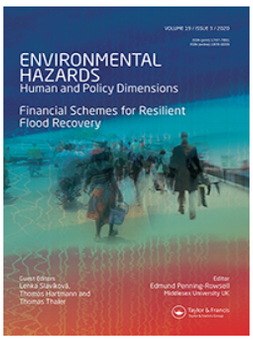

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An assessment of best practices of extreme weather insurance and directions for a more resilient society

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ABSTRACT

Extreme weather resilience has been defined as being based on three pillars: resistance (the ability to lower impacts), recovery (the ability to bounce back), and adaptive capacity (the ability to learn and improve). These resilience pillars are important both before and after the occurrence of extreme weather events. Extreme weather insurance can influence these pillars of resilience depending on how particular insurance mechanisms are structured. We explore how the lessons learnt from the current best insurance practices can improve resilience to extreme weather events. We employ an extensive inventory of private property and agricultural crop insurance mechanisms to conduct a multi-criteria analysis of insurance market outcomes. We draw conclusions regarding the patterns in the best practice from six European countries to increase resilience. We suggest that requirements to buy a bundle extreme weather event insurance with general insurance packages are strengthened and supported with structures to financing losses through public-private partnerships. Moreover, support for low income households through income vouchers could be provided. Similarly, for the agricultural sector we propose moving towards comprehensive crop yield insurance linked to general agricultural subsidies. In both cases a nationally representative body can coordinate the various stakeholders into acting in concert.

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Extreme weather; insurance; resilience; climate change adaptation; risk management

1. Introduction

Extreme weather events can have large impacts on society. For example, in 2016 a combination of flash floods and storms in Germany, Belgium, and Switzerland inflicted $2.2 billion in losses. Similarly, across central Europe a hail storm led to $1.9 billion in damage (Munich Re, 2017). About 50% of these costs were absorbed by insurers. However, this is not always the case. There can be limits to insurance, as can be seen

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when insurers leave markets or restrict coverage (Cremades et al., 2018). A sufficiently resilient society can limit these impacts, as resilience is a proactive and forward-looking concept. While there is no commonly accepted definition of resilience, resilience can build upon three pillars: resistance, recovery, and adaptive capacity (Thieken, Mariani, Longfield, & Vanneuville, 2014). Resistance is the ability to limit disaster impacts. Recovery relates to the time needed to return to the pre-disaster state. Adaptive capacity refers to the ability to be better prepared for future disasters.

There are several strategies for improving the resistance and recovery pillars. These strategies can be broadly grouped into prevention, mitigation, and risk-transfer. Prevention measures are put in place to prevent damage from certain extreme weather events from occurring. One example of such a measure is a dike (Aerts, Botzen, De Moel, & Bowman, 2013). Mitigation actions limit damage when an event occurs, for example, building codes (Burby, 2001) or property-level measures (Kreibich, Thieken, Petrow, Müller, & Merz, 2005) that reduce the susceptibility to damage. Risk-transfer strategies, on the other hand, do not decrease the direct impacts from an event. Instead, they allow financial reserves to be developed in order to aid recovery, thereby helping people get back on their feet (Botzen, 2013). Additionally, as prevention and mitigation cannot prevent all of the potential impacts of extreme weather events, risk-transfer helps society to manage the remaining risk, if risk-transfer and mitigation are sufficiently linked, allowing for proactive risk management.

Proactive risk management is required to minimise current and future extreme weather impacts. The Sendai framework for disaster risk reduction for the period 2015–2030 prioritises developing societal resilience through the use of measures that finance recovery costs while incentivising risk reduction (Mysiak, Surminski, Thieken, Mechler, & Aerts, 2016). Insurance, the prime example of risk-transfer, fills these roles by providing compensation after an extreme weather event, while acting as a potential price signal of risk. A strong price signal provides an incentive for active policyholder-level risk management. Additionally, insurance regulations or requirements can enforce a certain low level of vulnerability before potential policyholders can be insured. Finally, a functioning insurance sector can aggregate and disseminate information before and after disasters.

However, despite the potential for insurance to act as a transformative strategy for meeting the objectives of the Sendai framework and adapting to climate change, the role of insurance is viewed differently across stakeholders, depending on their level of risk and cultural context. Acknowledging the importance of local context is important, as it shows that there is not a one-size-fits-all solution – what might be acceptable in one region may not be in another, leading to the idiosyncratic development of insurance markets (Surminski et al., 2015). These differences can allow for a range of structures and outcomes that can be studied, and potential patterns in success factors and common outcomes can be identified.

To this end, we conducted a comparative study of private property and agricultural insurance in 12 different countries for a range of extreme weather events. The objective was to identify best practice in order to draw conclusions about improving extreme weather resilience, which can inform future policy directions across Europe. For private property insurance, we investigated floods (pluvial, fluvial, and coastal), hail, and windstorms, and for the agricultural insurance sector, we also included droughts.[1] We developed a holistic evaluation framework based on a multi-criteria analysis (MCA) in order

to judge best practice holistically across extreme weather events and five key outcomes: insurance penetration rates, risk-signalling and risk-reduction incentives, insurance affordability and availability, the speed and certainty of payments, and insurer solvency. These outcomes were determined by a review of the literature and stakeholder engagement. Moreover, we assumed the presence of three different risk management objectives: providing high degrees of coverage and affordability; balancing the different objectives of relevant stakeholders; and the ability of insurance to act as a risk management mechanism.

One novel way that we extend the current literature is by collecting and reporting new information on the functioning of insurance markets for extreme weather risks in Europe holistically across multiple hazards, rather than focussing on a single risk, as is common in the academic literature, e.g. Michel-Kerjan and Kunreuther (2011), Hudson, Botzen, Feyen, and Aerts (2016) or Unterberger, Hudson, Botzen, Schroeer, and Steininger (2019). On the basis of this data collection, we draw conclusions about best practices for Europe that can be used to enhance the flood resilience of European households. Additionally, our study extends the nascent literature investigating insurance mechanisms via MCA. For example, Hochrainer-Stigler and Lorant (2018) who presented an MCA of potential reforms to the European Union Solidarity Fund or Unterberger et al. (2019) who study potential reforms to the Austria Catastrophe Fund. We develop this limited literature by presenting an MCA framework and data collection approach that was used to study a range of extreme weather events across varying contexts within 12 European countries, across two insurance sectors.

