.
Financial literacy	Positive	Limited financial literacy or a lack of understanding of insurance products are important factors that reduce the uptake of insurance. Knowledge of probability is more important than financial literacy per se.
Tenancy	Negative	Tenants are less likely than property owners to have climate insurance. Some findings from the agricultural sector seem to suggest that tenancy has a positive impact on insurance.
Imperfect knowledge of own coverage	Negative	Some households may incorrectly assume that certain hazards are included in their policy when in fact they are not. Not empirically tested.
Attribution of responsibility	Negative	Mostly investigated in the context of risk preparedness and protections more broadly. Evidence of the impact on the demand for insurance is still limited. In some countries, there is the belief that the responsibility of protection falls on the state and public administrations, which correlates with lower insurance uptake.
Trust	Positive	Lack of trust in insurance and/or financial institutions decreases uptake. Both empirical and experimental evidence.

Fatalism and wishful thinking	Negative	When people perceive they do not have control over events, they are less likely to insure. Less attention has been paid to wishful thinking.
Substitutability	No	Most empirical and experimental investigations do not find evidence in support of the claim that agents view risk-reduction measures and insurance as substitutes. Conversely, some evidence of advantageous selection has been detected.

Table 6.3: Summary of supply-side drivers of IPG

Factor	Observed effect on supply	Results and considerations
Insurability	NA	Climatic risks may break several requirements of insurability – e.g., due to uncertainty in probability and magnitude of event, correlation of losses, high catastrophic potential. Climate change exacerbates these issues, but there are challenges to integrate it into actuarial models.
Capital costs	Negative	Insurers have to hold large reserves of capital to ensure solvency, these extra costs are passed on to consumers. External capital (e.g., reinsurance) is more expensive than internal one. Can also distort managerial decision-making.
Moral hazard	Ambiguous	Theoretical studies confirm the negative effect of moral hazards. Results from empirical and experimental studies on the presence of moral hazards are mixed.
Adverse selection	Negative	Most of the studies confirm that areas at higher risk are more likely to demand insurance. Insurers then have to raise premiums.

Chapter 5 presented the results of the literature review on the potential innovations and opportunities to address the barriers reported in Chapter 4 and help closing the climate insurance protection gap. Overall, the number of studies that conduct an empirical or experimental analysis of such innovations is considerably smaller than those focusing on the barriers. Also, only a subset of such studies actually deals with climate insurance, so in this examination we had to widen the scope of the review and source information from several disciplines. On the one hand, this is not surprising, since new practices have inevitably had less time to be investigated. And a certain degree of extrapolation was expected given the very nature of innovations. On the other hand, however, further research and practical applications through pilot studies will have to be conducted to effectively evaluate the potential of these innovations and to develop business models and guiding principles. The PIISA project aims to do that with its innovation activities in WPs 2-3, and the information contained in this report should provide the necessary knowledge and foundation to facilitate such activities.

Tables 6.4-6.7 summarise the main outcomes emerging from the review of the literature on, respectively, the innovations in terms of insurance products' characteristics (Chapter 5.1); the alternative forms of insurance and risk transfer instruments different from indemnity insurance (Chapter 5.2); the advancements in data collection, processing and analysis techniques (Chapter 5.3); and, the potential for strengthening the collaboration between the insurance industry and other stakeholders (Chapter 5.4).

Table 6.4: Summary of product characteristics innovations

Innovation	Observed effect on uptake	Results and considerations
Multi-year contracts	Positive	Several empirical and experimental studies suggest they would increase the demand for climate insurance. However, they are still not widely adopted. Some disadvantages: higher premiums, climate change reduces pricing accuracy.
Bundling	Positive	Linking climate coverage to other products (e.g., mortgage or fire insurance) increases take-up. Evidence on the effectivenss of multi-peril policies is still limited.
Opt-out contracts	Positive	Two experimental studies show that opt-out contracts could increase take-up, but effect varies depending on the context. No empirical investigation was found.
Premium discounts	Ambiguous	Offering premium discounts to investment in risk reduction is often advocated as a promising measure, but it seems that in reality they are not as effective as predicated.
Subsidies	Ambiguous	Increase uptake but reduce incentives to invest in risk reduction. Should come from public budgets and not premium cross-subsidization.

Means-tested vouchers + loans	Positive	Can improve affordability and uptake without crowding out risk reduction. Investigations only "theoretical" in the US. No loan programs has been successful in practice so far.

Table 6.5: Summary of innovative insurance risk transfer products

Innovation	Results and considerations
Parametric insurance	Most research and products focus on developing countries. In developed countries mostly agriculture sector. Index-based insurance can eliminate moral hazard and adverse selection problems. However, basis risk remains a limitation in the eyes of consumers, especially more risk-averse ones, which reduces its diffusion.
ILS	Designed to transfer risk from insurance companies or governments to investors in the capital markets. Increase diversification, enhance liquidity, international investors are more risk-neutral than national agents. CAT bonds promote price discovery and transparency, encouraging competition and innovation in risk transfer mechanisms. Parametric ones are more efficient than indemnity-based. Preferable to standard reinsurance in cases of high reinsurer default risk, low basis risk and in high-risk layers. However, mostly restricted to larger agents (small insurers and SMEs do not issue them).
Microinsurance	Product tailored to the needs of low-income households. Often have clear-cut terms, limited coverage and lower premiums. Allow to reach unserved areas and segments of the population. Still does not properly address other demand-side barriers like lack of trust, information asymmetries, lack of financial literacy.
Takaful	A form of Islamic insurance that proceeds from the principle of mutual assistance and shared risk, in harmony with Islamic law. Can be valuable tool given the growing share of Muslim community in Europe. Challenges: ensuring Shariah compliance increases operational costs and limits innovation; lack of standardised regulations and low consumer awareness challenge its growth.
Insuretech	Application of data innovations (blockchain, AI, DLT, machine learning, remote sensing) to insurance.

Decentralised insurance	Insurance systems and mechanisms that function without central authorities or intermediaries. Advantages: transparency, security, and trust among participants Challenges: regulatory uncertainty, as the legislative landscape is still evolving and could significantly differ across jurisdictions; scalability could represent another concern.
Ecosystem-based insurance	Studies confirm the effectiveness of ecosystem-based insurance in promoting environmental conservation, enhancing resilience to climate change, and closing the protection gap. Challenges: complexity of measuring and quantifying ecosystem services; climate change increases uncertainty on the performance of NbS in the future; public goods issues.

Table 6.6: Summary of innovations in data collection and processing

Innovation	Results and considerations
Drone imagery	There are very few studies focusing on insurance, so expected advantages have not been tested empirically. It has the potential to enable rapid and accurate damage estimation and claim settlement following disasters. It can also improve risk assessment thanks to the collection of detailed micro-level data, which can improve underwriting. It presents coverage limitations, and still requires human input on the ground.
Satellite imagery	Most of the insurance literature considers satellite imagery in relation to parametric products for policy design and event triggering. It provides comprehensive data on climate-related events, allowing for a better assessment and pricing of catastrophic risks, and it has the potential to improve underwriting accuracy. Opportunities to be used for damage estimation in indemnity contracts is underexplored. It is highly dependent on weather conditions and terrain morphology, so data accuracy can vary.
Blockchain	There are very few studies focusing on climate insurance. Blockchain enhances transparency, allowing for a reduction in information asymmetries and greater trust. It has the potential to enable rapid claim settlements and improve customer satisfaction.
AI	There are very few studies focusing on climate insurance. It has the potential to improve the accuracy of risk assessment due to the ability to process vast amounts of data, which can enhance the pricing of catastrophic risks and underwriting. It can also enable rapid claim settlements, allow the development of personalised policies and improve customer satisfaction. There remain concerns about the transparency of the underlying process,

	the accuracy of the output generated by AI and the ultimate responsibility for its decisions.
Cybersecurity	It is not explored yet in the context of climate insurance. If the industry continues to move toward a greater digitalization, it could become a serious issue. At present, cyber risk is regarded as a bigger protection gap than natural catastrophes.

Table 6.7: Summary of opportunities for enhanced collaboration

Opportunity for collaboration	Benefits	Barriers
Between insurers	Improves diversification. Increases resources to finance extreme losses. Helps ensuring the solvency of the insurance industry.	Regulation limiting cooperation due to anti-competitive behaviour. Unwillingness to share information with competitors.
With construction companies	Constructors could include protection measures in their projects, leveraging insurance schemes with competitive terms as a selling point.	Lack of communication channels.
With public administrations and planners	It can prevent development in high-risk zones and ensures constructions according to minimum standards, which would reduce the exposure on the insurance sector.	Lack of clear ownership and responsibility for risk management. Instability of political preferences.
Multi-actor, multi-sector	Collaboration across stakeholders can help adapt insurance arrangements to changing situations. Enhance the risk reduction capabilities of insurance schemes, reducing the pressure on insurance mechanisms and improving affordability.	Lack of clear ownership and responsibility for risk management. Lack of coordination in managing certain risks. Lack of communication channels.

To conclude, this report has highlighted that, despite the numerous postulated benefits of climate insurance (see, among others, Botzen, 2013; Kunreuther & Michel-Kerjan, 2013; Surminski, 2014), the diffusion of coverage against climatic risk in Europe is still limited (EIOPA, 2023b), and with considerable differences across countries, hazards and sectors. This is a result of limitations in the insurability of climatic events, especially more severe ones, which couples with several barriers (economic, psychological, cultural, regulatory) that further obstruct the diffusion of climate insurance. In addition, in order to fulfill its risk reduction potential as postulated by the Sendai framework (Mysiak et al., 2016), climate risk insurance should more effectively be incorporated in the 'Loss & Damage' framework. This would require a major overhaul with innovative approaches and sourcing new and additional finance (Nordlander et al., 2020), and should be accompanied by enhanced international cooperation around insurance as a climate risk management tool (Schäfer et al., 2019).

Bibliography

Abdikerimova, S., & Feng, R. (2022). Peer-to-peer multi-risk insurance and mutual aid. European Journal of Operational Research, 299(2), 735–749. https://doi.org/10.1016/j.ejor.2021.09.017

Abdou, H. A., Khurshid, A., & Lister, R. J. (2014). A comparative study of Takaful and conventional insurance: Empirical evidence from the Malaysian market. Insurance Markets and Companies: Analyses and Actuarial Computations, 5(1). https://www.proquest.com/docview/2622625411/citation/BD5F4A9186214661PQ/1

Agarwal, S., Bhardwaj, G., Saraswat, E., Singh, N., Aggarwal, R., & Bansal, A. (2022). Insurtech Fostering Automated Insurance Process using Deep Learning Approach. 2022 2nd International Conference on Innovative Practices in Technology and Management (ICIPTM), 2, 386–392. https://doi.org/10.1109/ICIPTM54933.2022.9753891

Agbenyo, W., Jiang, Y., Wang, J., Ntim-Amo, G., Dunya, R., & Frempong, L. N. (2024). Does weather index-based insurance adoption influence Cocoa Output? An endogenous swicth regression approach. Climate and Development, 16(1), 77–86. https://doi.org/10.1080/17565529.2023.2179868

Ahmed Salman, S. (2014). Contemporary Issues in Takaful (Islamic Insurance). Asian Social Science, 10(22), p210. https://doi.org/10.5539/ass.v10n22p210

Akerlof, G. A. (1970). The Market for «Lemons»: Quality Uncertainty and the Market Mechanism. The Quarterly Journal of Economics, 84(3), 488. https://doi.org/10.2307/1879431

Alfieri, L., Feyen, L., Dottori, F., & Bianchi, A. (2015). Ensemble flood risk assessment in Europe under high end climate scenarios. Global Environmental Change, 35, 199–212. https://doi.org/10.1016/j.gloenvcha.2015.09.004

Andor, M. A., Osberghaus, D., & Simora, M. (2020). Natural Disasters and Governmental Aid: Is there a Charity Hazard? Ecological Economics, 169, 106534. https://doi.org/10.1016/j.ecolecon.2019.106534

Andráško, I., Dolák Klemešová, K., Dolák, L., Trojan, J., & Fiedor, D. (2020). "Surely it will come again…". Flood threat appraisal, mitigation strategies and protection motivation in Czech communities endangered by floods. Moravian Geographical Reports, 28(3), 170–186. https://doi.org/10.2478/mgr-2020-0013

Anh, N. V., & Duc, T. M. (2024). Big Data-Driven Predictive Modeling for Pricing, Claims Processing and Fraud Reduction in the Insurance Industry Globally. International Journal of Responsible Artificial Intelligence, 14(2), Articolo 2.

Atreya, A., Ferreira, S., & Michel-Kerjan, E. (2015). What drives households to buy flood insurance? New evidence from Georgia. Ecological Economics, 117, 153–161. https://doi.org/10.1016/j.ecolecon.2015.06.024

Babcicky, P., & Seebauer, S. (2017). The two faces of social capital in private flood mitigation: Opposing effects on risk perception, self-efficacy and coping capacity. Journal of Risk Research, 20(8), 1017–1037. https://doi.org/10.1080/13669877.2016.1147489

Bantwal, V. J., & Kunreuther, H. C. (2000). A Cat Bond Premium Puzzle? Journal of Psychology and Financial Markets, 1(1), 76–91. https://doi.org/10.1207/S15327760JPFM0101_07

Barnett, B. J., & Mahul, O. (2007). Weather Index Insurance for Agriculture and Rural Areas in

Lower-Income Countries. American Journal of Agricultural Economics, 89(5), 1241–1247. https://doi.org/10.1111/j.1467-8276.2007.01091.x

Barocas, S., & Selbst, A. D. (2016). Big Data's Disparate Impact Essay. California Law Review, 104(3), 671–732.

Barreal, J., Loureiro, M. L., & Picos, J. (2014). On insurance as a tool for securing forest restoration after wildfires. Forest Policy and Economics, 42, 15–23. https://doi.org/10.1016/j.forpol.2014.02.001

Barry, L. (2020). Insurance, Big Data and Changing Conceptions of Fairness. European Journal of Sociology, 61(2), 159–184. https://doi.org/10.1017/S0003975620000089

Baumgärtner, S. (2007). THE INSURANCE VALUE OF BIODIVERSITY IN THE PROVISION OF ECOSYSTEM SERVICES. Natural Resource Modeling, 20(1), 87–127. https://doi.org/10.1111/j.1939-7445.2007.tb00202.x

Belissa, T. K., Lensink, R., & Van Asseldonk, M. (2020). Risk and ambiguity aversion behavior in index-based insurance uptake decisions: Experimental evidence from Ethiopia. Journal of Economic Behavior & Organization, 180, 718–730. https://doi.org/10.1016/j.jebo.2019.07.018

Benami, E., Jin, Z., Carter, M. R., Ghosh, A., Hijmans, R. J., Hobbs, A., Kenduiywo, B., & Lobell, D. B. (2021). Uniting remote sensing, crop modelling and economics for agricultural risk management. Nature Reviews Earth & Environment, 2(2), 140–159. https://doi.org/10.1038/s43017-020-00122-y

Berger, L., & Bosetti, V. (2020). Characterizing ambiguity attitudes using model uncertainty. Journal of Economic Behavior & Organization, 180, 621–637. https://doi.org/10.1016/j.jebo.2020.02.014

Bernard, C., Liu, F., & Vanduffel, S. (2020). Optimal insurance in the presence of multiple policyholders. Journal of Economic Behavior & Organization, 180, 638–656. https://doi.org/10.1016/j.jebo.2020.02.012

Bernardino, G. (2020). Challenges and opportunities for the insurance sector in Europe. Annales des Mines - Réalités industrielles, Février 2020(1), 99–102. https://doi.org/10.3917/rindu1.201.0099

Bianconi, R. (2020, settembre 9). An Introduction to Weather Derivatives. Medium. https://medium.com/@remy.bianconi/an-introduction-to-weather-derivatives-5d6726e2ed54

Biener, C., & Eling, M. (2012). Insurability in Microinsurance Markets: An Analysis of Problems and Potential Solutions. The Geneva Papers on Risk and Insurance - Issues and Practice, 37(1), 77–107. https://doi.org/10.1057/gpp.2011.29

Biener, C., & Eling, M. (2016). Can Group Incentives Alleviate Moral Hazard? The Role of Pro-Social Preferences. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.2783412

Binswanger-Mkhize, H. P. (2012). Is There Too Much Hype about Index-based Agricultural Insurance? Journal of Development Studies, 48(2), 187–200. https://doi.org/10.1080/00220388.2011.625411

Born, P. H., & Klimaszewski-Blettner, B. (2013). Should I Stay or Should I Go? The Impact of Natural Disasters and Regulation on U.S. Property Insurers' Supply Decisions. Journal of Risk and Insurance, 80(1), 1–36. https://doi.org/10.1111/j.1539-6975.2012.01477.x

Botzen, W. J. W. (2013). Managing Extreme Climate Change Risks through Insurance (1st ed.). Cambridge University Press. https://doi.org/10.1017/CBO9781139519540

Botzen, W. J. W., Aerts, J. C. J. H., & Van Den Bergh, J. C. J. M. (2009a). Dependence of flood risk perceptions on socioeconomic and objective risk factors. Water Resources Research, 45(10), 2009WR007743. https://doi.org/10.1029/2009WR007743

Botzen, W. J. W., Aerts, J. C. J. H., & Van Den Bergh, J. C. J. M. (2009b). Willingness of homeowners to mitigate climate risk through insurance. Ecological Economics, 68(8–9), 2265–2277. https://doi.org/10.1016/j.ecolecon.2009.02.019

Botzen, W. J. W., & Bouwer, L. M. (2016). Weather Indicators for Insured Hailstorm Damage to Motor Vehicles and Potential Climate Change Impacts. The Geneva Papers on Risk and Insurance - Issues and Practice, 41(3), 512–527. https://doi.org/10.1057/gpp.2015.16

Botzen, W. J. W., Kunreuther, H., & Michel-Kerjan, E. (2015). Divergence between individual perceptions and objective indicators of tail risks: Evidence from floodplain residents in New York City. Judgment and Decision Making, 10(4), 365–385. https://doi.org/10.1017/S1930297500005179

Botzen, W. J. W., Kunreuther, H., & Michel-Kerjan, E. (2019). Protecting against disaster risks: Why insurance and prevention may be complements. Journal of Risk and Uncertainty, 59(2), 151–169. https://doi.org/10.1007/s11166-019-09312-6

Botzen, W. J. W., & Van Den Bergh, J. C. J. M. (2009). Managing natural disaster risks in a changing climate. Environmental Hazards, 8(3), 209–225. https://doi.org/10.3763/ehaz.2009.0023

Botzen, W. J. W., & Van Den Bergh, J. C. J. M. (2012a). MONETARY VALUATION OF INSURANCE AGAINST FLOOD RISK UNDER CLIMATE CHANGE. International Economic Review, 53(3), 1005–1026. https://doi.org/10.1111/j.1468-2354.2012.00709.x

Botzen, W. J. W., & Van Den Bergh, J. C. J. M. (2012b). Risk attitudes to low-probability climate change risks: WTP for flood insurance. Journal of Economic Behavior & Organization, 82(1), 151–166. https://doi.org/10.1016/j.jebo.2012.01.005

Bouwer, L. M., Huitema, D., & Aerts, C. J. H. (2007). Adaptive flood management: The role of insurance and compensation in Europe (W-07/08). Vrije Universiteit. https://edepot.wur.nl/62342

Bracci, E., Tallaki, M., Ievoli, R., & Diplotti, S. (2021). Knowledge, diffusion and interest in blockchain technology in SMEs. Journal of Knowledge Management, 26(5), 1386–1407. https://doi.org/10.1108/JKM-02-2021-0099

Bradt, J. T., Kousky, C., & Wing, O. E. J. (2021). Voluntary purchases and adverse selection in the market for flood insurance. Journal of Environmental Economics and Management, 110, 102515. https://doi.org/10.1016/j.jeem.2021.102515

Brahm, M., Vila, D., Martinez Saenz, S., & Osgood, D. (2019). Can disaster events reporting be used to drive remote sensing applications? A Latin America weather index insurance case study. Meteorological Applications, 26(4), 632–641. https://doi.org/10.1002/met.1790

Breckner, M., Englmaier, F., Stowasser, T., & Sunde, U. (2016). Resilience to natural disasters—Insurance penetration, institutions, and disaster types. Economics Letters, 148, 106–110. https://doi.org/10.1016/j.econlet.2016.09.023

Brockett, P. L., Wang, M., & Yang, C. (2005). Weather Derivatives and Weather Risk

Management. Risk Management and Insurance Review, 8(1), 127–140. https://doi.org/10.1111/j.1540-6296.2005.00052.x

Browne, M. J., & Hoyt, R. E. (2000). The Demand for Flood Insurance: Empirical Evidence. Journal of Risk and Uncertainty, 20(3), 291–306. https://doi.org/10.1023/A:1007823631497

Browne, M. J., Knoller, C., & Richter, A. (2015). Behavioral bias and the demand for bicycle and flood insurance. Journal of Risk and Uncertainty, 50(2), 141–160. https://doi.org/10.1007/s11166-015-9212-9

Bruggeman, V., & Faure, M. (2019). The Compensation for Victims of Disasters in Belgium, France, Germany, and the Netherlands. Loyola Consumer Law Review, 31.

Brunette, M., Cabantous, L., Couture, S., & Stenger, A. (2013). The impact of governmental assistance on insurance demand under ambiguity: A theoretical model and an experimental test. Theory and Decision, 75(2), 153–174. https://doi.org/10.1007/s11238-012-9321-8

Bryan, G. (2010). Ambiguity and insurance [Unpublished manuscript]. https://pdfs.semanticscholar.org/131f/224c121a377b0d675f43155f0f2245a3041a.pdf?_ga=2.125464524.732340984.1564399767-2060515288.1564399767

Bubeck, P., Botzen, W. J. W., & Aerts, J. C. J. H. (2012). A Review of Risk Perceptions and Other Factors that Influence Flood Mitigation Behavior. Risk Analysis, 32(9), 1481–1495. https://doi.org/10.1111/j.1539-6924.2011.01783.x

Buchanan, J. M. (1975). The Samaritan's Dilemma. In Altruism, Morality and Economic Theory (pp. 71–85). E. S. Phelps.