In conducting the MCA, we identified Denmark, France, Spain, and the UK as exemplars of best practice for private property insurance, while for the agriculture sector the exemplars were Austria, Spain, and Sweden. Across both sectors we find that, despite the differing development trajectories for insurance markets, the best practice cases display similar patterns of behaviour even if the implementation differed in practice. Therefore, our results indicate a set of market features that improve flood resilience if applied to less well-performing markets. Moreover, the relatively low scores achieved in the MCA indicate that there is room for improvement in how Europe uses insurance to boost flood resilience, by focusing more on the resistance and adaptive capacity-boosting elements of resilience.

Finally, the suggested series of policy recommendations for increasing resilience has features similar to those of the reforms for the National Flood Insurance Program in the United States as proposed, for example, by Michel-Kerjan and Kunreuther (2011). This demonstrates the overall generalizability of both these results and policy directions at the global level regarding how insurance could move forwards.

2. Methodology

2.1. The interaction of insurance and resilience

The traditional role of insurance is focused upon enhancing the recovery pillar of resilience, with insurance providing financial protection against extreme weather events. Insurance coverage replaces a randomly occurring large loss with a smaller fixed cost, which is welfare enhancing for risk-averse individuals (Mas-Colell, 1995). The rapid provision of compensation payments is especially important in the wake of large events. For

example, the 2002 flood in Germany caused an average loss of €58,000, while the 2013/2014 winter flooding in the UK inflicted an average loss of €35,000 (Chatterton et al., 2016). Such amounts can be beyond the means of those affected to be able recover from the disaster in a timely manner. The provision of secure compensation limits the long-run negative impacts of a slower recovery (Botzen, 2013; Schäfer, Warner, & Kreft, 2019). Therefore, sufficient insurance coverage improves the recovery pillar by increasing and diversifying the policyholder's recovery capacity.

Concerning the resistance pillar, insurance can also play a role in proactively limiting impacts before extreme weather events occur (Kunreuther & Michel-Kerjan, 2009). One such avenue is the provision of direct incentives for policyholder risk reduction. For example, by allowing premiums to reflect the underlying risk, policyholders can be provided with premium discounts if they implement risk-reducing measures (Hudson et al., 2016; Kunreuther & Michel-Kerjan, 2013). The second is in setting minimum requirements in order to be insured, such as meeting building code regulations, which has been successful in the USA (Burby, 2001).

The final pillar is adaptive capacity. A functioning insurance market can contribute towards creating a more adaptively capable society by acting as an information generation and dissemination platform. For example, insurers require diverse portfolios of policyholders who undertake different strategies for extreme weather event risk management. The insurer is in a position to aggregate these experiences and see which measures are more likely to be successful and can share this information with policyholders. Additionally, a functional insurance market can facilitate adaptive capacity, as the various risk management stakeholders contribute different areas of expertise. This combination of expertise creates a more detailed understanding of where and how the disaster impacts materialise, which would not be available if stakeholders were not encouraged to act in concert.

2.2. Case study selection

This section is a select summary of the characteristics of insurance mechanisms, the details of which we reported in our report published by the European Comission (2017), which contains the underlying data and inventory of insurance mechanisms. In that report, we used the inventory proposed in Paudel et al. (2012) as a baseline for data collection. The table and adapted definitions from the underlying report are presented in Appendix 2. We reviewed the academic and grey literature to fill in the requirements of the inventory. An initial literature search was conducted for the European Union. The final 12 case studies shown in Figure 1(a) were selected based on data availability, quality, and consistency for the studied insurance markets. Following this selection, relevant local stakeholders (e.g. national insurance associations) were approached to assess the validity of this information and adjust and update it as required.

Figure 1(b and c) provide examples of the information uncovered. They highlight the degree to which the public and private sectors collaborate with regard to extreme weather insurance. The information indicates that the majority of extreme weather insurance is provided by the private market. The remainder of the extreme weather insurance is provided through a combination of public-private partnerships. These public-private partnerships can vary in scope across countries. For example, the French partnership covers a

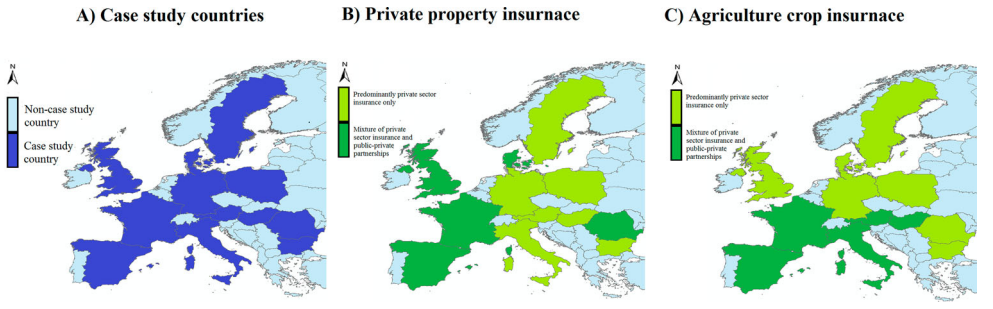

Figure 1. Selected European case study countries, noted in dark blue.

large range of extreme weather events, while the UK partnership is focused upon flooding. However, there is no country that relies solely on publicly provided insurance, even though public compensation schemes exist.

In terms of provision, in the private property sector wind and hail storms are generally covered as part of household insurance policies. Flooding coverage tends to be voluntary, which is associated with low coverage rates. In the agricultural insurance sector, the event most commonly protected against is hail.

2.3. Extreme weather event insurance assessment criteria

Functional extreme weather event insurance markets must meet conditions of actuarial and economic insurability (Charpentier, 2008). Actuarial insurability can be defined as consisting of random quantifiable events with losses being relatively uncorrelated across policyholders. Economic insurability requires the absence of major information asymmetries between market agents and that there be sufficient overlap between the consumers' willingness to pay for insurance and the offered premiums. However, meeting these conditions is not sufficient to determine best practice, as meeting the insurability conditions produces a range of trade-offs. For instance, there is a known trade-off between the incentive for risk reduction and the affordability of premiums. Additionally, the importance of these trade-offs differs across stakeholders and their objectives within the public policy process (Surminski, 2018).