Bulte, E., Cecchi, F., Lensink, R., Marr, A., & Van Asseldonk, M. (2020). Does bundling crop insurance with certified seeds crowd-in investments? Experimental evidence from Kenya. Journal of Economic Behavior & Organization, 180, 744–757. https://doi.org/10.1016/j.jebo.2019.07.006

Buzzacchi, L., & Turati, G. (2014). Optimal Risk Allocation in the Provision of Local Public Services: Can a Private Insurer be Better Than a Federal Relief Fund? CESifo Economic Studies, 60(4), 747–779. https://doi.org/10.1093/cesifo/ifu024

Cai, H., Chen, Y., Fang, H., & Zhou, L.-A. (2015). The Effect of Microinsurance on Economic Activities: Evidence from a Randomized Field Experiment. Review of Economics and Statistics, 97(2), 287–300. https://doi.org/10.1162/REST_a_00476

Cai, J., & Song, C. (2017). Do disaster experience and knowledge affect insurance take-up decisions? Journal of Development Economics, 124, 83–94. https://doi.org/10.1016/j.jdeveco.2016.08.007

Cappiello, A. (2018). Digital Disruption and InsurTech Start-ups: Risks and Challenges. In A. Cappiello (Eds.), Technology and the Insurance Industry: Re-configuring the Competitive Landscape (pp. 29–50). Springer International Publishing. https://doi.org/10.1007/978-3-319-74712-5_3

Carter, M., De Janvry, A., Sadoulet, E., & Sarris, A. (2015). Assurance climatique indicielle pour les pays en développement: Examen des faits et propositions visant à augmenter le taux de souscription: Revue d'économie du développement, Vol. 23(1), 5–57. https://doi.org/10.3917/edd.291.0005

Carter, M., De Janvry, A., Sadoulet, E., & Sarris, A. (2017). Index Insurance for Developing Country Agriculture: A Reassessment. Annual Review of Resource Economics, 9(1), 421–438.

https://doi.org/10.1146/annurev-resource-100516-053352

Carter, R. L., & Dickinson, G. M. (1992). Obstacles to the Liberalization of Trade in Insurance. (2012/04/20 ed., Vol. 120). Cambridge University Press; Cambridge Core. https://www.cambridge.org/core/product/F314714D4DC5B730E0250216F7567E3F

Castillo, M. J., Boucher, S., & Carter, M. (2016). Index Insurance: Using Public Data to Benefit Small-Scale Agriculture. International Food and Agribusiness Management Review. https://doi.org/10.22004/ag.econ.240698

CCR. (2021). Natural Disaster Compensation Scheme in France, Principles and Operation. https://www.ccr.fr/documents/35794/35836/indemnisation+cat-nat.pdf/ff905a8f-ccb3-44e2-a0d0-b92c6d2e352e?t=1452598764000

Cesari, R., & D'Aurizio, L. (2019). Calamità naturali e coperture assicurative: Valutazione dei rischi e policy options per il caso italiano (13; Quaderni). IVASS. https://www.ivass.it/pubblicazioni-e-statistiche/pubblicazioni/quaderni/2019/iv13/index.html

Cesarini, L., Figueiredo, R., Monteleone, B., & Martina, M. L. V. (2021). The potential of machine learning for weather index insurance. Natural Hazards and Earth System Sciences, 21(8), 2379–2405. https://doi.org/10.5194/nhess-21-2379-2021

Charpentier, A. (2008). Insurability of Climate Risks. The Geneva Papers on Risk and Insurance - Issues and Practice, 33(1), 91–109. https://doi.org/10.1057/palgrave.gpp.2510155

Charpentier, A., Barry, L., & James, M. R. (2022). Insurance against natural catastrophes: Balancing actuarial fairness and social solidarity. The Geneva Papers on Risk and Insurance - Issues and Practice, 47(1), 50–78. https://doi.org/10.1057/s41288-021-00233-7

Christophers, B. (2019). The allusive market: Insurance of flood risk in neoliberal Britain. Economy and Society, 48(1), 1–29. https://doi.org/10.1080/03085147.2018.1547494

Clarke, D. J. (2016). A Theory of Rational Demand for Index Insurance. American Economic Journal: Microeconomics, 8(1), 283–306. https://doi.org/10.1257/mic.20140103

Clement, K. Y., Wouter Botzen, W. J., Brouwer, R., & Aerts, J. C. J. H. (2018). A global review of the impact of basis risk on the functioning of and demand for index insurance. International Journal of Disaster Risk Reduction, 28, 845–853. https://doi.org/10.1016/j.ijdrr.2018.01.001

Cole, S., Giné, X., Tobacman, J., Topalova, P., Townsend, R., & Vickery, J. (2013). Barriers to Household Risk Management: Evidence from India. American Economic Journal: Applied Economics, 5(1), 104–135. https://doi.org/10.1257/app.5.1.104

Collier, B., Skees, J., & Barnett, B. (2009). Weather Index Insurance and Climate Change: Opportunities and Challenges in Lower Income Countries. The Geneva Papers on Risk and Insurance - Issues and Practice, 34(3), 401–424. https://doi.org/10.1057/gpp.2009.11

Conte, M. N., & Kelly, D. L. (2018). An imperfect storm: Fat-tailed tropical cyclone damages, insurance, and climate policy. Journal of Environmental Economics and Management, 92, 677–706. https://doi.org/10.1016/j.jeem.2017.08.010

Cornia, A., Dressel, K., & Pfeil, P. (2016). Risk cultures and dominant approaches towards disasters in seven European countries. Journal of Risk Research, 19(3), 288–304. https://doi.org/10.1080/13669877.2014.961520

Cotrufo, S., Sandu, C., Giulio Tonolo, F., & Boccardo, P. (2018). Building damage assessment scale tailored to remote sensing vertical imagery. European Journal of Remote Sensing, 51(1), 991–1005. https://doi.org/10.1080/22797254.2018.1527662

Coughlan De Perez, E., Van Den Hurk, B., Van Aalst, M. K., Amuron, I., Bamanya, D., Hauser, T., Jongma, B., Lopez, A., Mason, S., Mendler De Suarez, J., Pappenberger, F., Rueth, A., Stephens, E., Suarez, P., Wagemaker, J., & Zsoter, E. (2016). Action-based flood forecasting for triggering humanitarian action. Hydrology and Earth System Sciences, 20(9), 3549–3560. https://doi.org/10.5194/hess-20-3549-2016

Cummins, J. D. (2008). CAT Bonds and Other Risk-Linked Securities: State of the Market and Recent Developments. Risk Management and Insurance Review, 11(1), 23–47. https://doi.org/10.1111/j.1540-6296.2008.00127.x

Cummins, J. D., & Barrieu, P. (2013). Innovations in Insurance Markets: Hybrid and Securitized Risk-Transfer Solutions. In G. Dionne (Eds.), Handbook of Insurance (pp. 547–602). Springer. https://doi.org/10.1007/978-1-4614-0155-1_20

Cyprus Civil Defence. (2020). Report on Disaster Risk Management in the Repubblic of Cyprus. https://www.moi.gov.cy/moi/CD/cd.nsf/All/CD5C4F5974A63727C22586A2003CF5AC/$file/2020%20DRM%20REPORT.pdf?OpenElement

Davlasheridze, M., & Miao, Q. (2019). Does Governmental Assistance Affect Private Decisions to Insure? An Empirical Analysis of Flood Insurance Purchases. Land Economics, 95(1), 124–145. https://doi.org/10.3368/le.95.1.124

Davoudi, S., & Brooks, E. (2012). Environmental Justice and the City: Full Report. Newcastle University, Global Urban Research Unit. https://www.ncl.ac.uk/mediav8/apl/files/guru-ewp/ewp48.pdf

De Leeuw, J., Vrieling, A., Shee, A., Atzberger, C., Hadgu, K. M., Biradar, C. M., Keah, H., & Turvey, C. (2014). The Potential and Uptake of Remote Sensing in Insurance: A Review. Remote Sensing, 6(11), Articolo 11. https://doi.org/10.3390/rs61110888

De Masi, F., & Porrini, D. (2018). Vulnerability to Natural Disasters and Insurance: Insights from the Italian Case. International Journal of Financial Studies, 6(2), 56. https://doi.org/10.3390/ijfs6020056

De Moel, H., Jongman, B., Kreibich, H., Merz, B., Penning-Rowsell, E., & Ward, P. J. (2015). Flood risk assessments at different spatial scales. Mitigation and Adaptation Strategies for Global Change, 20(6), 865–890. https://doi.org/10.1007/s11027-015-9654-z

DEFRA. (2014). Managing the future financial risk of flooding: Impact Assessment.

Demir, M., Turetken, O., & Ferworn, A. (2019). Blockchain Based Transparent Vehicle Insurance Management. 2019 Sixth International Conference on Software Defined Systems (SDS), 213–220. https://doi.org/10.1109/SDS.2019.8768669

Dercon, S., Gunning, J. W., & Zeitlin, A. (2019). The demand for insurance under limited trust: Evidence from a field experiment in Kenya [CSAE Working Paper WPS/2019-06]. https://ora.ox.ac.uk/objects/uuid:c59af3dd-67b8-4c10-b9b4-4536a8c5caf5/files/sqn59q4471

Deryugina, T., & Kirwan, B. (2018). DOES THE SAMARITAN'S DILEMMA MATTER? EVIDENCE FROM U.S. AGRICULTURE. Economic Inquiry, 56(2), 983–1006. https://doi.org/10.1111/ecin.12527

Diakakis, M., Priskos, G., & Skordoulis, M. (2018). Public perception of flood risk in flash flood prone areas of Eastern Mediterranean: The case of Attica Region in Greece. International Journal of Disaster Risk Reduction, 28, 404–413. https://doi.org/10.1016/j.ijdrr.2018.03.018

Dixon, L., Clancy, N., Miller, B., Hoegberg, S., Lewis, M., Bender, B., Ebinger, S., Hodges, M., Syck, G., Nagy, C., & Choquette, S. (2017). The Cost and Affordability of Flood Insurance in New York City: Economic Impacts of Rising Premiums and Policy Options for One- to Four-Family Homes. RAND Corporation. https://doi.org/10.7249/RR1776

Dudek, T., Ulm, E. R., & Noy, I. (2021). Demand for Multi-Year Catastrophe Insurance Contracts: Experimental Evidence for Mitigating the Insurance Gap (CESifo Working Paper 9442). https://www.cesifo.org/en/publications/2021/working-paper/demand-multi-year-catastrophe-insurance-contracts-experimental

Duus-Otterström, G., & Jagers, S. C. (2011). Why (most) climate insurance schemes are a bad idea. Environmental Politics, 20(3), 322–339. https://doi.org/10.1080/09644016.2011.573354

Eerola, T., Hakala, T., Järvinen, S., Korte, S., Myyrä, S., & Viljanen, S. (Forthcoming). Potential for agricultural insurance in the Boreal region [PIISA deliverable].

EIOPA. (2023a). Dashboard on insurance protection gap for natural catastrophes [dataset]. https://www.eiopa.europa.eu/tools-and-data/dashboard-insurance-protection-gap-natural-catastrophes_en

EIOPA. (2023b). Policy options to reduce the climate insurance protection gap (p. 48) [Discussion Paper]. European Insurance and Occupational Pension Authority. https://www.ecb.europa.eu/pub/pdf/other/ecb.policyoptions_EIOPA~c0adae58b7.en.pdf

EIOPA. (2024). Measures to address demand side aspects of the NATCAT protection gap (EIOPA-BoS-24/022; EIOPA Staff Paper). https://www.eiopa.europa.eu/document/download/be654e97-0428-4702-bd75-fb5d217e1960_en?filename=Revised%20Staff%20Paper%20on%20measures%20to%20address%20demand-side%20aspects%20of%20the%20NatCat%20protection%20gap.pdf

Eling, M., Nuessle, D., & Staubli, J. (2022). The impact of artificial intelligence along the insurance value chain and on the insurability of risks. The Geneva Papers on Risk and Insurance - Issues and Practice, 47(2), 205–241. https://doi.org/10.1057/s41288-020-00201-7

Ellsberg, D. (1961). Risk, Ambiguity, and the Savage Axioms. The Quarterly Journal of Economics, 75(4), 643. https://doi.org/10.2307/1884324

Eltazarov, S., Bobojonov, I., Kuhn, L., & Glauben, T. (2021). Mapping weather risk – A multi-indicator analysis of satellite-based weather data for agricultural index insurance development in semi-arid and arid zones of Central Asia. Climate Services, 23, 100251. https://doi.org/10.1016/j.cliser.2021.100251

Ender, M., & Zhang, R. (2015). Efficiency of weather derivatives for Chinese agriculture industry. China Agricultural Economic Review, 7(1), 102–121. https://doi.org/10.1108/CAER-06-2013-0089

Enz, R. (2000). The S-Curve Relation Between Per-Capita Income and Insurance Penetration. The Geneva Papers on Risk and Insurance - Issues and Practice, 25(3), 396–406. https://doi.org/10.1111/1468-0440.00072

European Commission. (2017). Insurance of weather and climate-related disaster risk: Inventory and analysis of mechanisms to support damage prevention in the EU : final report. Publications

Office. https://data.europa.eu/doi/10.2834/40222

European Commission. (2021). Closing the climate protection gap—Scoping policy and data gaps (127; Commission Staff Working Documents). European Commission. https://climate.ec.europa.eu/document/download/fcbc99b7-fab5-46e3-93b5-4bd5e27ad954_en?filename=swd_2021_123_en.pdf

European Commission. (2023). Approved 28 CAP Strategic Plans (2023-2027) Summary overview for 27 Member States Facts and figures. European Commission. https://agriculture.ec.europa.eu/system/files/2023-06/approved-28-cap-strategic-plans-2023-27.pdf

European Investment Bank. (2023). Investing in nature-based solutions: State of play and way forward for public and private financial measures in Europe. Publications Office. https://data.europa.eu/doi/10.2867/031133

Evans, L., Maio, G. R., Corner, A., Hodgetts, C. J., Ahmed, S., & Hahn, U. (2013). Self-interest and pro-environmental behaviour. Nature Climate Change, 3(2), 122–125. https://doi.org/10.1038/nclimate1662

Faiella, A., Menoni, S., Boni, M. P., Panoutsopoulou, M., Thoma, T., Salari, S., & Rueda, N. (2022). Enabling Knowledge through Structured Disaster Damage & Loss Data Management System. Sustainability, 14(10), 6187. https://doi.org/10.3390/su14106187

Fisher, E., Hellin, J., Greatrex, H., & Jensen, N. (2019). Index insurance and climate risk management: Addressing social equity. Development Policy Review, 37(5), 581–602. https://doi.org/10.1111/dpr.12387

Fox, C. R., & Tversky, A. (1995). Ambiguity Aversion and Comparative Ignorance. The Quarterly Journal of Economics, 110(3), 585–603. https://doi.org/10.2307/2946693

Frazier, T., Boyden, E. E., & Wood, E. (2020). Socioeconomic implications of national flood insurance policy reform and flood insurance rate map revisions. Natural Hazards, 103(1), 329–346. https://doi.org/10.1007/s11069-020-03990-1

Frezal, S., & Barry, L. (2020). Fairness in Uncertainty: Some Limits and Misinterpretations of Actuarial Fairness. Journal of Business Ethics, 167(1), 127–136. https://doi.org/10.1007/s10551-019-04171-2

Frigo, A., & Venturini, A. (2024). La copertura assicurativa contro i rischi naturali: Un’analisi preliminare (830; Questioni di Economia e Finanza). Banca d’Italia. https://www.bancaditalia.it/pubblicazioni/qef/2024-0830/index.html

Froot, K. A. (2001). The market for catastrophe risk: A clinical examination. Journal of Financial Economics, 60(2–3), 529–571. https://doi.org/10.1016/S0304-405X(01)00052-6

Furlanetto, J., Dal Ferro, N., Caceffo, D., & Morari, F. (2024). Mapping hailstorm damage on winter wheat (Triticum aestivum L.) using a microscale UAV hyperspectral approach. Precision Agriculture, 25(2), 681–703. https://doi.org/10.1007/s11119-023-10088-8

Furlanetto, J., Dal Ferro, N., Longo, M., Sartori, L., Polese, R., Caceffo, D., Nicoli, L., & Morari, F. (2023). LAI estimation through remotely sensed NDVI following hail defoliation in maize (Zea mays L.) using Sentinel-2 and UAV imagery. Precision Agriculture, 24(4), 1355–1379. https://doi.org/10.1007/s11119-023-09993-9

Furlanetto, J., Longo, M., Nicoli, L., Caceffo, D., Persichetti, A., Morari, F., & Ferro, N. D. (2022).

Spectral mixture analysis to quantity winter wheat (Triticum aestivum L.) damage caused by hailstorms (EGU22-4868). EGU22. Copernicus Meetings. https://doi.org/10.5194/egusphere-egu22-4868

Gagliardi, N., Arévalo, P., & Pamies, S. (2022). The fiscal impact of extreme weather and climate events: Evidence for EU countries. (Discussion Paper 168; DISCUSSION PAPER, p. 40). European Commission. Directorate General for Economic and Financial Affairs.Publications Office. https://data.europa.eu/doi/10.2765/867213

Gallagher, J. (2014). Learning about an Infrequent Event: Evidence from Flood Insurance Take-Up in the United States. American Economic Journal: Applied Economics, 6(3), 206–233. https://doi.org/10.1257/app.6.3.206

Garrido, A., & Zilberman, D. (2008). Revisiting the demand for agricultural insurance: The case of Spain. Agricultural Finance Review, 68(1), 43–66. https://doi.org/10.1108/00214660880001218

Gatzert, N., & Kellner, R. (2011). The influence of non-linear dependencies on the basis risk of industry loss warranties. Insurance: Mathematics and Economics, 49(1), 132–144. https://doi.org/10.1016/j.insmatheco.2011.02.005

GFIA. (2023). Global protection gaps and recommendations for bridging them. https://gfiainsurance.org/topics/487/protection-gaps

Giampietri, E., Yu, X., & Trestini, S. (2020). The role of trust and perceived barriers on farmer's intention to adopt risk management tools. Bio-Based and Applied Economics, 1-24 Pages. https://doi.org/10.13128/BAE-8416

Giné, X., Menand, L., Townsend, R., & Vickery, J. (2010). Microinsurance: A case study of the Indian rainfall index insurance market. The World Bank. https://doi.org/10.1596/1813-9450-5459

Gizzi, F. T., Porrini, D., & De Masi, F. (2021). Building a Natural Hazard Insurance System (NHIS): The Long-lasting Italian Case. Sustainability, 13(21), 12269. https://doi.org/10.3390/su132112269

Gizzi, F. T., Potenza, M. R., & Zotta, C. (2016). The Insurance Market of Natural Hazards for Residential Properties in Italy. Open Journal of Earthquake Research, 05(01), 35–61. https://doi.org/10.4236/ojer.2016.51004

Glaas, E., Keskitalo, E. C. H., & Hjerpe, M. (2017). Insurance sector management of climate change adaptation in three Nordic countries: The influence of policy and market factors. Journal of Environmental Planning and Management, 60(9), 1601–1621. https://doi.org/10.1080/09640568.2016.1245654

Gómez-Limón, J. A., & Granado-Díaz, R. (2023). Assessing the demand for hydrological drought insurance in irrigated agriculture. Agricultural Water Management, 276, 108054. https://doi.org/10.1016/j.agwat.2022.108054

Goodwin, B. K. (2001). Problems with Market Insurance in Agriculture. American Journal of Agricultural Economics, 83(3), 643–649.

Gor, N. (2013). Microtakaful-Islamic insurance for deprived: Innovation, sustainability and inclusive growth. International Journal of Business, Economics and Law, 3(2). https://ijbel.com/wp-content/uploads/2014/01/KLE3223-NIKUNJ-MICROTAKAFUL-ISLAMIC-INSURANCE-FOR-DEPRIVED.pdf

Götze, T., & Gürtler, M. (2022). Risk transfer beyond reinsurance: The added value of CAT bonds.