Insurance market outcomes should be evaluated within their wider contexts. We base the best practice benchmarks on a set of criteria drawn from risk management objectives for insurance from the academic and grey literature, for example, which is detailed in Appendix 1: Golnaraghi, Surminski, and Schanz (2017), Kunreuther (2017), Surminski (2018), The Geneva Association (2018). Additionally, during the completion of our report we consulted expert stakeholders from the insurance industry and academia via three project workshops/events, a series of email/telephone interviews, and a review of the public consultation responses to the European Commission Green Paper on the Insurance of Natural and Man-made Disasters. This process highlighted the importance of the following outcomes: the overall penetration rate across extreme weather events, risk signalling or risk reduction ability, the ability to absorb large losses, the ability to provide quick and certain compensation, and the overall affordability and availability of insurance. See Appendix 1 for details.

2.4. Extreme weather event insurance evaluation criteria

For each of the criteria, a market sector is awarded points according to Table 1. Moreover, while the core evaluation criteria are the same across both investigated sectors, the criteria are operationalised differently. The criteria presented in Table 1 were presented twice to groups of stakeholders in order to receive feedback on the overall suitability of the points scoring system. The stakeholders broadly accepted the scoring system, with minor suggestions for use in the developed MCA framework. Appendix 2 provides a more detailed description of the points scoring system.

The MCA expresses a sector's performance with a single overall score, while allowing each outcome to be taken into account according to its perceived importance. This is shown in Equation 1 as the overall score equalling the weighted sum of the individual standardised criterion scores:

$$S^1_{c,s} = \sum_{i=1}^{i=5} \omega^1_i \mathrm{MCA}_{c,s,i} \tag{1}$$

$S^1_{c,s}$ is the overall score for country c and sector s under criterion Weighting Scheme 1 (superscript 1). This score is the weighted sum of the individual standardised criterion scores (i) for country $c(\mathrm{MCA}_{c,i})$. The criterion weights (ω^1_i) are defined per weighting scheme as a proxy for risk management objectives. The value for $\mathrm{MCA}_{c,s,i}$ is produced by following either Equation 2, for a continuous ranking, or Equation 3, for a relative ranking.

$$\mathrm{MCA}_{c,s,i} = \frac{(\mathrm{MCA}_{c,s,i})^{\text{raw score}}}{\text{Max points possible for criterion } c} \tag{2}$$

$$\mathrm{MCA}_{c,s,i} = \frac{(\mathrm{MCA}_{c,s,i})^{\text{raw score}} - (\mathrm{MCA}_{c,s,\min})^{\text{raw score}}}{(\mathrm{MCA}_{c,s,\max})^{\text{raw score}} - (\mathrm{MCA}_{c,s,\min})^{\text{raw score}}} \tag{3}$$

The weights are based on one of three scenarios (see Table 2): Weighting Scheme 1: Providing high degrees of coverage and affordability; Weighting Scheme 2: Balancing the different objectives of relevant stakeholders; and Weighting Scheme 3: The ability of insurance to act as a risk management mechanism.

Weighting Scheme 2 was developed based on input received from a series of stakeholder questionnaires (see Appendix 1). One aspect of these questionnaires was to ask the respondent to rank the five criteria in terms of their importance. However, the responses yielded similar weights, as most completed responses were provided by insurers and academics, which limited the scheme's overall representativeness. Weighting Schemes 1 and 3 were developed based on the judgement of the research team in order to accommodate the different risk management objectives that were retrieved from the literature review and stakeholder engagement process.

As an illustration, take Spanish private property insurance. For Criterion 1, the median insurance penetration rate was ~90%, which scores 4 points. For Criterion 2, the sector relies on small deductibles with flat rate premiums, which earns 1 point (if risk-based premiums were used, Spain would have scored 3 points). For Criterion 4a, all the relevant hazards are covered by the Spanish insurance system, scoring 3 points. For Criterion 4b, due to the income distribution and the average property insurance premium the rate of

Table 1. Scoring metric the private property insurance sector.

Private property insurance							Agriculture (crop) insurance						
		4 points	3 points	2 points	1 point	0 points			4 points	3 points	2 points	1 point	0 points
Criterion 1: Insurance penetration rate	The percentage of households that have coverage against the set of relevant extreme	[81,100]	[61,80]	[41,60]	[21,40]	[0,20]	Criterion 1: Insurance penetration rate	This is measured as the percentage of arable land that is insured against the set of relevant extreme weather events.	[40+]	[31,40]	[21,30]	[11,20]	[0,10]
Criterion 2: Risk signalling ability	The ability of insurance market structures to act as a signal of risk or risk reduction potential			Large deductibles (i.e. larger than €2000); Premium discounts; Required vulnerability standards; Risk based premiums	Small deductibles (i.e. smaller than €2000 but larger than €0); Awareness campaigns	No risk signalling	Criterion 2: Risk signalling ability	This criterion measures the 'holistic' ability of insurance market structures to act as a signal of risk or risk reduction potential.			Large deductibles (i.e. a loss of 30% or more); Premium discounts; Required vulnerability standards; Risk based premiums; Bonus-malus	Small deductibles (i.e. a loss less than 30%); Awareness campaigns	No risk signalling
Criterion 3: Ability to absorb large losses	This criterion judges the ability of the sector to absorb large losses in the case of large scale events.		Unlimited State grantee for extreme weather event losses	Access to private reinsurance for all risks; Access to sector/ disaster wide pool for all risks; Access to public sector reinsurance for all risks; Limited State grantee for extreme weather event losses	Access to private reinsurance for some risks Access to sector/disaster wide pool for some risks Access to public sector Reinsurance for some risks	Reliance on internal capital only	Criterion 3: Ability to absorb large losses	This criterion judges the ability of the sector to absorb large losses in the case of large scale events.			Unlimited State grantee for extreme weather event losses	Access to private reinsurance for all risks; Access to sector/ disaster wide pool for all risks; Access to public sector Reinsurance for all risks; Limited State grantee for extreme weather event losses	Access to private reinsurance for some risks; Access to sector/ disaster wide pool for some risks; Access to public sector Reinsurance for some risks

(*Continued*)

Table 1. Continued.