The Geneva Papers on Risk and Insurance - Issues and Practice, 47(1), 125–171. https://doi.org/10.1057/s41288-021-00234-6

Gradeci, K., Labonnote, N., Sivertsen, E., & Time, B. (2019). The use of insurance data in the analysis of Surface Water Flood events – A systematic review. Journal of Hydrology, 568, 194–206. https://doi.org/10.1016/j.jhydrol.2018.10.060

Gray, I. (2021). Hazardous simulations: Pricing climate risk in US coastal insurance markets. Economy and Society, 50(2), 196–223. https://doi.org/10.1080/03085147.2020.1853358

Gronberg, T. J., & Neilson, B. (2007). Incentive effects of weather derivatives. https://web.utk.edu/~wneilson/GronbergNeilsonIncentives.pdf

Grossi, P., Kunreuther, H., & Windeler, D. (2005). An Introduction to Catastrophe Models and Insurance. In P. Grossi & H. Kunreuther (Eds.), Catastrophe Modeling: A New Approach to Managing Risk (Vol. 25, pp. 23–42). Kluwer Academic Publishers. https://doi.org/10.1007/0-387-23129-3_2

Guzmán, D. A., Mohor, G. S., & Mendiondo, E. M. (2020). Multi-Year Index-Based Insurance for Adapting Water Utility Companies to Hydrological Drought: Case Study of a Water Supply System of the Sao Paulo Metropolitan Region, Brazil. Water, 12(11), 2954. https://doi.org/10.3390/w12112954

Haer, T., Botzen, W. J. W., & Aerts, J. C. J. H. (2019). Advancing disaster policies by integrating dynamic adaptive behaviour in risk assessments using an agent-based modelling approach. Environmental Research Letters, 14(4), 044022. https://doi.org/10.1088/1748-9326/ab0770

Hahn, T., Sioen, G. B., Gasparatos, A., Elmqvist, T., Brondizio, E., Gómez-Baggethun, E., Folke, C., Setiawati, M. D., Atmaja, T., Arini, E. Y., Jarzebski, M. P., Fukushi, K., & Takeuchi, K. (2023). Insurance value of biodiversity in the Anthropocene is the full resilience value. Ecological Economics, 208, 107799. https://doi.org/10.1016/j.ecolecon.2023.107799

Hamaker-Taylor, R., Perrels, A. Canevari, L., Nurmi, V., Rautio, T. Rycerz, A. Larosa, F. (2018). Results of Explorations of the Climate Services Market for the Financial Sector, EU-MACS Deliverable 2.1 [EU project deöiverable]. https://eu-macs.eu/wp-content/uploads/2019/02/EUMACS_D21_FINAL.pdf

Hamilton, S. (2020). Crop Insurance and the New Deal Roots of Agricultural Financialization in the United States. Enterprise & Society, 21(3), 648–680. https://doi.org/10.1017/eso.2019.43

Han, Y., & Peng, Z. (2019). The integration of local government, residents, and insurance in coastal adaptation: An agent-based modeling approach. Computers, Environment and Urban Systems, 76, 69–79. https://doi.org/10.1016/j.compenvurbsys.2019.04.001

Hanger, S., Linnerooth-Bayer, J., Surminski, S., Nenciu-Posner, C., Lorant, A., Ionescu, R., & Patt, A. (2018). Insurance, Public Assistance, and Household Flood Risk Reduction: A Comparative Study of Austria, England, and Romania. Risk Analysis, 38(4), 680–693. https://doi.org/10.1111/risa.12881

Harries, T. (2012). The Anticipated Emotional Consequences of Adaptive Behaviour—Impacts on the Take-up of Household Flood-Protection Measures. Environment and Planning A: Economy and Space, 44(3), 649–668. https://doi.org/10.1068/a43612

Harrison, S. E., Potter, S. H., Prasanna, R., Doyle, E. E. H., & Johnston, D. (2022). 'Sharing is caring': A socio-technical analysis of the sharing and governing of hydrometeorological hazard, impact, vulnerability, and exposure data in Aotearoa New Zealand. Progress in Disaster Science, 13, 100213. https://doi.org/10.1016/j.pdisas.2021.100213

Harvatt, J., Petts, J., & Chilvers, J. (2011). Understanding householder responses to natural hazards: Flooding and sea-level rise comparisons. Journal of Risk Research, 14(1), 63–83. https://doi.org/10.1080/13669877.2010.503935

Hassan, R., & Salman, S. A. (2017). Takaful vs. Conventional Insurance from the Risk and Solidarity Perspective. Sustainable Economic Development.

Hayek, F. A. (1960). The Constitution of Liberty. University of Chicago Press.

Headwaters Economics. (2016). Do Insurance Policies and Rates Influence Home Development on Fire-Prone Lands? (p. 14). https://headwaterseconomics.org/wp-content/uploads/Insurance-Wildfire-Home-Development.pdf

Herweijer, C., Ranger, N., & Ward, R. E. T. (2009). Adaptation to Climate Change: Threats and Opportunities for the Insurance Industry. The Geneva Papers on Risk and Insurance - Issues and Practice, 34(3), 360–380. https://doi.org/10.1057/gpp.2009.13

Hill, R. V., Kumar, N., Magnan, N., Makhija, S., De Nicola, F., Spielman, D. J., & Ward, P. S. (2019). Ex ante and ex post effects of hybrid index insurance in Bangladesh. Journal of Development Economics, 136, 1–17. https://doi.org/10.1016/j.jdeveco.2018.09.003

Hoeppe, P. (2016). Trends in weather related disasters – Consequences for insurers and society. Weather and Climate Extremes, 11, 70–79. https://doi.org/10.1016/j.wace.2015.10.002

Holland, C., & Kavuri, A. (2023). Artificial Intelligence (AI) and Business Innovation in Insurance: A Comparison of Incumbent Firms versus New Entrants. https://hdl.handle.net/10125/103097

Holub, M., & Fuchs, S. (2009). Mitigating mountain hazards in Austria – legislation, risk transfer, and awareness building. Natural Hazards and Earth System Sciences, 9(2), 523–537. https://doi.org/10.5194/nhess-9-523-2009

Holzheu, T., & Turner, G. (2018). The Natural Catastrophe Protection Gap: Measurement, Root Causes and Ways of Addressing Underinsurance for Extreme Events†. The Geneva Papers on Risk and Insurance - Issues and Practice, 43(1), 37–71. https://doi.org/10.1057/s41288-017-0075-y

Hu, L., Zhang, C., Zhang, M., Shi, Y., Lu, J., & Fang, Z. (2023). Enhancing FAIR Data Services in Agricultural Disaster: A Review. Remote Sensing, 15(8), 2024. https://doi.org/10.3390/rs15082024

Hudson, P. (2018). A comparison of definitions of affordability for flood risk adaption measures: A case study of current and future risk-based flood insurance premiums in Europe. Mitigation and Adaptation Strategies for Global Change, 23(7), 1019–1038. https://doi.org/10.1007/s11027-017-9769-5

Hudson, P., & Berghäuser, L. (2023). Investigating moral hazard and property-level flood resilience measures through panel data from Germany. International Journal of Disaster Risk Reduction, 84, 103480. https://doi.org/10.1016/j.ijdrr.2022.103480

Hudson, P., Botzen, W. J. W., Feyen, L., & Aerts, J. C. J. H. (2016). Incentivising flood risk adaptation through risk based insurance premiums: Trade-offs between affordability and risk reduction. Ecological Economics, 125, 1–13. https://doi.org/10.1016/j.ecolecon.2016.01.015

Hudson, P., Bubeck, P., & Thieken, A. H. (2022). A comparison of flood-protective decision-making between German households and businesses. Mitigation and Adaptation Strategies for Global Change, 27(1), 5. https://doi.org/10.1007/s11027-021-09982-1

Hudson, P., De Ruig, L. T., De Ruiter, M. C., Kuik, O. J., Botzen, W. J. W., Le Den, X., Persson, M., Benoist, A., & Nielsen, C. N. (2020). An assessment of best practices of extreme weather insurance and directions for a more resilient society. Environmental Hazards, 19(3), 301–321. https://doi.org/10.1080/17477891.2019.1608148

Hudson, P., & Thieken, A. H. (2022). The presence of moral hazard regarding flood insurance and German private businesses. Natural Hazards, 112(2), 1295–1319. https://doi.org/10.1007/s11069-022-05227-9

Hudson, P., Wouter Botzen, W. J., Czajkowski, J., & Kreibich, H. (2017). Moral Hazard in Natural Disaster Insurance Markets: Empirical Evidence from Germany and the United States. Land Economics, 93(2), 179–208. https://doi.org/10.3368/le.93.2.179

Ingels, M. W., Aerts, J. C. J. H., Botzen, W. J. W., Brusselaers, J., & Tesselaar, M. (forthcoming). Advancements in actuarial risk modelling (D1.2). PIISA.

IPCC. (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Core Writing Team, R. K. Pachauri, & L. A. Meyer, Eds.). IPCC. https://www.ipcc.ch/site/assets/uploads/2018/05/SYR_AR5_FINAL_full_wcover.pdf

IPCC. (2022). Climate Change 2022 – Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, V. Möller, & B. Rama, Eds.; 1st ed.). Cambridge University Press. https://doi.org/10.1017/9781009325844

Ivčević, A., Statzu, V., Satta, A., & Bertoldo, R. (2021). The future protection from the climate change-related hazards and the willingness to pay for home insurance in the coastal wetlands of West Sardinia, Italy. International Journal of Disaster Risk Reduction, 52, 101956. https://doi.org/10.1016/j.ijdrr.2020.101956

Iwahashi, Y., Sigit, G., Utoyo, B., Lubis, I., Junaedi, A., Trisasongko, B. H., Wijaya, I. M. A. S., Maki, M., Hongo, C., & Homma, K. (2023). Drought Damage Assessment for Crop Insurance Based on Vegetation Index by Unmanned Aerial Vehicle (UAV) Multispectral Images of Paddy Fields in Indonesia. Agriculture, 13(1), Articolo 1. https://doi.org/10.3390/agriculture13010113

Iyer, P., Bozzola, M., Hirsch, S., Meraner, M., & Finger, R. (2020). Measuring Farmer Risk Preferences in Europe: A Systematic Review. Journal of Agricultural Economics, 71(1), 3–26. https://doi.org/10.1111/1477-9552.12325

Jarzabkowski, P., Chalkias, K., Cacciatori, E., & Bednarek, R. (2018). Between State and Market: Protection Gap Entities and Catastrophic Risk. Cass Business School, City, University of London. https://www.bayes.city.ac.uk/__data/assets/pdf_file/0020/420257/PGE-Report-FINAL.pdf

Jha, N., Prashar, D., Khalaf, O. I., Alotaibi, Y., Alsufyani, A., & Alghamdi, S. (2021). Blockchain Based Crop Insurance: A Decentralized Insurance System for Modernization of Indian Farmers. Sustainability, 13(16), Articolo 16. https://doi.org/10.3390/su13168921

Johannsdottir, L. (2017). Climate Change and Iceland's Risk-Sharing System for Natural Disasters. The Geneva Papers on Risk and Insurance - Issues and Practice, 42(2), 275–295.

https://doi.org/10.1057/s41288-016-0002-7

Johnson, C., Penning-Rowsell, E., & Parker, D. (2007). Natural and imposed injustices: The challenges in implementing 'fair' flood risk management policy in England. The Geographical Journal, 173(4), 374–390. https://doi.org/10.1111/j.1475-4959.2007.00256.x

Johnson, P., Ricker, B., & Harrison, S. (2017). Volunteered Drone Imagery: Challenges and constraints to the development of an open shared image repository. Hawaii International Conference on System Sciences. https://doi.org/10.24251/HICSS.2017.242

Jongman, B., Koks, E. E., Husby, T. G., & Ward, P. J. (2014). Increasing flood exposure in the Netherlands: Implications for risk financing. Natural Hazards and Earth System Sciences, 14(5), 1245–1255. https://doi.org/10.5194/nhess-14-1245-2014

Kar, A. K., & Navin, L. (2021). Diffusion of blockchain in insurance industry: An analysis through the review of academic and trade literature. Telematics and Informatics, 58, 101532. https://doi.org/10.1016/j.tele.2020.101532

Karlan, D., Osei, R., Osei-Akoto, I., & Udry, C. (2014). Agricultural Decisions after Relaxing Credit and Risk Constraints. The Quarterly Journal of Economics, 129(2), 597–652. https://doi.org/10.1093/qje/qju002

Kath, J., Mushtaq, S., Henry, R., Adeyinka, A., & Stone, R. (2018). Index insurance benefits agricultural producers exposed to excessive rainfall risk. Weather and Climate Extremes, 22, 1–9. https://doi.org/10.1016/j.wace.2018.10.003

Kaufmann, M., Priest, S. J., & Leroy, P. (2018). The undebated issue of justice: Silent discourses in Dutch flood risk management. Regional Environmental Change, 18(2), 325–337. https://doi.org/10.1007/s10113-016-1086-0

Keskitalo, E. C. H., Vulturius, G., & Scholten, P. (2014). Adaptation to climate change in the insurance sector: Examples from the UK, Germany and the Netherlands. Natural Hazards, 71(1), 315–334. https://doi.org/10.1007/s11069-013-0912-7

Keucheyan, R. (2023). The "Environment Making State" and Climate Change: The French "Cat Nat" Reinsurance Scheme Under Strain. Antipode, 55(2), 506–526. https://doi.org/10.1111/anti.12901

Kleindorfer, P. R., Kunreuther, H., & Ou-Yang, C. (2012). Single-year and multi-year insurance policies in a competitive market. Journal of Risk and Uncertainty, 45(1), 51–78. https://doi.org/10.1007/s11166-012-9148-2

Kleinschroth, F., Banda, K., Zimba, H., Dondeyne, S., Nyambe, I., Spratley, S., & Winton, R. S. (2022). Drone imagery to create a common understanding of landscapes. Landscape and Urban Planning, 228, 104571. https://doi.org/10.1016/j.landurbplan.2022.104571

Koeva, M., Gasuku, O., Lengoiboni, M., Asiama, K., Bennett, R. M., Potel, J., & Zevenbergen, J. (2021). Remote Sensing for Property Valuation: A Data Source Comparison in Support of Fair Land Taxation in Rwanda. Remote Sensing, 13(18), Articolo 18. https://doi.org/10.3390/rs13183563

Kostić, N., & Sedej, T. (2022). Blockchain Technology, Inter-Organizational Relationships, and Management Accounting: A Synthesis and a Research Agenda. Accounting Horizons, 36(2), 123–141. https://doi.org/10.2308/HORIZONS-19-147

Kourtis, I. M., & Tsihrintzis, V. A. (2021). Adaptation of urban drainage networks to climate change:

A review. Science of The Total Environment, 771, 145431. https://doi.org/10.1016/j.scitotenv.2021.145431

Kousky, C. (2017). Revised Risk Assessments and the Insurance Industry. In E. J. Balleisen, L. S. Bennear, K. D. Krawiec, & J. B. Wiener (Eds.), Policy Shock (pp. 58–81). Cambridge University Press. https://doi.org/10.1017/9781316492635.003

Kousky, C. (2019). The Role of Natural Disaster Insurance in Recovery and Risk Reduction. Annual Review of Resource Economics, 11(1), 399–418. https://doi.org/10.1146/annurev-resource-100518-094028

Kousky, C., & Cooke, R. (2012). Explaining the Failure to Insure Catastrophic Risks. The Geneva Papers on Risk and Insurance - Issues and Practice, 37(2), 206–227. https://doi.org/10.1057/gpp.2012.14

Kousky, C., & Kunreuther, H. (2014). Addressing Affordability in the National Flood Insurance Program. Journal of Extreme Events, 1(1). https://doi.org/10.1142/S2345737614500018

Kousky, C., & Kunreuther, H. (2017). Defining the Roles of the Public and Private Sector in Risk Communication, Risk Reduction, and Risk Transfer. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.3029630

Kousky, C., Kunreuther, H., Xian, S., & Lin, N. (2021). Adapting our Flood Risk Policies to Changing Conditions. Risk Analysis, 41(10), 1739–1743. https://doi.org/10.1111/risa.13692

Kousky, C., & Light, S. E. (2019). Insuring Nature. Duke Law Journal, 69, 323–376.

Kraehnert, K., Osberghaus, D., Hott, C., Habtemariam, L. T., Wätzold, F., Hecker, L. P., & Fluhrer, S. (2021). Insurance Against Extreme Weather Events: An Overview. Review of Economics, 72(2), 71–95. https://doi.org/10.1515/roe-2021-0024

Kreibich, H., Seifert, I., Thieken, A. H., Lindquist, E., Wagner, K., & Merz, B. (2011). Recent changes in flood preparedness of private households and businesses in Germany. Regional Environmental Change, 11(1), 59–71. https://doi.org/10.1007/s10113-010-0119-3

Kron, W. (2009). Flood insurance: From clients to global financial markets. Journal of Flood Risk Management, 2(1), 68–75. https://doi.org/10.1111/j.1753-318X.2008.01015.x

Kron, W., Löw, P., & Kundzewicz, Z. W. (2019). Changes in risk of extreme weather events in Europe. Environmental Science & Policy, 100, 74–83. https://doi.org/10.1016/j.envsci.2019.06.007

Kucharczyk, M., & Hugenholtz, C. H. (2021). Remote sensing of natural hazard-related disasters with small drones: Global trends, biases, and research opportunities. Remote Sensing of Environment, 264, 112577. https://doi.org/10.1016/j.rse.2021.112577

Kunreuther, H. (2008). Reducing Losses from Catastrophic Risks through Long-Term Insurance and Mitigation. Social Research, 75(3), 905–930. JSTOR.

Kunreuther, H. (2015). The Role of Insurance in Reducing Losses from Extreme Events: The Need for Public–Private Partnerships. The Geneva Papers on Risk and Insurance - Issues and Practice, 40(4), 741–762. https://doi.org/10.1057/gpp.2015.14

Kunreuther, H. (2018). All-Hazards Homeowners Insurance: Challenges and Opportunities. Risk Management and Insurance Review, 21(1), 141–155. https://doi.org/10.1111/rmir.12091

Kunreuther, H. (2021). Improving the National Flood Insurance Program. Behavioural Public Policy, 5(3), 318–332. https://doi.org/10.1017/bpp.2018.26

Kunreuther, H., Conell-Price, L., Kovacs, P., & Goda, K. (2021). The Impact of a Government Risk Pool and an Opt-Out Framing on Demand for Earthquake Protection (w29144; p. w29144). National Bureau of Economic Research. https://doi.org/10.3386/w29144

Kunreuther, H., Ginsberg, R., Miller, L., Sagi, P., Slovic, P., Borkan, B., & Katz, N. (1978). Disaster Insurance Protection: Public Policy Lessons. Wiley.

Kunreuther, H., & Michel-Kerjan, E. (2013). Managing Catastrophic Risks Through Redesigned Insurance: Challenges and Opportunities. In G. Dionne (Eds.), Handbook of Insurance (pp. 517–546). Springer New York. https://doi.org/10.1007/978-1-4614-0155-1_19

Kunreuther, H., & Pauly, M. (2004). Neglecting Disaster: Why Don't People Insure Against Large Losses? Journal of Risk and Uncertainty, 28(1), 5–21. https://doi.org/10.1023/B:RISK.0000009433.25126.87

Lamond, J. E. (2014). The Role of Market-Based Flood Insurance in Maintaining Communities at Risk of Flooding: A SWOT Analysis. In C. A. Booth & S. M. Charlesworth (Eds.), Water Resources in the Built Environment (1st ed., pp. 258–270). Wiley. https://doi.org/10.1002/9781118809167.ch20

Lamond, J. E., & Penning-Rowsell, E. (2014). The robustness of flood insurance regimes given changing risk resulting from climate change. Climate Risk Management, 2, 1–10. https://doi.org/10.1016/j.crm.2014.03.001

Lamond, J. E., Proverbs, D. G., & Hammond, F. N. (2009). Accessibility of flood risk insurance in the UK: Confusion, competition and complacency. Journal of Risk Research, 12(6), 825–841. https://doi.org/10.1080/13669870902768614

Lampe, I., & Würtenberger, D. (2020). Loss aversion and the demand for index insurance. Journal of Economic Behavior & Organization, 180, 678–693. https://doi.org/10.1016/j.jebo.2019.10.019

Landry, C. E., Turner, D., & Petrolia, D. (2021). Flood Insurance Market Penetration and Expectations of Disaster Assistance. Environmental and Resource Economics, 79(2), 357–386. https://doi.org/10.1007/s10640-021-00565-x

Lanfranchi, D., & Grassi, L. (2022). Examining insurance companies' use of technology for innovation. The Geneva Papers on Risk and Insurance - Issues and Practice, 47(3), 520–537. https://doi.org/10.1057/s41288-021-00258-y

Laury, S. K., McInnes, M. M., & Swarthout, J. T. (2009). Insurance decisions for low-probability losses. Journal of Risk and Uncertainty, 39(1), 17–44. https://doi.org/10.1007/s11166-009-9072-2

Le Roux, S. (2020). Climate change catastrophes and insuring decisions: A study in the presence of ambiguity. Journal of Economic Behavior & Organization, 180, 992–1002. https://doi.org/10.1016/j.jebo.2018.07.021

Leal, M., Hudson, P., Mobini, S., Sörensen, J., Madeira, P. M., Tesselaar, M., & Zêzere, J. L. (2022). Natural hazard insurance outcomes at national, regional and local scales: A comparison between Sweden and Portugal. Journal of Environmental Management, 322, 116079. https://doi.org/10.1016/j.jenvman.2022.116079

Lehtonen, T.-K., & Liukko, J. (2011). The Forms and Limits of Insurance Solidarity. Journal of

Business Ethics, 103(S1), 33–44. https://doi.org/10.1007/s10551-012-1221-x

Li, A., Gong, Z., & Forrest, J. Y.-L. (2023). Financial fund allocation in China's catastrophe insurance market: A game-theoretic analysis. Natural Hazards, 117(3), 3181–3202. https://doi.org/10.1007/s11069-023-05982-3

Liesivaara, P., & Myyrä, S. (2017). The demand for public–private crop insurance and government disaster relief. Journal of Policy Modeling, 39(1), 19–34. https://doi.org/10.1016/j.jpolmod.2016.12.001

Lin, L., & Chen, C. C. (2019). The Promise and Perils of InsurTech. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.3463533

Liu, T., Shao, J., & Wang, X. (2022). Funding allocations for disaster preparation considering catastrophe insurance. Socio-Economic Planning Sciences, 84, 101413. https://doi.org/10.1016/j.seps.2022.101413

Liu, X., Van Kooten, G. C., Gerbrandt, E. M., & Duan, J. (2023). Prospects for weather-indexed insurance for blueberry growers. Agricultural Finance Review, 83(2), 333–351. https://doi.org/10.1108/AFR-05-2022-0059

Lo, A. Y. (2013a). The likelihood of having flood insurance increases with social expectations. Area, 45(1), 70–76. https://doi.org/10.1111/area.12002

Lo, A. Y. (2013b). The role of social norms in climate adaptation: Mediating risk perception and flood insurance purchase. Global Environmental Change, 23(5), 1249–1257. https://doi.org/10.1016/j.gloenvcha.2013.07.019

Lo, A. Y., & Chan, F. (2017). Preparing for flooding in England and Wales: The role of risk perception and the social context in driving individual action. Natural Hazards, 88(1), 367–387. https://doi.org/10.1007/s11069-017-2870-y

Longo, M., Furlanetto, J., Ferro, N. D., Caceffo, D., & Morari, F. (2022). Coupling process-based models and remote sensing data to predict yield loss by hail damage (EGU22-4594). EGU22. Copernicus Meetings. https://doi.org/10.5194/egusphere-egu22-4594

López Gunn, E., Rica, M., Zorrilla-Miras, P., Vay, L., Mayor, B., Pagano, A., Altamirano, M., & Giordano, R. (2021). The natural assurance value of nature-based solutions: A layered institutional analysis of socio ecological systems for long term climate resilient transformation. Ecological Economics, 186, 107053. https://doi.org/10.1016/j.ecolecon.2021.107053

Louaas, A., & Picard, P. (2021). Optimal insurance coverage of low-probability catastrophic risks. The Geneva Risk and Insurance Review, 46(1), 61–88. https://doi.org/10.1057/s10713-020-00049-w

Loukil, F., Boukadi, K., Hussain, R., & Abed, M. (2021). CioSy: A Collaborative Blockchain-Based Insurance System. Electronics, 10(11), Articolo 11. https://doi.org/10.3390/electronics10111343

Lucas, C. H. (2018). Concerning values: What underlies public polarisation about climate change? Geographical Research, 56(3), 298–310. https://doi.org/10.1111/1745-5871.12284

Lucas, C. H., & Booth, K. I. (2020). Privatizing climate adaptation: How insurance weakens solidaristic and collective disaster recovery. WIREs Climate Change, 11(6), e676. https://doi.org/10.1002/wcc.676

Ludy, J., & Kondolf, G. M. (2012). Flood risk perception in lands "protected" by 100-year levees.