Private property insurance							Agriculture (crop) insurance						
		4 points	3 points	2 points	1 point	0 points			4 points	3 points	2 points	1 point	0 points
Criterion 4a: Affordability	The percentage of the population finding insurance unaffordable	[0,5]	[6,10]	[11,15]	[16,20]	[≥21]	Criterion 4a: Affordability	The premium as a percentage of the total insured value	[0,1]	[1,2]	[2,4]	[4,6]	[≥6]
Criterion 4b: Availability	The number of extreme weather events that can be insured against				1 point per extreme weather event that is insurable		Criterion 4b: Availability	The number of extreme weather events that can be insured against				1 point per extreme weather	
Criterion 5a: Quick and certain compensation payments	The certainty of receiving accurate compensation			No ad-hoc government compensation is possible. There are only formal mechanisms for risk-transfer with clear rules.	Limited private sector insurance coverage and ad-hoc government compensation; Specialist loss adjusters are used to assess and process claims.	Complete reliance on ad-hoc government compensation.	Criterion 5a: Quick and certain compensation payments	Certainty			No ad-hoc government compensation is possible. There are only formal mechanisms for risk-transfer with clear rules	Limited private sector insurance coverage and ad-hoc government compensation; Specialist loss adjusters are used to assess and process claims.	Complete reliance on ad-hoc government compensation
Criterion 5b: Quick and certain compensation payments Only information was that the claim was to be settled after harvest	*Speed*	*Not studied due to limited information*					Criterion 5b: Quick and certain compensation payments	Speed	Up to 15	days	Up to 30 days	Up to 60 days	Up to 90 days

Table 2. Selected weighting schemes used.

	Weighting scheme 1	Weighting scheme 2	Weighting scheme 3
Insurance penetration rate	0.35	0.23	0.125
Risk signalling	0	0.22	0.5
Ability to absorb large losses	0.15	0.19	0.125
Affordability and availability	0.35	0.19	0.125
Quick and certain compensation	0.15	0.18	0.125

unaffordability earns Spain a score of 0 points. Therefore, for Criterion 4 Spain has a total score of 3 points. Finally, regarding the speed of certainty and payments, Spain has formal systems with clear rules and no ad hoc payments, with the common usage of professional loss adjusters, resulting in 3 points. Overall, once standardised Spain has a score of about 0.78 when Weighting Scheme 1 is employed and 0.48 when Weighting Scheme 3 is used.

A country is declared to exemplify best practice if it was ranked first or second under either of the ranking methods for a given ranking scheme. We then conducted a qualitative analysis of the identified market sectors to see what lessons can be drawn by detecting common behavioural patterns.

3. Results and discussion

Figure 2 presents the MCA outcome by highlighting the best practice cases. See Appendix 3 for a more detailed description. It must be noted that, due to our methodological approach, this analysis is conducted from a policymaker perspective.

Table 3 presents a summary of the common features of the examples of best practice, which can help to identify ways to enhance societal extreme weather resilience. However, while a comparative analysis reveals general patterns which should be tailored to meet specific local conditions, the general patterns reveal a starting point. While this study is focused on Europe and draws lessons mainly from the practices within Europe, countries

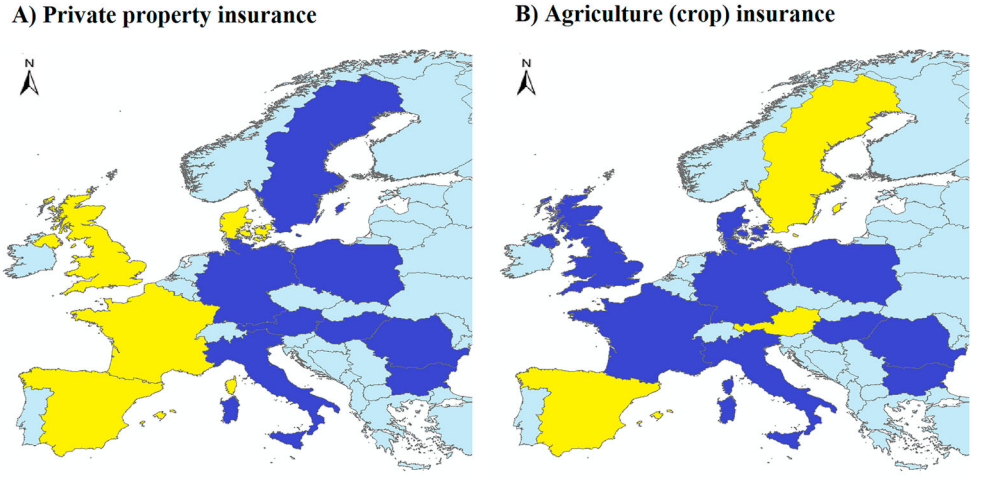

Figure 2. Countries in yellow are ranked as first or second out of the countries studied for at least one of the three weighting schemes.

Table 3. Summary of common features in the insurance markets studied.

Private property	Agriculture
Multiple extreme weather events are combined in a single policy.	The use of multi-risk, or yield, insurance.
The purchase of extreme weather event insurance is connected to a far more commonly required and enforced product.	All cultivated land must be insured.
Collaboration between public and private sector with a commonly stated and understood objective.	Premium subsidies direct investment to multi-risk policies.
Provision of a national pool or public reinsurance/support for catastrophic losses in addition to private reinsurance coverage.	Pool like structures or public reinsurance for systemic risks such as droughts.
	A tradition of collaboration between the public and private sector risk managers.

outside of Europe may also score highly in the MCA. For example, Australia displays many of the characteristics mentioned in Table 3, such as risk-based premiums and multi-peril coverage across a range of natural hazard insurance (Mcaneney, Mcaneney, Musulin, Walker, & Crompton, 2016).

An overview of the MCA results reveals the importance of flooding in driving the MCA results, as compared to windstorm or hail risks. Flooding is problematic because floods are highly localised, which limits the ease with which losses can be spread geographically and mutualised, in contrast to more spatially diverse hazards such as windstorms or hail. Overall, the average MCA score is highest under Weighting Scheme 1 and lowest under Weighting Scheme 3. Additionally, the standard deviation of the MCA scores fell moving from Scheme 1 to Scheme 3, indicating smaller differences in overall performance across countries. This indicates that, on the whole, the case studies are relatively successful at providing insurance as a social good. For private property insurance, the two main (and interconnected) problems to overcome are insuring flooding and encouraging households to buy insurance. This is due to the low rates of coverage outside of the best practice countries studied.

3.1. Resistance

3.1.1. Outcome of the MCA

The MCA results indicate that all 12 case studies score low regarding risk reduction, which is especially highlighted when the average score under Weighting Scheme 1 is compared to that under Weighting Scheme 3. Moreover, the standard deviation of scores falls from Weighting Scheme 1 to Scheme 3, indicating a more similar performance of countries as we focus on risk reduction or resistance-building aspects. Therefore, even in terms of the countries identified as exemplars of best practice, the resistance link is weak regarding how insurance and resilience are linked. Moreover, previous research has also established that is difficult to find insurance schemes that are successful at promoting risk reduction (Linnerooth-Bayer, Surminski, Bouwer, Noy, & Mechler, 2019; Surminski & Oramas-Dorta, 2014). This implies that the countries isolated as best practice are not isolated due to their resistance improving ability, but rather because they over-performed on the other criteria.

Denmark and the UK are identified as exemplars of best practice for private property insurance under Weighting Scheme 3 due to their general use of risk-based premiums, use of deductibles and a number of adaptation initiatives. French insurers are legally required to include a deductible starting at €380 and rising to €3,050 in line with the occurrence of floods. In these countries, the main source for providing resistance is the government rather than the policyholder. For example, in France local governments generate risk

prevention plans, which can mandate certain risk reduction activities or requirements to be enforced in selected areas. However, the extent to which these plans can require risk-reduction measures is limited in practice (Poussin, Botzen, & Aerts, 2013). Spanish property insurance also does not provide signals for risk reduction because risk reduction is the role of the government and not the insurer, whose role is to provide affordable insurance, as stated by the CCS stakeholders interviewed. The agricultural insurance in Spain is also similar, in that it does not have a strong focus on promoting risk reduction by policyholders. Rather, these markets as a whole rely on government-provided risk reduction to maintain flood risk at an insurable level, such as a 1 in 75 year protection standard in the UK.

For agricultural insurance, we see that the best practice countries of Austria and Spain both employ bonus-malus systems which reward policyholders with a reduction in premiums if insurance claims lie below a certain level and increase premiums if otherwise. Policyholders are indirectly rewarded for undertaking actions that lower long-run extreme weather event vulnerability. This approach allows for a certain degree of information asymmetry between the insurer and the policyholder, as the insurer cannot observe and evaluate all the actions that a policyholder may take, but it can monitor claims as a proxy measurement. The Spanish case goes beyond the bonus-malus system by offering two additional risk-reduction strategies. First, to be insured a farmer must meet certain pre-set conditions regarding vulnerability to extreme events. Second, premium discounts are given in return for employing risk-reduction measures.

Overall, the case study countries produce low scores in the MCA due to their reliance on incentives that provide indirect risk management signals such as awareness campaigns and deductibles. Awareness campaigns attempt to alter risk perceptions to improve the perceived benefits of implementing risk-reduction measures. For example, the German stakeholders engaged with during the project provided anecdotal evidence that their efforts in collaboration with local and federal governments in Germany through the *Elementarschadenskampagne* (elemental damage campaign) risk communication campaign helped to increase the flood insurance penetration rate across Germany.

3.1.2. Implications for policies to improve resilience

As noted in the previous section, the best practice cases identified by the MCA do not necessarily result in a systematic improvement for the resistance resilience pillar. For instance, the information campaign that the German stakeholders said was effective has its limitations as, to the best of our knowledge; a systematic evaluation of the campaign has not been conducted. Moreover, there are limitations to relying on awareness campaigns, because constant campaigns are required in order to prevent risk perceptions from declining due to availability biases (i.e. a tendency for experiences to be perceived as less important the longer ago they occurred). Moreover, the limited academic literature also displays mixed results. For instance, Osberghaus (2017) finds that in Germany more educated households are more responsive to flood risk adaption. While not directly related to risk communication, this finding indicates that there can be a positive response to education campaigns. Maidl and Buchecker (2015) used survey data to evaluate the success of a risk communication campaign aimed at increasing flood preparedness. Their study found that the campaign was able to increase preparedness intentions, though its success was based upon having a positive view of the material received as well as possessing a sufficient level of awareness. Rollason, Bracken, Hardy, and Large

(2018) discuss a risk communication strategy in the UK, finding that these communication strategies should be tailored to local contexts in order to be successful. Therefore, while anecdotal evidence suggests that the large-scale risk communication campaign in Germany has been successful, there should be more efforts to evaluate the success of such campaigns.

Secondly, we see that the link between insurance and the resistance resilience pillar is hampered by the reliance on deductibles, particularly when they are small. Deductibles alone are unlikely to incentivise proactive risk reduction because policyholders need to correctly understand the amount of their level of extreme weather risk that is not covered by the insurer before this can act as an incentive to lower risk. Empirical research has indicated that only large deductibles can act as an incentive for limiting natural disaster risk (Hudson, Botzen, Czajkowski, & Kreibich, 2017) and that more tangible incentives may be more successful. For example, Mol, Botzen, and Blasch (2018) find, via experiments, that premium discounts appear successful at encouraging policyholders to invest in flood damage mitigation measures. On the other hand, it has been noted in Australia that premiums do not provide a strong incentive to boost resistance due to the non-transparency of risks and premiums (Mcaneney et al., 2016).