Natural Hazards, 61(2), 829–842. https://doi.org/10.1007/s11069-011-0072-6

Lung, T., Lavalle, C., Hiederer, R., Dosio, A., & Bouwer, L. M. (2013). A multi-hazard regional level impact assessment for Europe combining indicators of climatic and non-climatic change. Global Environmental Change, 23(2), 522–536. https://doi.org/10.1016/j.gloenvcha.2012.11.009

Maestro Villarroya, T. (2016). Hydrological Drought Index Insurance for Irrigated Agriculture [PhD Thesis, Universidad Politécnica de Madrid]. https://doi.org/10.20868/UPM.thesis.43595

Martin, D. (2014, febbraio 8). River Quango has allowed 190,000 new homes on flood plains since 1996 despite concerns they could be uninsurable. Daily Mail. https://www.dailymail.co.uk/news/article-2561713/River-quango-allowed-190-000-new-homes-flood-plains-formed-Environment-Agency-agreed-construction-despite-concerns-uninsurable.html

Matczak, P., Lewandowski, J., Chorynski, A., Szwed, M., & Kundzewicz, Z. W. (2016). Stability and Change of Flood Risk Governance in Poland. In Z. W. Kundzewicz, M. Stoffel, T. Niedźwiedź, & B. Wyżga (Eds.), Flood Risk in the Upper Vistula Basin (pp. 381–398). Springer International Publishing. https://doi.org/10.1007/978-3-319-41923-7_19

Matese, A., Toscano, P., Di Gennaro, S. F., Genesio, L., Vaccari, F. P., Primicerio, J., Belli, C., Zaldei, A., Bianconi, R., & Gioli, B. (2015). Intercomparison of UAV, Aircraft and Satellite Remote Sensing Platforms for Precision Viticulture. Remote Sensing, 7(3), Articolo 3. https://doi.org/10.3390/rs70302971

Maysami, R. C., & Kwon, W. J. (1999). An Analysis of Islamic Takaful Insurance. Journal of Insurance Regulation, 18(1), 109.

McAneney, J., McAneney, D., Musulin, R., Walker, G., & Crompton, R. (2016). Government-sponsored natural disaster insurance pools: A view from down-under. International Journal of Disaster Risk Reduction, 15, 1–9. https://doi.org/10.1016/j.ijdrr.2015.11.004

McClelland, G. H., Schulze, W. D., & Coursey, D. L. (1993). Insurance for low-probability hazards: A bimodal response to unlikely events. Journal of Risk and Uncertainty, 7(1), 95–116. https://doi.org/10.1007/BF01065317

McFall, L., Meyers, G., & Hoyweghen, I. V. (2020). Editorial: The personalisation of insurance: Data, behaviour and innovation. Big Data & Society, 7(2), 205395172097370. https://doi.org/10.1177/2053951720973707

McIntosh, C., Povel, F., & Sadoulet, E. (2019). Utility, Risk and Demand for Incomplete Insurance: Lab Experiments with Guatemalan Co-Operatives. The Economic Journal, 129(622), 2581–2607. https://doi.org/10.1093/ej/uez005

Meier, U. B., & François Outreville, J. (2006). Business cycles in insurance and reinsurance: The case of France, Germany and Switzerland. The Journal of Risk Finance, 7(2), 160–176. https://doi.org/10.1108/15265940610648607

Menapace, L., Colson, G., & Raffaelli, R. (2016). A comparison of hypothetical risk attitude elicitation instruments for explaining farmer crop insurance purchases. European Review of Agricultural Economics, 43(1), 113–135. https://doi.org/10.1093/erae/jbv013

Meraner, M., & Finger, R. (2019). Risk perceptions, preferences and management strategies: Evidence from a case study using German livestock farmers. Journal of Risk Research, 22(1), 110–135. https://doi.org/10.1080/13669877.2017.1351476

Michel-Kerjan, E., & Kunreuther, H. (2011). Redesigning Flood Insurance. Science, 333(6041), 408–409. https://doi.org/10.1126/science.1202616

Michel-Kerjan, E., & Morlaye, F. (2008). Extreme Events, Global Warming, and Insurance-Linked Securities: How to Trigger the “Tipping Point”. The Geneva Papers on Risk and Insurance - Issues and Practice, 33(1), 153–176. https://doi.org/10.1057/palgrave.gpp.2510159

Miglietta, P. P., Porrini, D., Fusco, G., & Capitanio, F. (2020). Crowding out agricultural insurance and the subsidy system in Italy: Empirical evidence of the charity hazard phenomenon. Agricultural Finance Review, 81(2), 237–249. https://doi.org/10.1108/AFR-04-2020-0061

Mill, J. S. (1863). Utilitarianism. Routledge.

Miller, B., Dixon, L., & Clancy, N. (2019). Reasonable and Risk-Based? Replacing NFIP Generally Subsidized Rates with a Means-Tested Subsidy. Southern Economic Journal, 85(4), 1180–1195. https://doi.org/10.1002/soej.12329

Mills, E. (2012). The Greening of Insurance. Science, 338(6113), 1424–1425. https://doi.org/10.1126/science.1229351

Mishra, A. K., & El-Osta, H. S. (2002). Managing risk in agriculture through hedging and crop insurance: What does a national survey reveal? Agricultural Finance Review, 62(2), 135–148. https://doi.org/10.1108/00214930280001134

Mol, J. M., Botzen, W. J. W., & Blasch, J. E. (2020a). Behavioral motivations for self-insurance under different disaster risk insurance schemes. Journal of Economic Behavior & Organization, 180, 967–991. https://doi.org/10.1016/j.jebo.2018.12.007

Mol, J. M., Botzen, W. J. W., & Blasch, J. E. (2020b). Risk reduction in compulsory disaster insurance: Experimental evidence on moral hazard and financial incentives. Journal of Behavioral and Experimental Economics, 84, 101500. https://doi.org/10.1016/j.socec.2019.101500

Mol, J. M., Botzen, W. J. W., Blasch, J. E., & De Moel, H. (2020). Insights into Flood Risk Misperceptions of Homeowners in the Dutch River Delta. Risk Analysis, 40(7), 1450–1468. https://doi.org/10.1111/risa.13479

Mullins, M., Holland, C. P., & Cunneen, M. (2021). Creating ethics guidelines for artificial intelligence and big data analytics customers: The case of the consumer European insurance market. Patterns, 2(10), 100362. https://doi.org/10.1016/j.patter.2021.100362

Munich RE. (2021). Improving Flood Resilience Through Community Insurance and Nature-Based Solutions. Munich RE. https://www.munichre.com/content/dam/munichre/mram/content-pieces/pdfs/reinsurance-solutions/TNC_Whitepaper.pdf/_jcr_content/renditions/original./TNC_Whitepaper.pdf

Musshoff, O., Odening, M., & Xu, W. (2011). Management of climate risks in agriculture–will weather derivatives permeate? Applied Economics, 43(9), 1067–1077. https://doi.org/10.1080/00036840802600210

Mysiak, J., & Pérez-Blanco, C. D. (2016). Partnerships for disaster risk insurance in the EU. Natural Hazards and Earth System Sciences, 16(11), 2403–2419. https://doi.org/10.5194/nhess-16-2403-2016

Mysiak, J., Surminski, S., Thieken, A., Mechler, R., & Aerts, J. (2016). Brief communication: Sendai framework for disaster risk reduction – success or warning sign for Paris? Natural Hazards and Earth System Sciences, 16(10), 2189–2193. https://doi.org/10.5194/nhess-16-2189-2016

Nagendra, N. P., Narayanamurthy, G., Moser, R., Hartmann, E., & Sengupta, T. (2023). Technology Assessment Using Satellite Big Data Analytics for India's Agri-Insurance Sector. IEEE Transactions on Engineering Management, 70(3), 1099–1113. https://doi.org/10.1109/TEM.2022.3159451

Neumayer, E., & Barthel, F. (2011). Normalizing economic loss from natural disasters: A global analysis. Global Environmental Change, 21(1), 13–24. https://doi.org/10.1016/j.gloenvcha.2010.10.004

Njegomir, V., Demko-Rihter*, J., & Bojanić, T. (2021). Disruptive Technologies in the Operation of Insurance Industry. Tehnički Vjesnik, 28(5), 1797–1805. https://doi.org/10.17559/TV-20200922132555

Njegomir, V., & Rihter, J. (2012). INNOVATIONS OF INSURANCE COMPANIES AND INVESTMENT FUNDS.

Nordlander, L., Pill, M., & Martinez Romera, B. (2020). Insurance schemes for loss and damage: fools' gold? Climate Policy, 20:6, 704-714. https://doi.org/10.1080/14693062.2019.1671163

Nordmeyer, E. F., & Musshoff, O. (2023). German farmers' perceived usefulness of satellite-based index insurance: Insights from a transtheoretical model. Agricultural Finance Review, 83(3), 511–527. https://doi.org/10.1108/AFR-10-2022-0125

Norta, A., Rossar, R., Parve, M., & Laas-Billson, L. (2019). Achieving a High Level of Open Market-Information Symmetry with Decentralised Insurance Marketplaces on Blockchains. In K. Arai, R. Bhatia, & S. Kapoor (Eds.), Intelligent Computing (pp. 299–318). Springer International Publishing. https://doi.org/10.1007/978-3-030-22871-2_22

Nozick, R. (1974). Anarchy, State, and Utopia. Basic Books.

Nzembela, K., & Mazambani, L. (2019). Role of Microinsurance in Protecting the Poor. 10, 10–25. https://doi.org/10.9790/5933-1003051525

OECD. (2018). The Contribution of Reinsurance Markets to Managing Catastrophe Risk. http://www.oecd.org/finance/the-contribution-of-reinsurance-markets-to-managing-catastrophe-risk.pdf

OECD. (2021). Enhancing financial protection against catastrophe risks: The role of catastrophe. www.oecd.org/daf/fin/insurance/Enhancing-financial-protection-againstcatastrophe-risks.htm

O'Hare, P., White, I., & Connelly, A. (2016). Insurance as maladaptation: Resilience and the 'business as usual' paradox. Environment and Planning C: Government and Policy, 34(6), 1175–1193. https://doi.org/10.1177/0263774X15602022

Omar, I. A., Jayaraman, R., Salah, K., Hasan, H. R., Antony, J., & Omar, M. (2023). Blockchain-Based Approach for Crop Index Insurance in Agricultural Supply Chain. IEEE Access, 11, 118660–118675. https://doi.org/10.1109/ACCESS.2023.3327286

OMB. (2016). Standards and Finance to Support Community Resilience [Report]. Office of Management and Budget.

O'Neill, B., van Aalst, M., Zaiton Ibrahim, Z., Berrang Ford, L., Bhadwal, S., Buhaug, H., Diaz, D., Frieler, K., Garschagen, M., Magnan, A., Midgley, G., Mirzabaev, A., Thomas, A., & Warren, R. (2022). Key Risks Across Sectors and Regions. In H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.), Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of

Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. (pp. 2411–2538). Cambridge University Press. https://dx.doi.org/10.1017/9781009325844.025

O'Neill, J., & O'Neill, M. (2012). Social justice and the future of flood insurance.

Osberghaus, D. (2015). The determinants of private flood mitigation measures in Germany—Evidence from a nationwide survey. Ecological Economics, 110, 36–50. https://doi.org/10.1016/j.ecolecon.2014.12.010

Osberghaus, D., & Reif, C. (2021). How do different compensation schemes and loss experience affect insurance decisions? Experimental evidence from two independent and heterogeneous samples. Ecological Economics, 187, 107087. https://doi.org/10.1016/j.ecolecon.2021.107087

Otto, A., Agatz, N., Campbell, J., Golden, B., & Pesch, E. (2018). Optimization approaches for civil applications of unmanned aerial vehicles (UAVs) or aerial drones: A survey. Networks, 72(4), 411–458. https://doi.org/10.1002/net.21818

Otto, C., Kuhla, K., Geiger, T., Schewe, J., & Frieler, K. (2023). Better insurance could effectively mitigate the increase in economic growth losses from U.S. hurricanes under global warming. Science Advances, 9(1), eadd6616. https://doi.org/10.1126/sciadv.add6616

Outreville, J. F. (2011). The Relationship between Insurance Growth and Economic Development: 80 Empirical Papers for a Review of the Literature. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.1885401

Paauw, M., Smith, G., Crabbé, A., Fournier, M., Munck Af Rosenschöld, J., Priest, S., & Rekola, A. (2024). Recognition of differences in the capacity to deal with floods—A cross-country comparison of flood risk management. Journal of Flood Risk Management, e12965. https://doi.org/10.1111/jfr3.12965

Paleari, S. (2019). Disaster risk insurance: A comparison of national schemes in the EU-28. International Journal of Disaster Risk Reduction, 35, 101059. https://doi.org/10.1016/j.ijdrr.2018.12.021

Palm, R., & Hodgson, M. (1992). Earthquake Insurance: Mandated Disclosure and Homeowner Response in California. Annals of the Association of American Geographers, 82(2), 207–222. https://doi.org/10.1111/j.1467-8306.1992.tb01905.x

Papon, T. (2008). The Effect of Pre-commitment and Past-Experience on Insurance Choices: An Experimental Study. The Geneva Risk and Insurance Review, 33(1), 47–73. https://doi.org/10.1057/grir.2008.8

Patt, A., Peterson, N., Carter, M., Velez, M., Hess, U., & Suarez, P. (2009). Making index insurance attractive to farmers. Mitigation and Adaptation Strategies for Global Change, 14(8), 737–753. https://doi.org/10.1007/s11027-009-9196-3

Paudel, Y. (2012). A Comparative Study of Public—Private Catastrophe Insurance Systems: Lessons from Current Practices. The Geneva Papers on Risk and Insurance - Issues and Practice, 37(2), 257–285. https://doi.org/10.1057/gpp.2012.16

Paudel, Y., Botzen, W. J. W., & Aerts, J. C. J. H. (2013). Estimation of insurance premiums for coverage against natural disaster risk: An application of Bayesian Inference. Natural Hazards and Earth System Sciences, 13(3), 737–754. https://doi.org/10.5194/nhess-13-737-2013

Paudel, Y., Botzen, W. J. W., & Aerts, J. C. J. H. (2015). Influence of climate change and socioeconomic development on catastrophe insurance: A case study of flood risk scenarios in the Netherlands. Regional Environmental Change, 15(8), 1717–1729. https://doi.org/10.1007/s10113-014-0736-3

Peacock, W. G., & Girard, C. (1997). Ethnic and racial inequalities in hurricane damage and insurance settlements. In W. G. Peacock, B. H. Morrow, & H. Gladwin (Eds.), Hurricane Andrew: Ethnicity, Gender and the Sociology of Disasters (pp. 171–190). Routledge.

Penning-Rowsell, E. C. (2015). Flood insurance in the UK: a critical perspective. WIREs Water, 2(6), 601–608. https://doi.org/10.1002/wat2.1104

Penning-Rowsell, E. C., & Pardoe, J. (2012). Who Benefits and Who Loses from Flood Risk Reduction? Environment and Planning C: Government and Policy, 30(3), 448–466. https://doi.org/10.1068/c10208

Perrels, A. (2018). A Structured Analysis of Obstacles to Uptake of Climate Services and Identification of Policies and Measures to Overcome Obstacles so as to Promote Uptake [EU Project deliverable]. https://eu-macs.eu/wp-content/uploads/2018/12/EUMACS_D51_final-1.pdf

Perrels, A., Haakana, J., Hakala, O., Kujala, S., Láng-Ritter, I., Lehtonen, H., Lintunen, J., Pohjola, J., Sane, M., Fronzek, S., Luhtala, S., Mervaala, E., Luomaranta, A., Jylhä, K., Koikkalainen, K., Kuntsi-Reunanen, E., Rautio, T., Tuomenvirta, H., Uusivuori, J., & Veijalainen, N. (2022, aprile 28). Kustannusarviointi ilmastonmuutokseen liittyvästä toimimattomuudesta (KUITTI) [Sarjajulkaisu]. https://julkaisut.valtioneuvosto.fi/handle/10024/164032

Perrels, A., Le, T.-T., Cortekar, J., Hoa, E., & Stegmaier, P. (2020). How much unnoticed merit is there in climate services? Climate Services, 17, 100153. https://doi.org/10.1016/j.cliser.2020.100153

Peter, R., & Ying, J. (2020). Do you trust your insurer? Ambiguity about contract nonperformance and optimal insurance demand. Journal of Economic Behavior & Organization, 180, 938–954. https://doi.org/10.1016/j.jebo.2019.01.002

Petrolia, D. R., Hwang, J., Landry, C. E., & Coble, K. H. (2015). Wind Insurance and Mitigation in the Coastal Zone. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.2350361

Petrolia, D. R., Landry, C. E., & Coble, K. H. (2013). Risk Preferences, Risk Perceptions, and Flood Insurance. Land Economics, 89(2), 227–245. https://doi.org/10.3368/le.89.2.227

Pew Research Center. (2017). Europe’s Growing Muslim Population (p. 59). Pew Research Center. https://www.pewresearch.org/wp-content/uploads/sites/20/2017/11/FULL-REPORT-FOR-WEB-POSTING.pdf

Platteau, J.-P., De Bock, O., & Gelade, W. (2017). The Demand for Microinsurance: A Literature Review. World Development, 94, 139–156. https://doi.org/10.1016/j.worlddev.2017.01.010

Polacek, A. (2018). Catastrophe bonds: A primer and retrospective. Chicago Fed Letter. https://doi.org/10.21033/cfl-2018-405

Poljanšek, K., Marin Ferrer, M., De Groeve, T., & Clark, I. (Eds.). (2017). Science for disaster risk management 2017: Knowing better and losing less. Publications Office of the European Union. https://data.europa.eu/doi/10.2788/842809

Pollner, J. (2012). Financial and Fiscal Instruments for Catastrophe Risk Management: Addressing the Losses from Flood Hazards in Central Europe. The World Bank. https://doi.org/10.1596/978-0-8213-9579-0

Porrini, D., & Schwarze, R. (2014). Insurance models and European climate change policies: An assessment. European Journal of Law and Economics, 38(1), 7–28. https://doi.org/10.1007/s10657-012-9376-6

Poussin, J. K., Botzen, W. J. W., & Aerts, J. C. J. H. (2013). Stimulating flood damage mitigation through insurance: An assessment of the French CatNat system. Environmental Hazards, 12(3–4), 258–277. https://doi.org/10.1080/17477891.2013.832650

Poussin, J. K., Botzen, W. J. W., & Aerts, J. C. J. H. (2014). Factors of influence on flood damage mitigation behaviour by households. Environmental Science & Policy, 40, 69–77. https://doi.org/10.1016/j.envsci.2014.01.013

Pu, C., (Bill) Chen, Y., & Pan, X. (2018). Weather indexes, index insurance and weather index futures. Insurance Markets and Companies, 9(1), 32–40. https://doi.org/10.21511/ins.09(1).2018.04

Quaas, M. F., & Baumgärtner, S. (2008). Natural vs. Financial insurance in the management of public-good ecosystems. Ecological Economics, 65(2), 397–406. https://doi.org/10.1016/j.ecolecon.2007.07.004

Radu, D. (2022). Disaster risk financing: Limiting the fiscal cost of climate-related disasters. Publications Office of the European Union.

Ralph, O. (2016, aprile 4). Flood Re expects 350,000 properties to be put into scheme. Financial Times. https://www.ft.com/content/3c72961a-f820-11e5-96db-fc683b5e52db

Raschky, P. A., Schwarze, R., Schwindt, M., & Zahn, F. (2013). Uncertainty of Governmental Relief and the Crowding out of Flood Insurance. Environmental and Resource Economics, 54(2), 179–200. https://doi.org/10.1007/s10640-012-9586-y

Raschky, P. A., & Weck-Hannemann, H. (2007). Charity hazard—A real hazard to natural disaster insurance? Environmental Hazards, 7(4), 321–329. https://doi.org/10.1016/j.envhaz.2007.09.002

Rawls, J. (1971). A Theory of Justice. Harvard University Press.

Reguero, B. G., Beck, M. W., Schmid, D., Stadtmüller, D., Raepple, J., Schüssele, S., & Pfliegner, K. (2020). Financing coastal resilience by combining nature-based risk reduction with insurance. Ecological Economics, 169, 106487. https://doi.org/10.1016/j.ecolecon.2019.106487

Reisinger, A., Garschagen, M., Mach, K. J., Pathak, M., Poloczanska, E., van Aalst, M., Ruane, A. C., Howden, M., Hurlbert, M., Mintenbeck, K., Pedace, R., Corradi, M. R., Viner, D., Vera, C., Kreibiehl, S., O'Neill, B., Pörtner, H.-O., Sillmann, J., Jones, R., & Ranasinghe, R. (2020). The concept of risk in the IPCC Sixth Assessment Report: A summary of crossWorking Group discussions. https://www.ipcc.ch/site/assets/uploads/2021/01/The-concept-of-risk-in-the-IPCC-Sixth-Assessment-Report.pdf

RMS. (2017). UK government Department for International Development (DFID) commissioned report on disaster losses and aid payments. RMS. https://forms2.rms.com/DFID-Executive-Summary.html

Robinson, P. J., & Botzen, W. J. W. (2018). The impact of regret and worry on the threshold level of concern for flood insurance demand: Evidence from Dutch homeowners. Judgment and Decision Making, 13(3), 237–245. https://doi.org/10.1017/S1930297500007671

Robinson, P. J., & Botzen, W. J. W. (2020). Flood insurance demand and probability weighting:

The influences of regret, worry, locus of control and the threshold of concern heuristic. Water Resources and Economics, 30, 100144. https://doi.org/10.1016/j.wre.2019.100144

Robinson, P. J., & Botzen, W. J. W. (2022). Setting descriptive norm nudges to promote demand for insurance against increasing climate change risk. The Geneva Papers on Risk and Insurance - Issues and Practice, 47(1), 27–49. https://doi.org/10.1057/s41288-021-00248-0

Robinson, P. J., Botzen, W. J. W., Kunreuther, H., & Chaudhry, S. J. (2021). Default options and insurance demand. Journal of Economic Behavior & Organization, 183, 39–56. https://doi.org/10.1016/j.jebo.2020.12.017

Roder, G., Hudson, P., & Tarolli, P. (2019). Flood risk perceptions and the willingness to pay for flood insurance in the Veneto region of Italy. International Journal of Disaster Risk Reduction, 37, 101172. https://doi.org/10.1016/j.ijdrr.2019.101172

Rotter, J. B. (1966). Generalized expectancies for internal versus external control of reinforcement. Psychological Monographs: General and Applied, 80(1), 1–28. https://doi.org/10.1037/h0092976

Ruckelshaus, M., Reguero, B. G., Arkema, K., Compeán, R. G., Weekes, K., Bailey, A., & Silver, J. (2020). Harnessing new data technologies for nature-based solutions in assessing and managing risk in coastal zones. International Journal of Disaster Risk Reduction, 51, 101795. https://doi.org/10.1016/j.ijdrr.2020.101795

Rufat, S., Robinson, P. J., & Botzen, W. J. W. (2024). Insights into the complementarity of natural disaster insurance purchases and risk reduction behavior. Risk Analysis, 44(1), 141–154. https://doi.org/10.1111/risa.14130

Rumson, A. G., & Hallett, S. H. (2019). Innovations in the use of data facilitating insurance as a resilience mechanism for coastal flood risk. Science of The Total Environment, 661, 598–612. https://doi.org/10.1016/j.scitotenv.2019.01.114

Saenz, C. (2009). What is Affordable Health Insurance?: The Reasonable Tradeoff Account of Affordability. Kennedy Institute of Ethics Journal, 19(4), 401–414. https://doi.org/10.1353/ken.0.0294

Salman, S., Hassan, R., & Tahniyath, M. (2019). Takaful an Innovation to Contemporary Insurance. 9, 2249–2496.

Salvati, P., Bianchi, C., Fiorucci, F., Giostrella, P., Marchesini, I., & Guzzetti, F. (2014). Perception of flood and landslide risk in Italy: A preliminary analysis. Natural Hazards and Earth System Sciences, 14(9), 2589–2603. https://doi.org/10.5194/nhess-14-2589-2014

Santeramo, F. G. (2019). I Learn, You Learn, We Gain Experience in Crop Insurance Markets. Applied Economic Perspectives and Policy, 41(2), 284–304. https://doi.org/10.1093/aepp/ppy012

Savitt, A. (2017). Insurance as a tool for hazard risk management? An evaluation of the literature. Natural Hazards, 86(2), 583–599. https://doi.org/10.1007/s11069-016-2706-1

Sayers, P., Penning-Rowsell, E. C., & Horritt, M. (2018). Flood vulnerability, risk, and social disadvantage: Current and future patterns in the UK. Regional Environmental Change, 18(2), 339–352. https://doi.org/10.1007/s10113-017-1252-z

Schäfer, L., Warner, K., & Kreft, S. (2019). Exploring and Managing Adaptation Frontiers with Climate Risk Insurance. In R. Mechler, L. M. Bouwer, T. Schinko, S. Surminski, & J. Linnerooth-

Bayer (Eds.), Loss and Damage from Climate Change (pp. 317–341). Springer International Publishing. https://doi.org/10.1007/978-3-319-72026-5_13

Schäfer, L., Waters, E., Kreft, S., & Zissener, M. (2016). Making Climate Risk Insurance Work for the Most Vulnerable: Seven Guiding Principles (Policy report 2016 No. 1; UNU-EHS PUBLICATION SERIES, p. 63). UNU-EHS, Munich Climate Insurance Initiative. https://collections.unu.edu/eserv/UNU:5830/MCII_ProPoor_161031_Online_meta.pdf

Schanz, K.-U. (2018). Understanding and Addressing Global Insurance Protection Gaps (p. 46). The Geneva Association. https://www.genevaassociation.org/sites/default/files/research-topics-document-type/pdf_public/understanding_and_addressing_global_insurance_protection_gaps.pdf

Schanz, K.-U., & Sommerrock, F. (2016). Harnessing Technology to Narrow the Insurance Protection Gap (p. 48). The Geneva Association. https://www.genevaassociation.org/sites/default/files/research-topics-document-type/pdf_public/harnessing-technology-to-narrow-the-insurance-protection-gap.pdf

Schirrmann, M., Giebel, A., Gleiniger, F., Pflanz, M., Lentschke, J., & Dammer, K.-H. (2016). Monitoring Agronomic Parameters of Winter Wheat Crops with Low-Cost UAV Imagery. Remote Sensing, 8(9), Articolo 9. https://doi.org/10.3390/rs8090706

Schlesinger, H. (2013). The Theory of Insurance Demand. In G. Dionne (Eds.), Handbook of Insurance (pp. 167–184). Springer New York. https://doi.org/10.1007/978-1-4614-0155-1_7

Schuster, C. E. (2021). ‘Risky Data’ for Inclusive Microinsurance Infrastructures. Development and Change, 52(4), 780–804. https://doi.org/10.1111/dech.12663

Scolobig, A., De Marchi, B., & Borga, M. (2012). The missing link between flood risk awareness and preparedness: Findings from case studies in an Alpine Region. Natural Hazards, 63(2), 499–520. https://doi.org/10.1007/s11069-012-0161-1

Seebauer, S., & Babcicky, P. (2020). The Sources of Belief in Personal Capability: Antecedents of Self-Efficacy in Private Adaptation to Flood Risk. Risk Analysis, 40(10), 1967–1982. https://doi.org/10.1111/risa.13531

Seifert, I., Botzen, W. J. W., Kreibich, H., & Aerts, J. C. J. H. (2013). Influence of flood risk characteristics on flood insurance demand: A comparison between Germany and the Netherlands. Natural Hazards and Earth System Sciences, 13(7), 1691–1705. https://doi.org/10.5194/nhess-13-1691-2013

Seifert-Dähnn, I. (2018). Insurance engagement in flood risk reduction – examples from household and business insurance in developed countries. Natural Hazards and Earth System Sciences, 18(9), 2409–2429. https://doi.org/10.5194/nhess-18-2409-2018

Seo, J., Duque, L., & Wacker, J. (2018). Drone-enabled bridge inspection methodology and application. Automation in Construction, 94, 112–126. https://doi.org/10.1016/j.autcon.2018.06.006

Shafran, A. P. (2011). Self-protection against repeated low probability risks. Journal of Risk and Uncertainty, 42(3), 263–285. https://doi.org/10.1007/s11166-011-9116-2

Shao, W., Feng, K., & Lin, N. (2019). Predicting support for flood mitigation based on flood insurance purchase behavior. Environmental Research Letters, 14(5), 054014. https://doi.org/10.1088/1748-9326/ab195a

Shao, W., Xian, S., Lin, N., Kunreuther, H., Jackson, N., & Goidel, K. (2017). Understanding the effects of past flood events and perceived and estimated flood risks on individuals' voluntary flood insurance purchase behavior. Water Research, 108, 391–400. https://doi.org/10.1016/j.watres.2016.11.021

Sheehan, B., Mullins, M., Shannon, D., & McCullagh, O. (2023). On the benefits of insurance and disaster risk management integration for improved climate-related natural catastrophe resilience. Environment Systems and Decisions, 43(4), 639–648. https://doi.org/10.1007/s10669-023-09929-8

Sheth, A., & Subramanian, H. (2019). Blockchain and contract theory: Modeling smart contracts using insurance markets. Managerial Finance, 46(6), 803–814. https://doi.org/10.1108/MF-10-2018-0510

Shetty, A., Shetty, A. D., Pai, R. Y., Rao, R. R., Bhandary, R., Shetty, J., Nayak, S., Keerthi Dinesh, T., & Dsouza, K. J. (2022). Block Chain Application in Insurance Services: A Systematic Review of the Evidence. Sage Open, 12(1), 21582440221079877. https://doi.org/10.1177/21582440221079877

Sidgwick, H. (1874). The Methods of Ethics (7th edition, 1907). Mcmillan.

Siebert, A. (2016). Analysis of the future potential of index insurance in the West African Sahel using CMIP5 GCM results. Climatic Change, 134(1–2), 15–28. https://doi.org/10.1007/s10584-015-1508-x

Singer, A. W. (2019). Risk Management Magazine—Can Blockchain Improve Insurance? Magazine. https://www.rmmagazine.com/articles/article/2019/02/01/-Can-Blockchain-Improve-Insurance-

Slovic, P., Fischhoff, B., Lichtenstein, S., Corrigan, B., & Combs, B. (1977). Preference for Insuring against Probable Small Losses: Insurance Implications. The Journal of Risk and Insurance, 44(2), 237. https://doi.org/10.2307/252136

Sohrabi, N., & Tari, Z. (2020). On The Scalability of Blockchain Systems. 2020 IEEE International Conference on Cloud Engineering (IC2E), 124–133. https://doi.org/10.1109/IC2E48712.2020.00020

Solín, Ľ., Madajová, M., & Skubinčan, P. (2018). Mitigating flood consequences: Analysis of private flood insurance in Slovakia. Journal of Flood Risk Management, 11(S1). https://doi.org/10.1111/jfr3.12191

Spekkers, M. H., Clemens, F. H. L. R., & Ten Veldhuis, J. A. E. (2015). On the occurrence of rainstorm damage based on home insurance and weather data. Natural Hazards and Earth System Sciences, 15(2), 261–272. https://doi.org/10.5194/nhess-15-261-2015

Standaert, W., & Muylle, S. (2022). Framework for open insurance strategy: Insights from a European study. The Geneva Papers on Risk and Insurance - Issues and Practice, 47(3), 643–668. https://doi.org/10.1057/s41288-022-00264-8

Stiglitz, J. E. (1983). Risk, Incentives and Insurance: The Pure Theory of Moral Hazard. The Geneva Papers on Risk and Insurance - Issues and Practice, 8(1), 4–33. https://doi.org/10.1057/gpp.1983.2

Stone, J. M. (1973). A Theory of Capacity and the Insurance of Catastrophe Risks (Part I). The Journal of Risk and Insurance, 40(2), 231. https://doi.org/10.2307/252115

Sun, R.-T., Garimella, A., Han, W., Chang, H.-L., & Shaw, M. J. (2020). Transformation of the Transaction Cost and the Agency Cost in an Organization and the Applicability of Blockchain—A Case Study of Peer-to-Peer Insurance. Frontiers in Blockchain, 3. https://doi.org/10.3389/fbloc.2020.00024

Sunyer, M. A., Madsen, H., & Ang, P. H. (2012). A comparison of different regional climate models and statistical downscaling methods for extreme rainfall estimation under climate change. Atmospheric Research, 103, 119–128. https://doi.org/10.1016/j.atmosres.2011.06.011

Surminski, S. (2013). The role of insurance risk transfer in encouraging climate investment in developing countries. In P.-M. Dupuy & J. E. Viñuales (Eds.), Harnessing Foreign Investment to Promote Environmental Protection (1st ed., pp. 228–253). Cambridge University Press. https://doi.org/10.1017/CBO9781139344289.012

Surminski, S. (2014). The Role of Insurance in Reducing Direct Risk—The Case of Flood Insurance. International Review of Environmental and Resource Economics, 7(3–4), 241–278. https://doi.org/10.1561/101.00000062

Surminski, S. (2018). Fit for Purpose and Fit for the Future? An Evaluation of the UK's New Flood Reinsurance Pool. Risk Management and Insurance Review, 21(1), 33–72. https://doi.org/10.1111/rmir.12093

Surminski, S., Aerts, J. C. J. H., Botzen, W. J. W., Hudson, P., Mysiak, J., & Pérez-Blanco, C. D. (2015). Reflections on the current debate on how to link flood insurance and disaster risk reduction in the European Union. Natural Hazards, 79(3), 1451–1479. https://doi.org/10.1007/s11069-015-1832-5

Surminski, S., Bouwer, L. M., & Linnerooth-Bayer, J. (2016). How insurance can support climate resilience. Nature Climate Change, 6(4), 333–334. https://doi.org/10.1038/nclimate2979

Surminski, S., & Hudson, P. (2017). Investigating the Risk Reduction Potential of Disaster Insurance Across Europe. The Geneva Papers on Risk and Insurance - Issues and Practice, 42(2), 247–274. https://doi.org/10.1057/s41288-016-0039-7

Surminski, S., & Oramas-Dorta, D. (2014). Flood insurance schemes and climate adaptation in developing countries. International Journal of Disaster Risk Reduction, 7, 154–164. https://doi.org/10.1016/j.ijdrr.2013.10.005

Surminski, S., Roezer, V., & Golnaraghi, M. (2020). Flood Risk Management in Germany. The Geneva Association. https://www.genevaassociation.org/sites/default/files/flood-risk-management-germany.pdf

Surminski, S., & Thieken, A. H. (2017). Promoting flood risk reduction: The role of insurance in Germany and England. Earth's Future, 5(10), 979–1001. https://doi.org/10.1002/2017EF000587

Swedloff, R. (2014). Risk Classification's Big Data (R)Evolution Symposium. Connecticut Insurance Law Journal, 21(1), [i]-374.

Terpstra, T., & Gutteling, J. M. (2008). Households' Perceived Responsibilities in Flood Risk Management in The Netherlands. International Journal of Water Resources Development, 24(4), 555–565. https://doi.org/10.1080/07900620801923385

Tesselaar, M., Botzen, W. J. W., & Aerts, J. C. J. H. (2020). Impacts of Climate Change and Remote Natural Catastrophes on EU Flood Insurance Markets: An Analysis of Soft and Hard Reinsurance Markets for Flood Coverage. Atmosphere, 11(2), 146.

https://doi.org/10.3390/atmos11020146

Tesselaar, M., Botzen, W. J. W., Haer, T., Hudson, P., Tiggeloven, T., & Aerts, J. C. J. H. (2020). Regional Inequalities in Flood Insurance Affordability and Uptake under Climate Change. Sustainability, 12(20), 8734. https://doi.org/10.3390/su12208734

Tesselaar, M., Botzen, W. J. W., Robinson, P. J., Aerts, J. C. J. H., & Zhou, F. (2022). Charity hazard and the flood insurance protection gap: An EU scale assessment under climate change. Ecological Economics, 193, 107289. https://doi.org/10.1016/j.ecolecon.2021.107289

Thaler, R. H., & Sustein, C. R. (2008). Nudge: Improving Decisions About Health, Wealth, and Happiness. Yale University Press.

Thaler, T., Fuchs, S., Priest, S., & Doorn, N. (2018). Social justice in the context of adaptation to climate change—Reflecting on different policy approaches to distribute and allocate flood risk management. Regional Environmental Change, 18(2), 305–309. https://doi.org/10.1007/s10113-017-1272-8

Thaler, T., & Hartmann, T. (2016). Justice and flood risk management: Reflecting on different approaches to distribute and allocate flood risk management in Europe. Natural Hazards, 83(1), 129–147. https://doi.org/10.1007/s11069-016-2305-1

Thieken, A. H., Petrow, T., Kreibich, H., & Merz, B. (2006). Insurability and Mitigation of Flood Losses in Private Households in Germany. Risk Analysis, 26(2), 383–395. https://doi.org/10.1111/j.1539-6924.2006.00741.x

Thomassen, M. K. K., & Hauge, Å. L. (2022). Insurance loss data for improved climate change adaptation. Conditions for data sharing and utilization. SINTEF akademisk forlag. https://brage.inn.no/inn-xmlui/handle/11250/3029952

Tjäder, O., & Ulrich, L. (2023). The Great DeFi Dilemma: How stakeholders can navigate the uncertain waters of decentralised finance adoption: An explorative study. https://gupea.ub.gu.se/handle/2077/77893

Tune, G. S. (1964). Response preferences: A review of some relevant literature. Psychological Bulletin, 61(4), 286–302. https://doi.org/10.1037/h0048618

Tversky, A., & Kahneman, D. (1973). Availability: A heuristic for judging frequency and probability. Cognitive Psychology, 5(2), 207–232. https://doi.org/10.1016/0010-0285(73)90033-9

Tversky, A., & Kahneman, D. (1991). Loss Aversion in Riskless Choice: A Reference-Dependent Model. The Quarterly Journal of Economics, 106(4), 1039–1061. https://doi.org/10.2307/2937956

Ulbrich, U., Leckebusch, G. C., & Donat, M. G. (2013). Windstorms, the Most Costly Natural Hazard in Europe. In S. Boulter, J. Palutikof, D. J. Karoly, & D. Guitart (Eds.), Natural Disasters and Adaptation to Climate Change (1st ed., pp. 109–120). Cambridge University Press. https://doi.org/10.1017/CBO9780511845710.015

Unterberger, C., Hudson, P., Botzen, W. J. W., Schroeer, K., & Steininger, K. W. (2019). Future Public Sector Flood Risk and Risk Sharing Arrangements: An Assessment for Austria. Ecological Economics, 156, 153–163. https://doi.org/10.1016/j.ecolecon.2018.09.019

Väisänen, S., Lehtoranta, V., Parjanne, A., Rytkönen, A.-M., & Aaltonen, J. (2016). Willingness of residents to invest in flood mitigation measures and to purchase flood insurance. E3S Web of Conferences, 7, 22001. https://doi.org/10.1051/e3sconf/20160722001

Van Winsen, F., De Mey, Y., Lauwers, L., Van Passel, S., Vancauteren, M., & Wauters, E. (2016). Determinants of risk behaviour: Effects of perceived risks and risk attitude on farmer's adoption of risk management strategies. Journal of Risk Research, 19(1), 56–78. https://doi.org/10.1080/13669877.2014.940597

Vecere, A., Martina, M., Monteiro, R., & Galasso, C. (2021). Satellite precipitation–based extreme event detection for flood index insurance. International Journal of Disaster Risk Reduction, 55, 102108. https://doi.org/10.1016/j.ijdrr.2021.102108

Velandia, M., Rejesus, R. M., Knight, T. O., & Sherrick, B. J. (2009). Factors Affecting Farmers' Utilization of Agricultural Risk Management Tools: The Case of Crop Insurance, Forward Contracting, and Spreading Sales. Journal of Agricultural and Applied Economics, 41(1), 107–123. https://doi.org/10.1017/S1074070800002583

Venäläinen, A., Lehtonen, I., Laapas, M., Ruosteenoja, K., Tikkanen, O., Viiri, H., Ikonen, V., & Peltola, H. (2020). Climate change induces multiple risks to boreal forests and forestry in Finland: A literature review. Global Change Biology, 26(8), 4178–4196. https://doi.org/10.1111/gcb.15183

von Dahlen, S., & von Peter, G. (2012). Natural Catastrophes and Global Reinsurance – Exploring the Linkages (2012). (BIS Quarterly Review December 2012). https://ssrn.com/abstract=2206335

Vriens, E., & De Moor, T. (2020). Mutuals on the Move: Exclusion Processes in the Welfare State and the Rediscovery of Mutualism. Social Inclusion, 8(1), 225–237. https://doi.org/10.17645/si.v8i1.2125

Vroege, W., Dalhaus, T., & Finger, R. (2019). Index insurances for grasslands – A review for Europe and North-America. Agricultural Systems, 168, 101–111. https://doi.org/10.1016/j.agsy.2018.10.009

Vroege, W., & Finger, R. (2020). Insuring Weather Risks in European Agriculture. EuroChoices, 19(2), 54–62. https://doi.org/10.1111/1746-692X.12285

Walker, G., & Burningham, K. (2011). Flood risk, vulnerability and environmental justice: Evidence and evaluation of inequality in a UK context. Critical Social Policy, 31(2), 216–240. https://doi.org/10.1177/0261018310396149

Wang, M., Liao, C., Yang, S., Zhao, W., Liu, M., & Shi, P. (2012). Are People Willing to Buy Natural Disaster Insurance in China? Risk Awareness, Insurance Acceptance, and Willingness to Pay. Risk Analysis, 32(10), 1717–1740. https://doi.org/10.1111/j.1539-6924.2012.01797.x

Wang, Q., Lau, R. Y. K., Si, Y.-W., Xie, H., & Tao, X. (2023). Blockchain-Enhanced Smart Contract for Cost-Effective Insurance Claims Processing: Journal of Global Information Management, 31(7), 1–21. https://doi.org/10.4018/JGIM.329927

Werner, J. (2009). Risk and risk aversion when states of nature matter. Economic Theory, 41(2), 231–246. https://doi.org/10.1007/s00199-008-0388-y

Wiering, M., Kaufmann, M., Mees, H., Schellenberger, T., Ganzevoort, W., Hegger, D. L. T., Larrue, C., & Matczak, P. (2017). Varieties of flood risk governance in Europe: How do countries respond to driving forces and what explains institutional change? Global Environmental Change, 44, 15–26. https://doi.org/10.1016/j.gloenvcha.2017.02.006