Nevertheless, the best practice examples do offer directions for how other insurance markets could increase the resistance pillar of resilience. The linkages between insurance and the resistance pillar can be improved by developing a series of more direct mechanisms to incentivise risk reduction. Such mechanisms can be layered to offer a different range of possible incentives, like information provision about risk and effective risk-reduction measures with premium discounts for implementing these measures. This was found to be the case in Austria and Spain for crop insurance, as a layering of resistance boosting mechanisms is an aspect of the best practice examples that can be used across both private property insurance and crop insurance. The layered incentive arrangement allows the insurer to signal which measures are known to be effective. Moreover, this may be achieved while promoting decentralised adaptation through premium discounts, which should only promote adaptation when adaptation is cost-effective. Secondly, bonus-malus arrangements may help overcome elements of asymmetric information.

Therefore, it is beneficial to develop a wider portfolio of risk incentivisation mechanisms in collaboration with a wider range of stakeholders in order to create a suitable environment. For instance, the Department for Environment, Food and Rural Affairs in the UK commissioned reports looking into what could be suitable low-cost package of measures and strategies that homeowners can use to limit flood risk (Lamond, Rose, Bhattacharya-Mis, & Joseph, 2018). This was later further refined through a series of reports for the UK insurance pool Flood Re looking into how their use can be incentivised (Flood Re, 2018) and which ones are likely to be cost-effective (Lamond et al., 2018). Due to Flood Re often being criticised for a lack of focus on risk reduction (e.g. Surminski, 2018; Surminski & Eldridge, 2015), these actions by Flood Re indicate a promising direction for strengthening the resistance pillar of insurance in the UK. Moreover, in order to be successful at promoting the resistance pillar of resilience these insurance-based incentives should be part of a wider enabling environment and partnership arrangement, as insurance by itself is insufficient (Linnerooth-Bayer et al., 2019; Surminski & Thieken, 2017). However, there tends to be slow movement in bringing stakeholders together on this topic (see section 3.4.2), even though multi-sector engagement is required (Kunreuther, 2015).

Additionally, a concern for the growth of flood risk involves the use of land-use planning and how governments do not correctly consider how changes in land-use may impact flood risk (see Mcaneney et al. (2016) or (OECD, 2016)). However, while land-use planning is not predominantly within the insurance sphere of influence, the identified best practice countries highlight cases where land-use can still be influenced. For instance, in the UK, Flood Re prohibits the sale of insurance for buildings in high flood risk zones constructed after 2008. This is in order to provide an incentive to limit development in high-risk floodplains in the coming years, due to the common insurance requirements compelled by UK mortgage conditions. Therefore, while insurance may not be able to directly influence land-use planning, insurers may be able to steer land-use in a more resilient direction through their insurance requirements.

3.2. Recovery

3.2.1. Outcome of the MCA

The European insurance markets perform best when considered primarily as mechanisms focusing upon recovery, as seen by the highest MCA scores for Weighting Scheme 1. The best practice countries achieve high MCA scores because of high penetration rates, comprehensive multi-hazard coverage, and mechanisms in place to support large loss events. This combination of factors allows the insurance markets of France, Spain, and the UK to be in, overall, a good position to provide clear and secure compensation for private property insurance after a flood event. Spain, Austria, and Sweden provide similar arrangements regarding crop insurance. This is due to their use of multi-hazard crop insurance and a compulsion to insure all farmland rather than selecting only higher risk parcels.

In comparing the features of the three best practice cases in the private property and crop insurance sectors, we see that in both market sectors the best practice cases bundle several extreme weather risks into a single policy. However, it is unclear in these cases to what degree each extreme weather event contributes towards the insurance premium. In combing several risks together, a greater and more diversified pool of policyholders can be created. Moreover, these countries tended to have a formal or informal mandate to buy insurance. For instance, extreme weather insurance is a compulsory extension of general private property insurance in Spain and France. These two features taken together increases the ability of the extreme weather insurance markets to display the mutuality and solidarity needed to function (Linnerooth-Bayer et al., 2019).

While mandating multi-extreme weather event coverage provides wider access to the recovery mechanism of insurance, this in turn must be balanced with concerns about affordability. This trade-off is especially important if there is a wider movement towards risk-based premiums to provide stronger risk reduction incentives or if voluntary purchase options are retracted. The Spanish and French cases aim to limit unaffordability by directly linking the natural hazard premium to a fixed percentage of coverage brought. The Danish and UK cases are less clear on this topic. Although it is difficult to distinguish which part of the premium reflects which risk, it is clear that there is a large degree of cross-subsidisation between higher and lower risk households. However, a key observation regarding affordability is that the main driver, on average, of insurance unaffordability is the buying power of households rather than the amount of the insurance premiums. For example, the average rate of unaffordability in Bulgaria is estimated to be 23%, while in Romania the

rate is 26%, but the annual average premiums are only €90 and €30, respectively (Insurance Europe, 2015).

Finally, in order to support insurers in the wake of large events, the best practice countries have mechanisms in place that help to maintain solvency. France provides reinsurance for extreme weather events through a governmentally provided reinsurance facility, which in turn has an unlimited state guarantee. In the UK, however, private reinsurers have created the Flood Re pool to share losses between participating insurers, which in turn has quasi-governmental powers to raise levies to provide a suitable capital base.

3.2.1. Implications for policies to improve resilience

There are several implications of the conclusions drawn regarding how insurance best practice interacts with the recovery pillar of resilience. In principle, the provision of insurance greatly supports the recovery pillar, because policyholders are no longer solely reliant on their own resources (i.e. self-insurance) to get back on their feet after an extreme weather event. However, for this enhancement to be truly embraced and actively improve the recovery pillar of resilience, insurance coverage must be widespread.

The best practice countries were able to achieve this in both the private property and crop insurance markets due to a commonly observed effective compulsion to buy a comprehensive bundle of extreme weather event insurance. Moreover, in the case of Spain the potential for access to government compensation funds is only available for those who have purchased sufficient agricultural insurance coverage. This collection of features allows relatively rare extreme weather events, such as floods, to be pooled with more common extreme weather events such as hailstorms, as well as uncorrelated risks, such as house fires, which are more tangibly important to the policyholder. This combination of perils allows for improved risk diversification by increasing the range of high and low risk policyholders. Moreover, broad coverage of a variety of risks gives policyholders a high degree of certainty in receiving compensation after an extreme weather event occurs. These structured systems promote a reliance on formally developed and provided insurance mechanisms rather than ad hoc government support. Furthermore, promoting a reliance on formal and developed mechanisms promotes a higher level of development of the recovery resilience pillar because there are predictable expectations rather than actions based on changing public concerns and pressures. This is because mandated and comprehensive insurance coverage is more efficient than a system of ex post public disaster programmes (Kunreuther, 2006).

Therefore, in order to promote increased rates of coverage in the non-best practice regions of Europe, there could be an increased focus on mandates to buy a complete bundle of extreme weather event insurance. The development of such a mandate is not sufficient without enforcement or sufficient incentives for buying insurance. Therefore, linking multi-hazard insurance with products that a consumer sees as more important can increase resilience by increasing the opportunity cost of not buying comprehensive coverage. Private property insurance has a well-developed mechanism that links extreme weather insurance with mortgage requirements or fire insurance. While a similar observation was not made for farmers, it was found in the case of Spain that holding sufficient insurance coverage was a requirement for being able to receive potential compensation from the government. Therefore, we argue that this approach can be extended so that insurance coverage is tied to access to wider agricultural subsidies (e.g. the Common Agricultural

Policy) to increase the opportunity cost of not being insured. These suggestions for moving insurance forwards are common place in the countries identified among the selected cases as exemplars of best practice (although not in the worst performing countries) as well as several other countries in the world. Additionally, the relative salience of the risks of these events can be improved by making them more tangible, for example, by connecting the occurrence of flooding to the lifetime of a mortgage or a resident's tenure in their property. This, in turn, could lead to a stronger demand for multi-year insurance policies, which could create a more stable extreme weather insurance demand for insurers, as argued by Michel-Kerjan, Lemoyne De Forges, and Kunreuther (2012).

The above mechanisms can help boost the recovery pillar resilience and decrease the difficultly for insurers of insuring localised disasters by increasing currently limited demand. However, in doing so care must be taken to maintain a degree of clarity about how the premium is structured and connected to the types of insured extreme weather risks, to avoid the problems encountered in Australia regarding risk reduction (Mcaneney et al., 2016).

Not only is the clarity of the premium important, but also, in terms of the social justice implications when coverage is mandated, its total size. This is because if premiums are considered unaffordable then the purchaser is considered to be overly burdened by the purchase (National Research Council, 2015). Unaffordability in the case study countries is driven, in most cases, by the purchasing powers of households rather than the premiums themselves. However, if premiums are linked to risk, then premiums can become rapidly unaffordable in high risk areas, unless risk-reduction measures are taken either by the state, community, or individual. A high rate of unaffordability places additional burdens on policyholders, which limits their resilience potential. Therefore, as the results of the MCA indicate that unaffordability cannot be fully corrected from within the insurance market itself, mechanisms external to the market are required to support policyholders who would face unaffordable insurance premiums.

A commonly proposed method for addressing this problem is means-tested vouchers for enabling low-income households in high risk areas to purchase comprehensive insurance (Kousky & Kunreuther, 2014). Such vouchers can address equity concerns by removing the high premium burden placed on households while potentially allowing for insurance to have a stronger link to risk reduction. This is because vouchers allow unaffordability to be corrected from outside of the insurance market. The same can also hold for property-level adaptation measures in order to render them more affordable and increase uptake (Montgomery & Kunreuther, 2018). The voucher mechanism, or similar ones such as tax credits, allow for insurance to improve two pillars of resilience before and after extreme weather events. However, such mechanisms for purchasing insurance should also be time-limited (Kousky & Kunreuther, 2014) in order to avoid an indirect subsidy for lower-income households to locate in disaster prone areas in order to become eligible for the voucher. Including these social justice concerns can help to limit social inequalities that can occur if only certain segments of society can successfully adapt to extreme weather events.

However, a relevant concern is that in the case of a large event rapid insurance pay-outs may not be possible due to the assessment and claims process. For instance, this was a problematic experience after the Christchurch earthquake where, due to the magnitude of the event, payments were staggered over many years (King, Middleton, Brown,

Johnston, & Johal, 2014; Potter, Becker, Johnston, & Rossiter, 2015), as well as after Hurricane Katrina (Corey & Deitch, 2011; Green, Bates, & Smyth, 2007). This process can be further complicated by the presence of both private insurers and public compensation mechanisms. Therefore, it is important to correctly layer an insurance market so that those affected by a disaster have a single point of call for claiming assistance. This line of thought could also support the development of PPPs where the government acts as a formal reinsurer rather than offering direct compensation to people and thereby acting as a competitor to primary insurers. Creating such an enabling environment for facilitating fast payments is important, as Poontirakul, Brown, Seville, Vargo, and Noy (2017) notes that adequate and prompt payments promote recovery, while slow payment processes may be no better than receiving no compensation payments at all.

3.3. Adaptive capacity

3.3.1. Outcome of the MCA

There are several ways in which insurance can interact with the concept of adaptive capacity. The first is the ability of the insurance industry to inform policyholders through awareness-increasing activities, as discussed in Section 3.1. The second is through the ability to remain a viable adaptation mechanism moving forwards in light of increasing natural hazard losses. The best practice cases identified have extensive collaboration across stakeholders, which have allowed the insurance arrangements to adapt to changing situations in a broadly acceptable manner. For example, the Danish Storm Council is appointed by the Danish Minister for Business and Growth and consists of an independent chair and eight other members, in order to bring a holistic and collaborative understanding of risk management topics. These include stakeholders from the insurance industry, private citizens, municipalities and ministries. The Spanish approach to crop insurance is based around the Agroseguro entity that handles the entire insurance process, with the objective of managing agricultural risk as a whole for its stakeholders.

A challenge for transferring these best practices to other countries is that, for the most part, the institutions are long established. The Austrian Hail Insurance Company was founded in 1946, Agroseguro was founded in 1978, and the CCS can trace its origins to 1941. The most recently formed organisation is Flood Re in the UK. The introduction of Flood Re highlights several potential problems surrounding different levels of willingness to participate between insurers and the government as well as potential legal challenges, which is described in more detail by Mysiak and Pérez-Blanco (2016) and Surminski (2018). Taken together, the long tradition of a central body helps create a suitable enabling environment for insurance markets to operate in. However, such bodies can be very difficult to create without a suitable catalysing event, such as CATNAT and Flood Re being founded as a response to serious events. A discussion of the role of catalysing events is presented by Birkmann et al. (2010).