Wing, I. S., De Cian, E., & Mistry, M. N. (2021). Global vulnerability of crop yields to climate change. Journal of Environmental Economics and Management, 109, 102462. https://doi.org/10.1016/j.jeem.2021.102462

Winter, R. A. (2013). Optimal Insurance Contracts Under Moral Hazard. In G. Dionne (Eds.), Handbook of Insurance (pp. 205–230). Springer New York. https://doi.org/10.1007/978-1-4614-0155-1_9

WMO. (2020). State of the Global Climate 2020 (WMO-No. 1264; WMO, p. 56). World Meteorological Organization. https://library.wmo.int/viewer/56247?medianame=1264_Statement_2020_en_#page=1&viewer=picture&o=bookmark&n=0&q=

WMO. (2023). State of the Global Climate 2022 (WMO-No. 1316; WMO, p. 55). World Meteorological Organization. https://library.wmo.int/viewer/66214/download?file=Statement_2022.pdf&type=pdf&navigator=1

World Bank. (2018). Romania, Systematic Country Diagnosti , Climate and Disaster Management. The World Bank. https://documents1.worldbank.org/curated/en/785381530899707521/pdf/128046-SCD-PUBLIC-P160439-RomaniaSCDBackgroundNoteClimateandDisasterRiskManagement.pdf

Wu, Z., Zheng, X., Chen, Y., Huang, S., Hu, W., & Duan, C. (2023). Urban Flood Loss Assessment and Index Insurance Compensation Estimation by Integrating Remote Sensing and Rainfall Multi-Source Data: A Case Study of the 2021 Henan Rainstorm. Sustainability, 15(15), 11639. https://doi.org/10.3390/su151511639

Xian, S., Lin, N., & Kunreuther, H. (2017). Optimal house elevation for reducing flood-related losses. Journal of Hydrology, 548, 63–74. https://doi.org/10.1016/j.jhydrol.2017.02.057

Xiang, H., & Tian, L. (2011). Development of a low-cost agricultural remote sensing system based on an autonomous unmanned aerial vehicle (UAV). Biosystems Engineering, 108(2), 174–190. https://doi.org/10.1016/j.biosystemseng.2010.11.010

Yang, C. C., Li, L. S., & Wen, M.-M. (2011). Weather Risk Hedging in the European Markets and International Investment Diversification. The Geneva Risk and Insurance Review, 36(1), 74–94. https://doi.org/10.1057/grir.2010.4

Zandersen, M., Oddershede, J. S., Pedersen, A. B., Nielsen, H. Ø., & Termansen, M. (2021). Nature Based Solutions for Climate Adaptation—Paying Farmers for Flood Control. Ecological Economics, 179, 106705. https://doi.org/10.1016/j.ecolecon.2020.106705

Zhang, J., Czajkowski, J., Botzen, W. J. W., Robinson, P. J., & Tesselaar, M. (2022). Assessing the Drivers of Intrinsically Complex Hurricane Insurance Purchases: Lessons Learned from Survey Data in Florida. In J. M. Collins & J. M. Done (Eds.), Hurricane Risk in a Changing Climate (Vol. 2, pp. 283–321). Springer International Publishing. https://doi.org/10.1007/978-3-031-08568-0_12

Zhao, L. (2020). The Analysis of Application, Key Issues and the Future Development Trend of Blockchain Technology in the Insurance Industry. American Journal of Industrial and Business Management, 10(2), Articolo 2. https://doi.org/10.4236/ajibm.2020.102019

Zhao, W., Kunreuther, H., & Czajkowski, J. (2016). Affordability of the National Flood Insurance Program: Application to Charleston County, South Carolina. Natural Hazards Review, 17(1), 04015020. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000201

Zorn, M., Komac, B., Perko, D., & Ciglič, R. (2016). Dealing with natural disasters in a postsocialists society—The example of Slovenia. Acta Geobalcanica, 2(1), 55–62. https://doi.org/10.18509/AGB.2016.06

A Appendix

A.1 Search query strings

Below are reported the search queries strings used in Scopus and Web of Science.

Scopus

(“climate” OR “risk*” OR “climate risk*” OR “natural hazard*” OR “catastrophe*” OR “natcat*” OR “low-probability event*” OR “disaster*” OR “weather*” OR “risk perception”) AND ((“modelling” OR “forecast*” OR “projection*”) OR (“management” OR “reduction” OR “transfer” OR “pooling” OR “Insurance” OR “Reinsurance” OR “protection gap” OR “adaptation”)) AND (“Insurability” OR “Affordability” OR “Justice” OR “Solidarity” OR “Individual responsibility” OR “Solvency” OR “Public-private partnership” OR “PPP” OR “Disaster compensation” OR “Disaster relief” OR “Ecosystem service*” OR “Nature-based insurance” OR “Ecosystem-based”) AND (“Imperfect information” OR “Asymmetric information” OR “Charity hazard” OR “Risk aversion” OR “Loss aversion” OR “Ambiguity aversion” OR “Heuristics” OR “Status quo bias” OR “Availability bias” OR “Mental accounting” OR “Herding” OR “Threshold level of concern” OR “Trust” OR “Awareness” OR “Religion” OR “Social comparison” OR “Social norm*” OR “Basis risk” OR “Transaction costs” OR “Rapidity of payment*” OR “Cost of capital” OR “Moral hazard” OR “Annual contract” OR “annual pricing” OR “Long-term contract” OR “Long-term pricing” OR “Bounded rationality” OR “Bias in risk perception” OR “Accessibility challenges” OR “Regulatory barriers”) AND NOT “health”

Web of Science

(climate OR risk* OR climate risk* OR natural hazard* OR catastrophe* OR natcat* OR low-probability event* OR disaster* OR weather* OR risk perception) AND ((modelling OR forecast* OR projection*) OR (management OR reduction OR transfer OR pooling OR insurance OR reinsurance OR protection gap OR adaptation)) AND (insurability OR affordability OR justice OR solidarity OR individual responsibility OR solvency OR public-private partnership OR PPP OR disaster compensation OR disaster relief OR ecosystem service* OR nature-based insurance OR ecosystem-based) AND (imperfect information OR asymmetric information OR charity hazard OR risk aversion OR loss aversion OR ambiguity aversion OR heuristics OR status quo bias OR availability bias OR mental accounting OR herding OR threshold level of concern OR trust OR awareness OR religion OR social comparison OR social norm* OR basis risk OR transaction costs OR rapidity of payment* OR cost of capital OR moral hazard OR annual contract OR annual pricing OR long-term contract OR long-term pricing OR bounded rationality OR bias in risk perception OR accessibility challenges OR regulatory barriers) NOT health

A.2 Documents for AI-powered search

Below is the list of documents fed to Research Rabbit to conduct the AI-powered search.

1. Bruggeman, V., & Faure, M. (2018.). The Compensation for Victims of Disasters in and the Netherlands Germany, and the Netherlands. In Loyola Consumer Law Review (Vol. 31). https://lawecommons.luc.edu/lclr/vol31/iss2/5
2. Christophers, B. (2019). The allusive market: insurance of flood risk in neoliberal Britain. Economy and Society, 48(1), 1–29. https://doi.org/10.1080/03085147.2018.1547494
3. European Commission, Directorate-General for Climate Action, Kuik, O., Ruig, L., Persson, M. (2017). Insurance of weather and climate-related disaster risk : inventory and analysis of mechanisms to support

damage prevention in the EU : final report, Publications Office. https://data.europa.eu/doi/10.2834/40222
4. Holzheu, T., & Turner, G. (2018). The Natural Catastrophe Protection Gap: Measurement, Root Causes and Ways of Addressing Underinsurance for Extreme Events†. Geneva Papers on Risk and Insurance: Issues and Practice, 43(1), 37–71. https://doi.org/10.1057/s41288-017-0075-y
5. Hudson, P. (2018). A comparison of definitions of affordability for flood risk adaption measures: a case study of current and future risk-based flood insurance premiums in Europe. Mitigation and Adaptation Strategies for Global Change, 23(7), 1019–1038. https://doi.org/10.1007/s11027-017-9769-5
6. Hudson, P., Botzen, W. J. W., & Aerts, J. C. J. H. (2019). Flood insurance arrangements in the European Union for future flood risk under climate and socioeconomic change. Global Environmental Change, 58. https://doi.org/10.1016/j.gloenvcha.2019.101966
7. Hudson, P., Botzen, W. J. W., Czajkowski, J., & Kreibich, H. (2017). Moral Hazard in Natural Disaster Insurance Markets: Empirical Evidence from Germany and the United States. Land Economics, 93(2), 179-208. https://doi.org/10.3368/le.93.2.179
8. Hudson, P., de Ruig, L. T., de Ruiter, M. C., Kuik, O. J., Botzen, W. J. W., le Den, X., Persson, M., Benoist, A., & Nielsen, C. N. (2020). An assessment of best practices of extreme weather insurance and directions for a more resilient society. Environmental Hazards, 19(3), 301–321. https://doi.org/10.1080/17477891.2019.1608148
9. Jarzabkowski, P., Chalkias, K., Cacciatori, E., & Bednarek, R. (2018). Between state and market: protection gap entities and catastrophic risk. https://www.semanticscholar.org/paper/3a0a172d4cd3e6d7e12196a56e9f645be12c7794
10. Kousky, C., & Kunreuther, H. (2017). Defining the Roles of the Public and Private Sector in Risk Communication, Risk Reduction, and Risk Transfer. RFF Working Paper, 17-09, Resources for the Future. https://doi.org/10.2139/ssrn.3029630
11. Mandel, A., Tiggeloven, T., Lincke, D., Koks, E., Ward, P., & Hinkel, J. (2021). Risks on global financial stability induced by climate change: the case of flood risks. Climatic Change, 166(4). https://doi.org/10.1007/s10584-021-03092-2
12. O'Neill, J., & O'Neill, M. (2012). Social justice and the future of flood insurance. www.jrf.org.uk
13. OECD (2021), Enhancing financial protection against catastrophe risks: the role of catastrophe risk insurance programmes. www.oecd.org/daf/fin/insurance/Enhancing-financial-protection-againstcatastrophe-risks
14. Paleari, S. (2019). Disaster risk insurance: A comparison of national schemes in the EU-28. International Journal of Disaster Risk Reduction, 35. https://doi.org/10.1016/j.ijdrr.2018.12.021
15. Sakai, A., Fu, C Roch, F., & Wiriadinata, U. (2022). Sovereign Climate Debt Instruments: An Overview of the Green and Catastrophe Bond Markets. IMF Staff Climate Note, 2022/004. ISBN/ISSN: 9798400210006/2789-0600. https://www.imf.org/en/Publications/staff-climate-notes/Issues/2022/06/29/Sovereign-Climate-Debt-Instruments-An-Overview-of-the-Green-and-Catastrophe-Bond-Markets-518272
16. Sheehan, B., Mullins, M., Shannon, D., & McCullagh, O. (2023). On the benefits of insurance and disaster risk management integration for improved climate-related natural catastrophe resilience. Environment Systems and Decisions 43, 639–648. https://doi.org/10.1007/s10669-023-09929-8
17. Surminski, S. (2014). The role of insurance in reducing direct risk-the case of flood insurance. International Review of Environmental and Resource Economics, 7(3–4), 241–278. https://doi.org/10.1561/101.00000062
18. Tesselaar, M., Botzen, W. J. W., Haer, T., Hudson, P., Tiggeloven, T., & Aerts, J. C. J. H. (2020). Regional Inequalities in Flood Insurance Affordability and Uptake under Climate Change. Sustainability, 12(20), https://doi.org/10.3390/su12208734

A.3 Additional documents

A.3.1 Documents collected by the project proposers

Below is the list of documents collected by the project proposers.

1. Antofie, T., Luoni, S., Eklund, L., & Ferrer, M., (2020) Update of Risk Data Hub software and data architecture. Publications Office of the European Union. doi:10.2760/798003

2. Apergis, N., & Poufinas, T. (2020) The role of insurance growth in economic growth: Fresh evidence from a panel of OECD countries. The North American Journal of Economics and Finance, 53. https://doi.org/10.1016/j.najef.2020.101217.
3. Bucheli, J., Dalhaus, T., & Finger, R., (2021) The optimal drought index for designing weather index insurance. European Review of Agricultural Economics, 48(3), 573–597. https://doi.org/10.1093/erae/jbaa014.
4. Bucheli, J., Dalhaus, T., & Finger, R. (2022). Temperature effects on crop yields in heat index insurance. Food Policy, 107, 102214. https://doi.org/10.1016/j.foodpol.2021.102214
5. Courbage, C., & Golnaraghi, M. (2022). Extreme events, climate risks and insurance. The Geneva Papers on Risk and Insurance - Issues and Practice, 47(1–4). https://doi.org/10.1057/s41288-021-00260-4
6. Dudek, T., Ulm, E. R., & Noy, I. (2021). Demand for Multi-Year Catastrophe Insurance Contracts: Experimental Evidence for Mitigating the Insurance Gap (CESifo Working Paper 9442). https://www.cesifo.org/en/publications/2021/working-paper/demand-multi-year-catastrophe-insurance-contracts-experimental
7. Finger, R. Wüpper, D., & McCallum, C. (2023). The (in)stability of farmer risk preferences. Journal of Agricultural Economics. 74(1), 155-167. https://doi.org/10.1111/1477-9552.12496
8. Gray, I. (2021) Hazardous simulations: Pricing climate risk in US coastal insurance markets. Economy and Society, 50(2), 196-223. DOI: 10.1080/03085147.2020.1853358
9. Iyer, P., Bozzola, M., Hirsch, S., Meraner, M., & Finger, R. (2020). Measuring Farmer Risk Preferences in Europe: A Systematic Review Measuring Farmer Risk Preferences in Europe: A Systematic Review. Journal of Agricultural Economics, 71(1), 2020, 3–26. doi: 10.1111/1477-9552.12325
10. Kondrup, C., Mercogliano, P., Bosello, F., Mysiak, J., Scoccimarro, E., Rizzo, A., Ebrey, R., de Ruiter, M., Jeuken, A., & Watkiss, P. (2022). Climate adaptation modelling. https://doi.org/10.1007/978-3-030-86211-4
11. Kraehnert, K., Osberghaus, D., Hott, C., Habtemariam, L., Wätzold, F., Hecker, L. & Fluhrer, S. (2021). Insurance Against Extreme Weather Events: An Overview. Review of Economics, 72(2), 71-95. https://doi.org/10.1515/roe-2021-0024
12. Kreft, C., Robert Huber, R., Wuepper, D., & Finger, R. (2021). The role of non-cognitive skills in farmers' adoption of climate change mitigation measures. Ecological Economics, 189. https://doi.org/10.1016/j.ecolecon.2021.107169.
13. McFall, L. , Meyers, G., & Van Hoyweghen, I. (2020). Editorial: The personalisation of insurance: Data, behaviour and innovation. Big Data & Society, 7(2). https://doi.org/10.1177/2053951720973707
14. Mullins, M., Holland, C. P., & Cunneen, M. (2021). Creating ethics guidelines for artificial intelligence and big data analytics customers: The case of the consumer European insurance market, Patterns, 2(10). https://doi.org/10.1016/j.patter.2021.100362.
15. Ostrowska-Dankiewicz, A., Simionescu, M. (2020). Relationship between the Insurance Market and Macroeconomic Indicators in the EU Member States. Transformations in Business & Economics, Vol. 19, No 3 (51), 175-187. https://etalpykla.lituanistika.lt/object/LT-LDB-0001:J.04~2020~1618838816958/J.04~2020~1618838816958.pdf
16. Radu, N., Alexandru, F., & Badea, D. (2021). Integrating storm coverage in the management of householding insurance in romania. Proceedings of the international management conference, 15(1), 175-184. https://EconPapers.repec.org/RePEc:rom:mancon:v:15:y:2021:i:1:p:175-184.
17. Sainz de Murieta, E., Galarraga, I., & Olazabal, M. (2021). How well do climate adaptation policies align with risk-based approaches? An assessment framework for cities. Cities, 109, 103018. https://doi.org/10.1016/j.cities.2020.103018
18. Schaub, S., & Finger, R. (2020). Effects of drought on hay and feed grain prices. Environmental Research Letters, 15(3). DOI 10.1088/1748-9326/ab68ab
19. Spiegel, A., Britz, W., & Finger, R. (2021). Risk, Risk Aversion, and Agricultural Technology Adoption — A Novel Valuation Method Based on Real Options and Inverse Stochastic Dominance. Q Open, 1(2). https://doi.org/10.1093/qopen/qoab016
20. Vroege, W., Bucheli, J., Dalhaus, T., Hirschi, M., & Finger, R. (2021). Insuring crops from space: the potential of satellite-retrieved soil moisture to reduce farmers' drought risk exposure. European Review of Agricultural Economics, 48(2), 266–314, https://doi.org/10.1093/erae/jbab010

A.3.2 Documents collected by the authors

Below is the list of documents collected by the authors

1. Abdikerimova, S., & Feng, R. (2022). Peer-to-peer multi-risk insurance and mutual aid. European Journal of Operational Research, 299(2), 735-749. doi: 10.1016/j.ejor.2021.09.017
2. Abdou, H. A., Ali, K., & Lister, R. J. (2014). A comparative study of Takaful and conventional insurance: empirical evidence from the Malaysian market. Insurance Markets and Companies: Analyses and Actuarial Computations, (5, Iss. 1), 22-34.
3. Agarwal, S., Bhardwaj, G., Saraswat, E., Singh, N., Aggarwal, R., & Bansal, A. (2022, February). Insurtech fostering automated insurance process using deep learning approach. In 2022 2nd International conference on innovative practices in technology and management (ICIPTM) (Vol. 2, pp. 386-392). IEEE.
4. Akerlof, G. A. (1970). The Market for «Lemons»: Quality Uncertainty and the Market Mechanism. The Quarterly Journal of Economics, 84(3), 488. https://doi.org/10.2307/1879431
5. Bantwal, V. J., & Kunreuther, H. C. (2000). A cat bond premium puzzle?. The Journal of Psychology and Financial Markets, 1(1), 76-91. https://doi.org/10.1207/S15327760JPFM0101_07
6. Barocas S and Selbst AD (2016) Big Data's disparate impact. California Law Review 104(3): 671–732
7. Belissa, T. K., Lensink, R., & Van Asseldonk, M. (2020). Risk and ambiguity aversion behavior in index-based insurance uptake decisions: Experimental evidence from Ethiopia. Journal of Economic Behavior & Organization, 180, 718–730. https://doi.org/10.1016/j.jebo.2019.07.018
8. Benami, E., Jin, Z., Carter, M. R., Ghosh, A., Hijmans, R. J., Hobbs, A., ... & Lobell, D. B. (2021). Uniting remote sensing, crop modelling and economics for agricultural risk management. Nature Reviews Earth & Environment, 2(2), 140-159. doi: 10.1038/s43017-020-00122-y
9. Bernard, C., Liu, F., & Vanduffel, S. (2020). Optimal insurance in the presence of multiple policyholders. Journal of Economic Behavior & Organization, 180, 638–656. https://doi.org/10.1016/j.jebo.2020.02.012
10. Bernardino, G. (2020, February). Challenges and opportunities for the insurance sector in Europe. In Annales des Mines-Réalités industrielles (No. 1, pp. 99-102). Cairn/Softwin.
11. Berger, L., & Bosetti, V. (2020). Characterizing ambiguity attitudes using model uncertainty. Journal of Economic Behavior & Organization, 180, 621–637. https://doi.org/10.1016/j.jebo.2020.02.014
12. Bianconi, R. (2020), An Introduction to Weather Derivatives, Medium, 09/09/2020 https://medium.com/@remy.bianconi/an-introduction-to-weather-derivatives-5d6726e2ed54
13. Bracci, E., Tallaki, M., Ievoli, R., & Diplotti, S. (2022). Knowledge, diffusion and interest in blockchain technology in SMEs. Journal of Knowledge Management, 26(5), 1386-140. doi: 10.1108/JKM-02-2021-0099
14. Brahm, M., Vila, D., Martinez Saenz, S., & Osgood, D. (2019). Can disaster events reporting be used to drive remote sensing applications? A Latin America weather index insurance case study. Meteorological Applications, 26(4), 632-641. https://doi.org/10.1002/met.1790
15. Brockett, P., Wang, M., & Yang, C. (2005). Weather derivatives and weather risk management. Risk Management and Insurance Review, 8(1), 127-140. http://dx.doi.org/10.1111/j.1540-6296.2005.00052.x
16. Browne, M.J., Hoyt, R.E (2000). The Demand for Flood Insurance: Empirical Evidence. Journal of Risk and Uncertainty 20, 291–306. https://doi.org/10.1023/A:1007823631497
17. Browne, M. J., Knoller, C., & Richter, A. (2015). Behavioral bias and the demand for bicycle and flood insurance. Journal of Risk and Uncertainty, 50(2), 141–160. https://doi.org/10.1007/s11166-015-9212-9
18. Bulte, E., Cecchi, F., Lensink, R., Marr, A., & Van Asseldonk, M. (2020). Does bundling crop insurance with certified seeds crowd-in investments? Experimental evidence from Kenya. Journal of Economic Behavior & Organization, 180, 744–757. https://doi.org/10.1016/j.jebo.2019.07.006
19. Cai, H., Chen, Y., Fang, H., & Zhou, L.-A. (2015). The Effect of Microinsurance on Economic Activities: Evidence from a Randomized Field Experiment. Review of Economics and Statistics, 97(2), 287–300. https://doi.org/10.1162/REST_a_00476
20. Cappiello, A. (2018). Digital Disruption and InsurTech Start-ups: Risks and Challenges. In A. Cappiello (A c. Di), Technology and the Insurance Industry: Re-configuring the Competitive Landscape (pp. 29–50). Springer International Publishing. https://doi.org/10.1007/978-3-319-74712-5_3

21. Carter, R. L., & Dickinson, G. M. (1992). Obstacles to the Liberalization of Trade in Insurance. (2012/04/20 ed., Vol. 120). Cambridge University Press; Cambridge Core. https://www.cambridge.org/core/product/F314714D4DC5B730E0250216F7567E3F
22. Castillo, M. J., Boucher, S., & Carter, M. (2016). Index insurance: Using public data to benefit small-scale agriculture. International Food and Agribusiness Management Review, 19, 93-114. doi: 10.22004/ag.econ.240698
23. CCR. (2021). Natural Disaster Compensation Scheme in France, Principles and Operation. https://www.ccr.fr/documents/35794/35836/indemnisation+cat-nat.pdf/ff905a8f-ccb3-44e2-a0d0-b92c6d2e352e?t=1452598764000
24. Cole, S., Giné, X., Tobacman, J., Topalova, P., Townsend, R., & Vickery, J. (2013). Barriers to Household Risk Management: Evidence from India. American Economic Journal: Applied Economics, 5(1), 104–135. https://doi.org/10.1257/app.5.1.104
25. Collier, B., Skees, J., & Barnett, B. (2009). Weather index insurance and climate change: Opportunities and challenges in lower income countries. The Geneva Papers on Risk and Insurance-Issues and Practice, 34, 401-424. https://doi.org/10.1057/gpp.2009.11
26. Cyprus Civil Defence. (2020). Report on Disaster Risk Management in the Repubblic of Cyprus. https://www.moi.gov.cy/moi/CD/cd.nsf/All/CD5C4F5974A63727C22586A2003CF5AC/$file/2020%20DRM%20REPORT.pdf?OpenElement
27. De Leeuw, J., Vrieling, A., Shee, A., Atzberger, C., Hadgu, K. M., Biradar, C. M., ... & Turvey, C. (2014). The potential and uptake of remote sensing in insurance: A review. Remote Sensing, 6(11), 10888-10912. doi: 10.3390/rs61110888
28. DEFRA. (2014). Managing the future financial risk of flooding: Impact Assessment.
29. Dercon, S., Gunning, J. W., & Zeitlin, A. (2019). The demand for insurance under limited trust: Evidence from a field experiment in Kenya [CSAE Working Paper WPS/201906]. https://ora.ox.ac.uk/objects/uuid:c59af3dd-67b8-4c10-b9b4-4536a8c5caf5/files/sqn59q4471
30. Eerola, T., Hakala, T., Järvinen, S., Korte, S., Myyrä, S., & Viljanen, S. (Forthcoming). Potential for agricultural insurance in the Boreal region [PIISA deliverable].
31. EIOPA. (2023). Dashboard on insurance protection gap for natural catastrophes [dataset]. https://www.eiopa.europa.eu/tools-and-data/dashboard-insurance-protection-gap-natural-catastrophes_en
32. EIOPA. (2024). Measures to address demand side aspects of the NATCAT protection gap (EIOPA-BoS-24/022; EIOPA Staff Paper). https://www.eiopa.europa.eu/document/download/be654e97-0428-4702-bd75-fb5d217e1960_en?filename=Revised%20Staff%20Paper%20on%20measures%20to%20address%20demand-side%20aspects%20of%20the%20NatCat%20protection%20gap.pdf
33. Eling, M., Nuessle, D., & Staubli, J. (2022). The impact of artificial intelligence along the insurance value chain and on the insurability of risks. The Geneva Papers on Risk and Insurance-Issues and Practice, 47(2), 205-241. doi: 10.1057/s41288-020-00201-7
34. Ellsberg, D. (1961). Risk, Ambiguity, and the Savage Axioms. The Quarterly Journal of Economics, 75(4), 643. https://doi.org/10.2307/1884324
35. Eltazarov, S., Bobojonov, I., Kuhn, L., & Glauben, T. (2021). Mapping weather risk–a multi-indicator analysis of satellite-based weather data for agricultural index insurance development in semi-arid and arid zones of Central Asia. Climate Services, 23, 100251. doi: 10.1016/j.cliser.2021.100251
36. Ender, M., & Zhang, R. (2015). Efficiency of weather derivatives for Chinese agriculture industry. China Agricultural Economic Review, 7(1), 102-121. https://doi.org/10.1108/CAER-06-2013-0089
37. Enz, R. (2000). The S-Curve Relation Between Per-Capita Income and Insurance Penetration. The Geneva Papers on Risk and Insurance - Issues and Practice, 25(3), 396–406. https://doi.org/10.1111/1468-0440.00072
38. Ericson, R., Barry, D., & Doyle, A. (2000). The moral hazards of neoliberalism: lessons from the private insurance industry. *Economy and Society,* 29(4) https://www.tandfonline.com/doi/epdf/10.1080/03085140050174778?needAccess=true
39. European Commission. (2021). Closing the climate protection gap—Scoping policy and data gaps (127; Commission Staff Working Documents). European Commission. https://climate.ec.europa.eu/document/download/fcbc99b7-fab5-46e3-93b5-4bd5e27ad954_en?filename=swd_2021_123_en.pdf

40. European Commission. (2023). Approved 28 CAP Strategic Plans (2023-2027) Summary overview for 27 Member States Facts and figures. European Commission. https://agriculture.ec.europa.eu/system/files/2023-06/approved-28-cap-strategic-plans-2023-27.pdf
41. European Investment Bank. (2023). Investing in nature-based solutions: State of play and way forward for public and private financial measures in Europe. Publications Office. https://data.europa.eu/doi/10.2867/031133
42. Evans, L., Maio, G. R., Corner, A., Hodgetts, C. J., Ahmed, S., & Hahn, U. (2013). Self-interest and pro-environmental behaviour. Nature Climate Change, 3(2), 122–125. https://doi.org/10.1038/nclimate1662
43. Fox, C. R., & Tversky, A. (1995). Ambiguity aversion and comparative ignorance. The quarterly journal of economics, 110(3), 585-603. https://doi.org/10.2307/2946693
44. Frigo, A., & Venturini, A. (2024). La copertura assicurativa contro i rischi naturali: Un'analisi preliminare. *Banca d'Italia, Questioni di Economia e Finanza, Occasional paper series*, No. 830. https://www.bancaditalia.it/pubblicazioni/qef/2024-0830/QEF_830_24.pdf
45. Furlanetto, J., Dal Ferro, N., Caceffo, D., Morari, F. (2023) Mapping hailstorm damage on winter wheat (Triticum aestivum L.) using a microscale UAV hyperspectral approach. *Precision Agriculture*. https://doi.org/10.1007/s11119-023-10088-8
46. Furlanetto, J., Dal Ferro, N., Longo, M., Sartori, L., Polese, R., Caceffo, D., Nicoli, L., Morari, F. (2023) LAI estimation through remotely sensed NDVI following hail defoliation in maize (Zea mays L.) using Sentinel-2 and UAV imagery. *Precision Agriculture*, 24, 1355–1379. https://doi.org/10.1007/s11119-023-09993-9
47. Furlanetto, J., Longo, M., Nicoli, L., Caceffo, D., Persichetti, A., Morari, F., & Dal Ferro, N. (2022, May). Spectral mixture analysis to quantity winter wheat (Triticum aestivum L.) damage caused by hailstorms. In EGU General Assembly Conference Abstracts (pp. EGU22-4868).
48. Garrido, A., & Zilberman, D. (2008). Revisiting the demand for agricultural insurance: The case of Spain. Agricultural Finance Review, 68(1), 43–66. https://doi.org/10.1108/00214660880001218
49. Gómez-Limón, J. A., & Granado-Díaz, R. (2023). Assessing the demand for hydrological drought insurance in irrigated agriculture. Agricultural Water Management, 276, 108054. https://doi.org/10.1016/j.agwat.2022.108054
50. Goodwin, B. K. (2001). Problems with market insurance in agriculture. American Journal of Agricultural Economics, 83(3), 643-649. Retrieved from https://www.jstor.org/stable/1245093?seq=1#page_scan_tab_contents
51. Goodwin, B. K., & Vado, L. A. (2007). Public responses to agricultural disasters: Rethinking the role of government. *Canadian Journal of Agricultural Economics/ Revue canadienne d'agroeconomie*, 55(4), 399-590. https://dx.doi.org/10.1111/j.1744-7976.2007.00099.x
52. Gor, N. (2013). Microtakaful-Islamic insurance for deprived: innovation, sustainability and inclusive growth. International Journal of Business, Economics and Law, 3(2), 18-24.
53. Götze, T., & Gürtler, M. (2022). Risk transfer beyond reinsurance: The added value of CAT bonds. The Geneva Papers on Risk and Insurance - Issues and Practice, 47(1), 125–171. https://doi.org/10.1057/s41288-021-00234-6
54. Gronberg, T. J., & Neilson, W. S. (2007). Incentive under Weather Derivatives vs. Crop Insurance. Unpublished Manuscript). Institute for Science, Technology and Public Policy, Texas A&M University. Available at: https://web.utk.edu/~wneilson/GronbergNeilsonIncentives.pdf
55. Hamilton, S. (2020). Crop Insurance and the New Deal Roots of Agricultural Financialization in the United States. Enterprise & Society, 21(3), 648–680. https://doi.org/10.1017/eso.2019.43
56. Hanger, S., Linnerooth-Bayer, J., Surminski, S., Nenciu-Posner, C., Lorant, A., Ionescu, R., & Patt, A. (2018). Insurance, Public Assistance, and Household Flood Risk Reduction: A Comparative Study of Austria, England, and Romania. Risk Analysis, 38(4), 680–693. https://doi.org/10.1111/risa.12881
57. Harries, T. (2012). The Anticipated Emotional Consequences of Adaptive Behaviour—Impacts on the Take-up of Household Flood-Protection Measures. Environment and Planning A: Economy and Space, 44(3), 649–668. https://doi.org/10.1068/a43612
58. Headwaters Economics. (2016). Do Insurance Policies and Rates Influence Home Development on Fire-Prone Lands? (p. 14). https://headwaterseconomics.org/wp-content/uploads/Insurance-Wildfire-Home-Development.pdf

59. Hu, L., Zhang, C., Zhang, M., Shi, Y., Lu, J., & Fang, Z. (2023). Enhancing FAIR data services in agricultural disaster: A review. Remote Sensing, 15(8), 2024. doi: 10.3390/rs15082024
60. Ivčević, A., Statzu, V., Satta, A., & Bertoldo, R. (2021). The future protection from the climate change-related hazards and the willingness to pay for home insurance in the coastal wetlands of West Sardinia, Italy. *International Journal of Disaster Risk Reduction*, 52, 2212-4209. https://doi.org/10.1016/j.ijdrr.2020.101956
61. Iwahashi, Y., Sigit, G., Utoyo, B., Lubis, I., Junaedi, A., Trisasongko, B. H., Wijaya, I. M. A. S., Maki, M., Hongo, C., & Homma, K. (2023). Drought Damage Assessment for Crop Insurance Based on Vegetation Index by Unmanned Aerial Vehicle (UAV) Multispectral Images of Paddy Fields in Indonesia. Agriculture, 13(1), Articolo 1. https://doi.org/10.3390/agriculture13010113
62. Jha, N., Prashar, D., Khalaf, O. I., Alotaibi, Y., Alsufyani, A., & Alghamdi, S. (2021). Blockchain based crop insurance: a decentralized insurance system for modernization of Indian farmers. Sustainability, 13(16), 8921. doi: 10.3390/su13168921
63. Johannsdottir, L. (2017). Climate Change and Iceland's Risk-Sharing System for Natural Disasters. The Geneva Papers on Risk and Insurance - Issues and Practice, 42(2), 275–295. https://doi.org/10.1057/s41288-016-0002-7
64. Johnson, C., Penning-Rowsell, E., & Parker, D. (2007). Natural and imposed injustices: the challenges in implementing 'fair' flood risk management policy in England. *The Geographical Journal*, 173(4), 374–390. https://dx.doi.org/10.1111/j.1475-4959.2007.00256.x
65. Johnson, P., Ricker, B., & Harrison, S. (2017). Volunteered Drone Imagery: Challenges and constraints to the development of an open shared image repository. doi: 10.24251/HICSS.2017.242
66. Kar, A. K., & Navin, L. (2021). Diffusion of blockchain in insurance industry: An analysis through the review of academic and trade literature. Telematics and Informatics, 58, 101532. doi: 10.1016/j.tele.2020.101532
67. Karlan, D., Osei, R., Osei-Akoto, I., & Udry, C. (2014). Agricultural Decisions after Relaxing Credit and Risk Constraints. The Quarterly Journal of Economics, 129(2), 597–652. https://doi.org/10.1093/qje/qju002
68. Keucheyan, R. (2023). The "Environment Making State" and Climate Change: The French "Cat Nat" Reinsurance Scheme Under Strain. Antipode, 55(2), 506–526. https://doi.org/10.1111/anti.12901
69. Kleinschroth, F., Banda, K., Zimba, H., Dondeyne, S., Nyambe, I., Spratley, S., & Winton, R. S. (2022). Drone imagery to create a common understanding of landscapes. Landscape and Urban Planning, 228, 104571. doi: 10.1016/j.landurbplan.2022.104571
70. Koeva, M., Gasuku, O., Lengoiboni, M., Asiama, K., Bennett, R. M., Potel, J., & Zevenbergen, J. (2021). Remote sensing for property valuation: a data source comparison in support of fair land taxation in rwanda. Remote Sensing, 13(18), 3563. doi: 10.3390/rs13183563
71. Kostić, N., & Sedej, T. (2022). Blockchain technology, inter-organizational relationships, and management accounting: A synthesis and a research agenda. Accounting Horizons, 36(2), 123-141. doi: 10.2308/HORIZONS-19-147
72. Kousky, C. (2017). Revised Risk Assessments and the Insurance Industry. In E. J. Balleisen, L. S. Bennear, K. D. Krawiec, & J. B. Wiener (A c. Di), Policy Shock (pp. 58–81). Cambridge University Press. https://doi.org/10.1017/9781316492635.003
73. Kucharczyk, M., & Hugenholtz, C. H. (2021). Remote sensing of natural hazard-related disasters with small drones: Global trends, biases, and research opportunities. Remote Sensing of Environment, 264, 112577. doi: 10.1016/j.rse.2021.112577
74. Kunreuther, H. (2015). The Role of Insurance in Reducing Losses from Extreme Events: The Need for Public–Private Partnerships. Geneva Pap Risk Insur Issues Pract 40, 741–762. https://doi.org/10.1057/gpp.2015.14
75. Kunreuther, H. (2018). All-Hazards Homeowners Insurance: Challenges and Opportunities. Risk Management and Insurance Review, 21(1), 141–155. https://doi.org/10.1111/rmir.12091
76. Kunreuther, H., Conell-Price, L., Kovacs, P., & Goda, K. (2021). The Impact of a Government Risk Pool and an Opt-Out Framing on Demand for Earthquake Protection (w29144; p. w29144). National Bureau of Economic Research. https://doi.org/10.3386/w29144
77. Kunreuther, H., Ginsberg, R., Miller, L., Sagi, P., Slovic, P., Borkan, B., & Katz, N. (1978). Disaster Insurance Protection: Public Policy Lessons. Wiley.

78. Lampe, I., & Würtenberger, D. (2020). Loss aversion and the demand for index insurance. Journal of Economic Behavior & Organization, 180, 678–693. https://doi.org/10.1016/j.jebo.2019.10.019
79. Lanfranchi, D., & Grassi, L. (2022). Examining insurance companies' use of technology for innovation. The Geneva Papers on Risk and Insurance-Issues and Practice, 47(3), 520-537. https://doi.org/10.1057/s41288-021-00258-y
80. Le Roux, S. (2020). Climate change catastrophes and insuring decisions: A study in the presence of ambiguity. Journal of Economic Behavior & Organization, 180, 992–1002. https://doi.org/10.1016/j.jebo.2018.07.021
81. Leal, M., Hudson, P., Mobini, S., Sörensen, J., Madeira, P. M., Tesselaar, M., & Zêzere, J. L. (2022). Natural hazard insurance outcomes at national, regional and local scales: A comparison between Sweden and Portugal. Journal of Environmental Management, 322, 116079. https://doi.org/10.1016/j.jenvman.2022.116079
82. Lin, L., & Chen, C. (2020). The promise and perils of InsurTech. Singapore Journal of Legal Studies, (Mar 2020), 115-142. doi: 10.2139/ssrn.3463533
83. Liu, X., Van Kooten, G. C., Gerbrandt, E. M., & Duan, J. (2023). Prospects for weather-indexed insurance for blueberry growers. Agricultural Finance Review, 83(2), 333–351. https://doi.org/10.1108/AFR-05-2022-0059
84. Longo, M., Furlanetto, J., Dal Ferro, N., Caceffo, D., & Morari, F. (2022, May). Coupling process-based models and remote sensing data to predict yield loss by hail damage. In EGU General Assembly Conference Abstracts (pp. EGU22-4594).
85. Loukil, F., Boukadi, K., Hussain, R., & Abed, M. (2021). Ciosy: A collaborative blockchain-based insurance system. Electronics, 10(11), 1343. doi: 10.3390/electronics10111343
86. Lucas, C. H. (2018). Concerning values: What underlies public polarisation about climate change?Geographical Research,56(3), 298–310. doi: 10.1111/1745-5871.12284
87. Martin, D. (2014, February 8). River Quango has allowed 190,000 new homes on flood plains since 1996 despite concerns they could be uninsurable. Daily Mail. https://www.dailymail.co.uk/news/article-2561713/River-quango-allowed-190-000-new-homes-flood-plains-formed-Environment-Agency-agreed-construction-despite-concerns-uninsurable.html
88. Matese, A., Toscano, P., Di Gennaro, S. F., Genesio, L., Vaccari, F. P., Primicerio, J., Belli, C., Zaldei, A., Bianconi, R., & Gioli, B. (2015). Intercomparison of UAV, Aircraft and Satellite Remote Sensing Platforms for Precision Viticulture. Remote Sensing, 7(3), Articolo 3. https://doi.org/10.3390/rs70302971
89. Matheswaran, K., Alahacoon, N., Pandey, R., Amarnath, G. (2019). Flood risk assessment in South Asia to prioritize flood index insurance applications in Bihar, India. *Geomatics, Natural Hazards and Risk*, 10(1), 26-48. https://doi.org/10.1080/19475705.2018.1500495
90. Maysami, R. C., & Kwon, W. J. (1999). An Analysis of Islamic Takaful Insurance. Journal of Insurance Regulation, 18(1).
91. McClelland, G. H., Schulze, W. D., & Coursey, D. L. (1993). Insurance for low-probability hazards: A bimodal response to unlikely events. Journal of Risk and Uncertainty, 7(1), 95–116. https://doi.org/10.1007/BF01065317
92. Michel-Kerjan, E., & Morlaye, F. (2008). Extreme events, global warming, and insurance-linked securities: How to trigger the "tipping point". The Geneva Papers on Risk and Insurance-Issues and Practice, 33, 153-176. https://doi.org/10.1057/palgrave.gpp.2510159
93. Mishra, A. K., & El-Osta, H. S. (2002). Managing risk in agriculture through hedging and crop insurance: What does a national survey reveal? Agricultural Finance Review, 62(2), 135–148. https://doi.org/10.1108/00214930280001134
94. Mullins, M., Holland, C. P., & Cunneen, M. (2021). Creating ethics guidelines for artificial intelligence and big data analytics customers: The case of the consumer European insurance market. Patterns, 2(10). doi: 10.1016/j.patter.2021.100362
95. Munich RE. (2021). Improving Flood Resilience Through Community Insurance and Nature-Based Solutions. Munich RE. https://www.munichre.com/content/dam/munichre/mram/content-pieces/pdfs/reinsurance-solutions/TNC_Whitepaper.pdf/_jcr_content/renditions/original./TNC_Whitepaper.pdf
96. Musshoff et al. (2011). Management of climate risks in agriculture – will weather derivatives permeate? Applied Economics, 43(9), 1067-1077. https://doi.org/10.1080/00036840802600210

97. Mysiak, J., Surminski, S., Thieken, A., Mechler, R., & Aerts, J. (2016). Brief communication: Sendai framework for disaster risk reduction – success or warning sign for Paris? Natural Hazards and Earth System Sciences, 16(10), 2189–2193. https://doi.org/10.5194/nhess-16-2189-2016
98. Nagendra, N. P., Narayanamurthy, G., Moser, R., Hartmann, E., & Sengupta, T. (2023). Technology Assessment Using Satellite Big Data Analytics for India's Agri-Insurance Sector. IEEE Transactions on Engineering Management, 70(3), 1099-1113. doi: 10.1109/TEM.2022.3159451
99. Njegomir, V., & Demko Rihter, J. (2013). Innovations of insurance companies and investment funds. Management Journal for Theory and Practice Management, 68, 59-67.
100. Njegomir, V., & Bojanić, T. (2021). Disruptive technologies in the operation of insurance industry. Tehnički vjesnik, 28(5), 1797-1805. doi: 10.17559/TV-20200922132555
101. Nordlander, L., Pill, M., & Martinez Romera, B. (2020). Insurance schemes for loss and damage: fools' gold? *Climate Policy*, 20:6, 704-714. https://doi.org/10.1080/14693062.2019.1671163
102. Nordmeyer, E. F., & Musshoff, O. (2023). German farmers' perceived usefulness of satellite-based index insurance: insights from a transtheoretical model. Agricultural Finance Review, 83(3), 511-527. https://doi.org/10.1108/AFR-10-2022-0125
103. Norta, A., Rossar, R., Parve, M., & Laas-Billson, L. (2019). Achieving a high level of open market-information symmetry with decentralised insurance marketplaces on blockchains. In Intelligent Computing: Proceedings of the 2019 Computing Conference, Volume 1 (pp. 299-318). Springer International Publishing. doi: 10.1007/978-3-030-22871-2_22
104. Nzembela, K., & Mazambani, L. (2019). Role of Microinsurance in Protecting the Poor. 10, 10–25. https://doi.org/10.9790/5933-1003051525
105. OECD. (2018). The Contribution of Reinsurance Markets to Managing Catastrophe Risk.
106. OMB. (2016). Standards and Finance to Support Community Resilience [Report]. Office of Management and Budget.
107. Otto A, Agatz N, Campbell J, Golden B, Pesch E. (2018) Optimization approaches for civil applications of unmanned aerial vehicles (UAVs) or aerial drones: A survey. *Networks*, 72, 1–48. https://doi.org/10.1002/net.21
108. Outreville, J. F. (2011). The Relationship between Insurance Growth and Economic Development: 80 Empirical Papers for a Review of the Literature. ICER Working Paper No. 12/2011. http://dx.doi.org/10.2139/ssrn.1885401
109. Palm, R., & Hodgson, M. (1992). Earthquake Insurance: Mandated Disclosure and Homeowner Response in California. Annals of the Association of American Geographers, 82(2), 207–222. https://doi.org/10.1111/j.1467-8306.1992.tb01905.x
110. Peter, R., & Ying, J. (2020). Do you trust your insurer? Ambiguity about contract nonperformance and optimal insurance demand. Journal of Economic Behavior & Organization, 180, 938–954. https://doi.org/10.1016/j.jebo.2019.01.002
111. Pew Research Center. (2017). Europe's Growing Muslim Population (p. 59). Pew Research Center. https://www.pewresearch.org/wp-content/uploads/sites/20/2017/11/FULL-REPORT-FOR-WEB-POSTING.pdf
112. Poljanšek, K., Marin Ferrer, M., De Groeve, T., & Clark, I. (A c. Di). (2017). Science for disaster risk management 2017: Knowing better and losing less. Publications Office of the European Union. https://data.europa.eu/doi/10.2788/842809
113. Poussin, J. K., Botzen, W. J. W., & Aerts, J. C. J. H. (2014). Factors of influence on flood damage mitigation behaviour by households. Environmental Science & Policy, 40, 69–77. https://doi.org/10.1016/j.envsci.2014.01.013
114. Pu, C., Chen, Y. B., & Pan, X. (2018). Weather indexes, index insurance and weather index futures. Insurance Markets and Companies, 9(1), 32. doi: 10.21511/ins.09(1).2018.04
115. Radu, D. (2022). Disaster risk financing: Limiting the fiscal cost of climate-related disasters. Publications Office of the European Union.
116. Ralph, O. (2016, April 4). Flood Re expects 350,000 properties to be put into scheme. Financial Times. https://www.ft.com/content/3c72961a-f820-11e5-96db-fc683b5e52db
117. Raschky, P. A., & Weck-Hannemann, H. (2007). Charity hazard—A real hazard to natural disaster insurance? Environmental Hazards, 7(4), 321–329. https://doi.org/10.1016/j.envhaz.2007.09.002

118. Reguero, B. G., Beck, M. W., Schmid, D., Stadtmüller, D., Raepple, J., Schüssele, S., & Pfliegner, K. (2020). Financing coastal resilience by combining nature-based risk reduction with insurance. Ecological Economics, 169, 106487. https://doi.org/10.1016/j.ecolecon.2019.106487
119. RMS. (2017). UK government Department for International Development (DFID) commissioned report on disaster losses and aid payments. RMS. https://forms2.rms.com/DFID-Executive-Summary.html
120. Robinson, P. J., & Botzen, W. J. W. (2018). The impact of regret and worry on the threshold level of concern for flood insurance demand: Evidence from Dutch homeowners. Judgment and Decision Making, 13(3), 237–245.
121. Robinson, P. J., & Botzen, W. J. W. (2022). Setting descriptive norm nudges to promote demand for insurance against increasing climate change risk. The Geneva Papers on Risk and Insurance - Issues and Practice, 47(1), 27–49. https://doi.org/10.1057/s41288-021-00248-0
122. Robinson, P. J., Botzen, W. J. W., Kunreuther, H., & Chaudhry, S. J. (2021). Default options and insurance demand. Journal of Economic Behavior & Organization, 183, 39–56. https://doi.org/10.1016/j.jebo.2020.12.017
123. Rotter, J. B. (1966). Generalized expectancies for internal versus external control of reinforcement. Psychological Monographs: General and Applied, 80(1), 1–28. https://doi.org/10.1037/h0092976
124. Rumson, A. G., & Hallett, S. H. (2019). Innovations in the use of data facilitating insurance as a resilience mechanism for coastal flood risk. Science of The Total Environment, 661, 598-612. doi: 10.1016/j.scitotenv.2019.01.114
125. Saenz, C. (2009). What is Affordable Health Insurance?: The Reasonable Tradeoff Account of Affordability. Kennedy Institute of Ethics Journal 19(4), 401-414. https://doi.org/10.1353/ken.0.0294
126. Salman, S. A. (2014). Contemporary issues in Takaful (Islamic insurance). Asian Social Science, 10(22), 210. doi: 10.5539/ass.v10n22p210
127. Salman, S. A., Hassan, R., & Tahniyath, M. (2019). Takaful an innovation to contemporary insurance. International Journal of Research in Social Sciences, 9(8), 434-442.
128. Santeramo, F. G. (2019). I Learn, You Learn, We Gain Experience in Crop Insurance Markets. Applied Economic Perspectives and Policy, 41(2), 284–304. https://doi.org/10.1093/aepp/ppy012
129. Schirrmann, M., Giebel, A., Gleiniger, F., Pflanz, M., Lentschke, J., & Dammer, K. H. (2016). Monitoring agronomic parameters of winter wheat crops with low-cost UAV imagery. Remote Sensing, 8(9), 706. doi: 10.3390/rs8090706
130. Schlesinger, H. (2013). The Theory of Insurance Demand. In G. Dionne (A c. Di), Handbook of Insurance (pp. 167–184). Springer New York. https://doi.org/10.1007/978-1-4614-0155-1_7
131. Seifert-Dahnn, I. (2018). Insurance engagement in flood risk reduction - examples from household and business insurance in developed countries. N*atural Hazards and Earth System Sciences,* 18(9), 2409–2429. https://dx.doi.org/10.5194/nhess-18-2409-2018
132. Seo, J., Duque, L., & Wacker, J. (2018). Drone-enabled bridge inspection methodology and application. Automation in construction, 94, 112-126. doi: 10.1016/j.autcon.2018.06.006
133. Shao, W. Y., Xian, S. Y., Lin, N., Kunreuther, H., Jackson, N., & Goidel, K. (2017). Understanding the effects of past flood events and perceived and estimated flood risks on individuals' voluntary flood insurance purchase behavior. *Water Research*, 108, 391-400 https://dx.doi.org/10.1016/j.watres.2016.11.021
134. Sheth, A., & Subramanian, H. (2020). Blockchain and contract theory: modeling smart contracts using insurance markets. Managerial Finance, 46(6), 803-814. https://doi.org/10.1108/MF-10-2018-0510
135. Shetty, A., Shetty, A. D., Pai, R. Y., Rao, R. R., Bhandary, R., Shetty, J., Nayak, S., Keerthi Dinesh, T., & Dsouza, K. J. (2022). Block Chain Application in Insurance Services: A Systematic Review of the Evidence. Sage Open, 12(1), 21582440221079877. https://doi.org/10.1177/21582440221079877
136. Singer, A. W. (2019). Can blockchain improve insurance?. Risk Management, 66(1), 20-25. Retrieved from https://www.rmmagazine.com/articles/article/2019/02/01/-Can-Blockchain-Improve-Insurance-
137. Slovic, P., Fischhoff, B., Lichtenstein, S., Corrigan, B., & Combs, B. (1977). Preference for Insuring against Probable Small Losses: Insurance Implications. The Journal of Risk and Insurance, 44(2), 237. https://doi.org/10.2307/252136
138. Sohrabi, N., & Tari, Z. (2020, April). On the scalability of blockchain systems. In 2020 IEEE International Conference on Cloud Engineering (IC2E) (pp. 124-133). IEEE. doi: 10.1109/IC2E48712.2020.00020

139. Sun, R. T., Garimella, A., Han, W., Chang, H. L., & Shaw, M. J. (2020). Transformation of the transaction cost and the agency cost in an organization and the applicability of blockchain—a case study of peer-to-peer insurance. Frontiers in Blockchain, 3, 24. doi: 10.3389/fbloc.2020.00024
140. Stiglitz, J. E. (1983). Risk, Incentives and Insurance: The Pure Theory of Moral Hazard. The Geneva Papers on Risk and Insurance - Issues and Practice, 8(1), 4–33. https://doi.org/10.1057/gpp.1983.2
141. Stone, J. M. (1973). A Theory of Capacity and the Insurance of Catastrophe Risks (Part I). The Journal of Risk and Insurance, 40(2), 231. https://doi.org/10.2307/252115
142. Sunyer, M. A., Madsen, H., & Ang, P. H. (2012). A comparison of different regional climate models and statistical downscaling methods for extreme rainfall estimation under climate change. Atmospheric Research, 103, 119–128. https://doi.org/10.1016/j.atmosres.2011.06.011
143. Surminski, S., Roezer, V., & Golnaraghi, M. (2020). Flood Risk Management in Germany. The Geneva Association. https://www.genevaassociation.org/sites/default/files/flood-risk-management-germany.pdf
144. Swedloff, R. (2014). Risk classification's big data (r) evolution. Conn. Ins. LJ, 21, 339.
145. Thaler, R. H., & Sustein, C. R. (2008). Nudge: Improving Decisions About Health, Wealth, and Happiness. Yale University Press.
146. Tjäder, O., & Ulrich, L. (2023). The Great DeFi Dilemma: How stakeholders can navigate the uncertain waters of decentralised finance adoption: An explorative study. Retrieved from https://hdl.handle.net/2077/77893
147. Tversky, A., & Kahneman, D. (1973). Availability: A heuristic for judging frequency and probability. Cognitive Psychology, 5(2), 207–232. https://doi.org/10.1016/0010-0285(73)90033-9
148. Velandia, M., Rejesus, R. M., Knight, T. O., & Sherrick, B. J. (2009). Factors Affecting Farmers' Utilization of Agricultural Risk Management Tools: The Case of Crop Insurance, Forward Contracting, and Spreading Sales. Journal of Agricultural and Applied Economics, 41(1), 107–123. https://doi.org/10.1017/S1074070800002583
149. Van Winsen, F., De Mey, Y., Lauwers, L., Van Passel, S., Vancauteren, M., & Wauters, E. (2016). Determinants of risk behaviour: Effects of perceived risks and risk attitude on farmer's adoption of risk management strategies. Journal of Risk Research, 19(1), 56–78. https://doi.org/10.1080/13669877.2014.940597
150. Vecere, A., Martina, M., Monteiro, R., Galasso, C. (2021). Satellite precipitation-based extreme event detection for flood index insurance. *International Journal of Disaster Risk Reduction*, 55, 102108. https://doi.org/10.1016/j.ijdrr.2021.102108
151. Villarroya, T. M., & Agrónoma, I. (2016). Hydrological Drought Index Insurance for Irrigated Agriculture. A Doctoral Thesis, Polytechnic University of Madrid. Retrieved from http://oa.upm.es/43595/
152. Vriens, E., & De Moor, T. (2020). Mutuals on the Move: Exclusion Processes in the Welfare State and the Rediscovery of Mutualism. *Institutions of Inclusion and Exclusion*, 8(1). https://dx.doi.org/10.17645/si.v8i1.2125
153. Wang, Q., Lau, R. Y. K., Si, Y.-W., Xie, H., & Tao, X. (2023). Blockchain-Enhanced Smart Contract for Cost-Effective Insurance Claims Processing: Journal of Global Information Management, 31(7), 1–21. https://doi.org/10.4018/JGIM.329927
154. Werner, J. (2009). Risk and risk aversion when states of nature matter. Economic Theory, 41(2), 231–246. https://doi.org/10.1007/s00199-008-0388-y
155. Wing, I. S., De Cian, E., & Mistry, M. N. (2021). Global vulnerability of crop yields to climate change. Journal of Environmental Economics and Management, 109, 102462. https://doi.org/10.1016/j.jeem.2021.102462
156. WMO. (2020). State of the Global Climate 2020 (WMO-No. 1264; WMO, p. 56). World Meteorological Organization. https://library.wmo.int/viewer/56247?medianame=1264_Statement_2020_en_#page=1&viewer=picture&o=bookmark&n=0&q=
157. WMO. (2023). State of the Global Climate 2022 (WMO-No. 1316; WMO, p. 55). World Meteorological Organization. https://library.wmo.int/viewer/66214/download?file=Statement_2022.pdf&type=pdf&navigator=1
158. Xian, S., Lin, N., & Kunreuther, H. (2017). Optimal house elevation for reducing flood-related losses. Journal of Hydrology, 548, 63–74. https://doi.org/10.1016/j.jhydrol.2017.02.057

159. Yang, C., Li, L. S., & Wen, M. (2011). Weather risk hedging in the European markets and international investment diversification. The Geneva Risk and Insurance Review, 36, 74-94. Retrieved from https://link.springer.com/ article/10.1057/grir.2010.4
160. Zhang, J., Czajkowski, J., Botzen, W. J. W., Robinson, P. J., & Tesselaar, M. (2022). Assessing the Drivers of Intrinsically Complex Hurricane Insurance Purchases: Lessons Learned from Survey Data in Florida. In J. M. Collins & J. M. Done (A c. Di), Hurricane Risk in a Changing Climate (Vol. 2, pp. 283–321). Springer International Publishing. https://doi.org/10.1007/978-3-031-08568-0_12
161. Zhao, L. (2020). The analysis of application, key issues and the future development trend of blockchain technology in the insurance industry. American Journal of Industrial and Business Management, 10(2), 305-314. doi: 10.4236/ajibm.2020.102019
162. Zhao, W., Kunreuther, H., & Czajkowski, J. (2016). Affordability of the National Flood Insurance Program: Application to Charleston County, South Carolina. Natural Hazards Review, 17(1), 04015020. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000201

A.4 Variables used in the full-text screening and data extraction

Below is the list of variables and the respective values and instructions used for the data extraction in the full-text screening.

Variable	Description and values
Accept:	Select one of these options Y = the document contains useful elements for the deliverable N = the document is not useful for the deliverable NA = the document is not available to access"
Explanation:	Briefly explain the reasons for accepting or rejecting the document
Title:	Title of the document
Country:	Two-digit country code according to UN nomenclature
Analysis:	Specify the type of analysis reported in the paper. Use the following abbreviations: lit = literature review map = mapping review (has a geographical connotation) mod = modelling or forecast surv = survey or questionnaire --> the aim is to provide a description exp = experiments (economic, behavioural, psychological) --> the aim is to study a (causal) relationship between factors stat = statistical or econometric analysis other = please specify If multiple the document reports multiple types of analysis, please put all the applicable ones separated by commas. For instance: lit, map, other (specify)
Model:	If available, specify which model(s) was used for the analysis. For instance: discrete choice experiment, conditional logit model, fixed effects estimation
Sector:	Specify to which sector investigated in the analysis or targeted by the insurance instruments (where relevant). Use the following

	abbreviations: hous = households busi = businesses agri = agriculture fore = forests city = cities eco = ecosystems nbs = nature-based solutions other = please specify ns = not specified If multiple sectors are analysed at the same time, please put all the applicable ones separated by commas. For instance: agri, fore, other (specify)
Hazard:	Specify the hazard investigated in the analysis and/or targeted by the insurance instruments. Use the following abbreviations. flood = flooding drou = droughts wind = wind, wind gusts, windthrow wild = wildfires heat = heatwaves storm = storms, convective storms hail = hail, hailstorms snow = snow rain = rainfall hurr = hurricane, medicane ligh = lightnings bio = biotic risks (e.g. pests) other = please specify ns = not specified If multiple hazards are analysed at the same time, please put all the applicable ones separated by commas. For instance: flood, wild, other (specify)
Insurance_instrument:	Specify the type of insurance or financial instrument analysed. Use the following abbreviations: ind = indemnity insurance par = parametric insurance idx = index-based insurance micr = microinsurance tak = takaful tech = insuretech rein = reinsurance PPP = public-private partnership bond = cat bonds, resilience bonds ils = insurance linked securities other = please specify ns = not specified If multiple types of instruments are analysed, please put all the applicable ones separated by commas. For instance: ind, par, other (specify)
Results:	Briefly summarise the results of the document

Chapter:	Specify in which chapter of the deliverable the document should be mentioned. The list of chapters with a brief description for each of them is reported below. The full structure of the deliverable, with a breakdown of the topics contained in each chapter, it available on sharepoint at the link reported in the adjacent cell. Chapters: 1 = introduction (terminology, state of the art, motivation for deliverable) 2 = mapping of insurance market in Europe 3 = causes of insurance protection gap (demand, supply, policy barriers) 4 = climate (change) modelling/forecast, and how insurers factor in climate and global environmental change in their products 5 = innovations in design and delivery of insurance products, market proliferation, etc. If the document can contribute to more than one chapter, please indicate all the relevant chapters separated by commas. For instance: 2, 4, 5
Insurance_benefits:	Briefly list the benefits of insurance. If the document does not contain information on this, leave the cell blank.
IPG_def:	Definition(s) of insurance protection gap used. If the document does not contain information on this, leave the cell blank.
IPG_size:	Briefly report the estimated size of IPG in the countries/regions analysed. If the document does not contain information on this, leave the cell blank.
Climate_modelling:	Briefly describe what the document says about climate modelling techniques. If the document does not contain information on this, leave the cell blank.
Climate_model_ins:	Briefly describe what the document says about how insurance companies source and use information on future climate scenarios. If the document does not contain information on this, leave the cell blank.
Ins_enforcement:	Specify the type of insurance enforcement system applied in the country(ies) analysed. Use the following abbreviations: comp = compulsory semi = semi-voluntary volu = voluntary other(specify) If more than one type of system is discussed, please put all that applies, if possible referencing the corresponding country. For instance, volu (IT, IR), comp (FR, SP), other(specify). If the document does not contain information on this, leave the cell blank.
National_scheme:	Specify the type of national insurance scheme adopted in the country(ies) analysed. Use the following abbreviations: publ = full public ex post disaster relief guar = only public guarantee on insurable assets and/or events

	PPP = PPP mark = full market-based system puma = public insurer in a free-market system other (specify) If more than one type of system is discussed, please put all that applies, if possible referencing the corresponding country. For instance, mark (IR), PPP (FR, SP), other(specify). If the document does not contain information on this, leave the cell blank.
Demand_barr:	If chapter 3 is selected, please specify which (if any) demand-side barriers are discussed. Use the following abbreviations: imri = Imperfect information about risk and risk reduction imlo = Imperfect information about low-probability events asym = Asymmetric information (lower-risk agents not willing to pay community premiums) char = Charity hazard affo = Affordability riav = Risk aversion loav = Loss aversion amav = Ambiguity aversion staq = Status quo bias avai = Availability ment = Mental accounting herd = Herding conc = Mismatch with threshold level of concern trus = Trust in financial institutions and insurance companies atti = Attitudes toward climate risk and insurance cult = Cultural and social norms other (specify) If multiple barriers are analysed at the same time, please put all the applicable ones separated by commas. For instance: imlo, riav, conc, other (specify). If the document does not contain information on this, leave the cell blank.
Supply_barr:	If chapter 3 is selected, please specify which (if any) supply-side barriers are discussed. Use the following abbreviations: insu = Insurability char = Limiting characteristics of insurance products (e.g., community premiums, fixed coverage, fixed deductibles, etc.) stru = Structure of (re)insurance products (e.g., annual vs longer-term pricing) basi = Basis risk tran = Transaction costs rapi = Rapidity of payments capi = Cost of capital mora = Moral hazard other (specify) If multiple barriers are analysed at the same time, please put all the applicable ones separated by commas. For instance: tran, capi, mora, other (specify). If the document does not contain information on this, leave the cell blank.

Regulatory_barr:	If chapter 3 is selected, please specify which (if any) regulatory/legislative barriers are discussed. Use the following abbreviations: affo = Affordability solv = Solvency (especially Solvency II) reg = Weak regulatory and legislative frameworks/environments (limited ability to enforce rules and ability to protect policyholders) cert = Certifications/Requirements and lack thereof reli = Disaster relief/compensation funds (certain vs ad hoc), and them being/not being included in national fiscal budgets just = Principles of justice and solidarity (e.g., see O'Neill and O'Neill (2012)) lppp = Limited diffusion and design of PPPs (e.g., FloodRe, France, Spain) righ = Ambiguity/Imperfections in the allocation of property rights (e.g., for forest insurance) cmh = Country-level moral hazard (in case of common EU fund for disaster relief/compensation) glob = Regulations that limit access to global reinsurance markets or limit activities of international (re)insurers on national market other(specify) If multiple barriers are analysed at the same time, please put all the applicable ones separated by commas. For instance: affo, reli, just, other (specify). If the document does not contain information on this, leave the cell blank.
Prod_innov:	If chapter 5 is selected, please specify which (if any) possible product innovations are discussed. Use the following abbreviations: dece = Decentralised insurance solutions bund = Bundling of perils and with other (more salient) products opt =Opt-out contracts long = Long(er)-term contracts and pricing surc = Surcharge to insurance premiums (e.g., France, Spain) disc = Subsidised premium discounts vouc = Means-tested vouchers cons = consultancy from Insurance companies other (specify) If multiple innovations are analysed at the same time, please put all the applicable ones separated by commas. For instance: bund, opt, vouc, other(specify). If the document does not contain information on this, leave the cell blank.
Data_innov:	If chapter 5 is selected, please specify which (if any) possible data innovations are discussed. Use the following abbreviations: dron = Drone imagery remo = Satelliteimagery and/or remote sensing bloc = Blockchain cybe = Cybersecurity other (specify) If multiple innovations are analysed at the same time, please put all the applicable ones separated by commas. For instance: dron,

	bloc, other(specify). If the docuement does not contain information on this, leave the cell blank.
Eco_nbs_ins:	Briefly describe what the document says about ecosystem services, ecosystem-based insurance, nature-based solutions and their potential use to integrate climate insurance. If the docuement does not contain information on this, leave the cell blank.

Funded by
the European Union