3.3.2. Implications for policies to improve resilience

While the resistance-improving aspect of the insurance best practice cases is the weakest aspect that can be formally measured through the MCA, the adaptive capacity elements are also weak. For instance, there is little evidence regarding the success at increasing resilience of risk communication campaigns. Moreover, the insurance mechanisms studied

tend to be rather static in terms of their overall structure. This hints that the interaction between insurance and adaptive capacity is underutilised. This is the case despite the collaborative structures in place that provide insurers with suitable support in case of large disaster events, which otherwise may threaten their solvency. Insolvent insurers would not be able to provide compensation to those affected. For example, in Spain the CCS has an equalisation fund financed by retained premiums, and on top of this fund the CCS can buy private reinsurance coverage and has access to a state guarantee. Similarly, Flood Re in the UK acts as an insurance pool financed by a surcharge on all insurance policies sold in the UK, with the ability to impose a second surcharge in case Flood Re's resources prove insufficient. These measures improve adaptive capacity by maintaining insurer solvency regarding high risk households.

Furthermore, the degree of collaboration between the insurance sector stakeholders and the government can be tailored with respect to formality and extent of the partnership. For instance, in France the public and private sector have a long-standing cooperation in the French Association for Disaster Risk Reduction. Another example is the Danish Storm Council. However, regardless of the degree of formality, there is a stated focus. Therefore, a suitable role for new bodies can in promoting risk reduction. This is because an external body dedicated to promoting and developing risk reduction strategies integrated across all relevant stakeholders can facilitate a minimum level of risk management and insurance viability. This could be achieved by adding a surcharge to insurance premiums that channels the revenue into a fund or funds for constructing protection measures, for general adaptation measures, or to subsidise more individual property-level measures. This fund could be a coordination entity whereby insurers, government agencies, etc. are involved in a not-for-profit manner.

In developing a coordination entity, the specific knowledge and expertise of each stakeholder can be leveraged to strengthen current weaknesses that a single stakeholder cannot surmount. For example, insurers can use their expertise to identify which adaptation measures lower risk, and a third-party organisation can provide certificates to those who employ these measures to signal that these measures have been correctly employed. This, in turn, allows the policyholder to obtain discounts on their insurance premiums or reimbursement for the measure's cost. This approach is similar to the elevation certificates offered for the National Flood Insurance Program in the USA, or the Texas Windstorm Insurance Association's WPI-18 certificates, as mentioned by Mcaneney et al. (2016). A single management body can organise and facilitate such stakeholder collaborations. Moreover, such a body brings together a range of experiences and capacities that can be used to develop the socially inclusive and useful risk communication campaigns required for the message to be acted upon.

4. Conclusion

Extreme weather events place a large burden on society due to their potentially disastrous consequences. Moreover, due to the combination of socio-economic development and climate change there is a growing threat from extreme weather events. Therefore, societal resilience against extreme weather events should be promoted and, if well organised and regulated, insurance is, potentially, a transformative mechanism for resilience.

The current role that extreme weather event insurance plays varies strongly across Europe, with a great deal of heterogeneity in provision and overall outcomes across

countries and sectors. A comparison of this diversity can identify what works well and what does not, with the aim of deriving recommendations for improving the performance of insurance markets to enhance extreme weather resilience. To conduct our comparative study, we used an extensive inventory of insurance markets covering 12 countries for private property and agricultural insurance across a range of extreme weather events. The comparative analysis identified that, for private property insurance, Denmark, France, Spain, and the UK represent exemplars of best practice. For the agriculture sector best practice exemplars were Austria, Spain, and Sweden.

Based on this analysis, from the policymaker perspective, we suggest a series of ways in which extreme weather event insurance can increase disaster resilience. For private property insurance, we suggest introducing a requirement to buy extreme weather event insurance along with general homeowners' insurance. Moreover, support for low income households through means-tested vouchers could be provided. For the agricultural sector, we propose moving towards comprehensive crop yield insurance by requiring farmers to buy a sufficiently comprehensive insurance product to be eligible for the general agricultural subsidies farmers receive. In both cases, a nationally representative body can coordinate the various stakeholders into acting in concert. This body could be financed by a premium surcharge which is then used to directly co-finance the employment of cost-effective risk-reduction measures. Moreover, this public-private collaboration could aim to strengthen the link between insurance and risk reduction through a combination of measures, including information provision about risk and mitigation measures, financial incentives like premium discounts and subsidies, and building codes and zoning regulations. In the long run, improved risk reduction will result in lower premiums. Additionally, this structure could help to support the financing of extreme losses to maintain the solvency of the insurance industry. This suggested series of policy recommendations for boosting resilience is similar to features of the reforms proposed for the National Flood Insurance Program in the United States by Michel-Kerjan and Kunreuther (2011). This shows the overall generalisability of these results and policy directions at the global level regarding how insurance should move forwards to enhance resilience.

Note

1. Please note that earthquakes or other seismic risks, while present in Europe, are not relevant to this study as it focuses on extreme weather events. Future research can address this gap in the literature.

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References

Aerts, J. C. J. H., Botzen, W. J. W., De Moel, H., & Bowman, M. (2013). Cost estimates for flood resilience and protection strategies in New York City. *Annals of the New York Academy of Sciences*, *1294*, 1–104.

Birkmann, J., Buckle, P., Jaeger, J., Pelling, M., Setiadi, N., Garschagen, M., … Kropp, J. (2010). Extreme events and disasters: A window of opportunity for change? Analysis of organizational, institutional and political changes, formal and informal responses after mega-disasters. *Natural Hazards*, *55*, 637–655.

Botzen, W. J. W. (2013). *Managing extreme climate change risks through insurance*. New York: Cambridge University Press.

Burby, R. (2001). Flood insurance and floodplain management: The US experience. *Global Environmental Change Part B: Environmental Hazards*, *3*, 111–122.

Charpentier, A. (2008). Insurability of climate risks. *The Geneva Papers*, *33*, 91–109.

Chatterton, J., Clarke, C., Daly, E., Dawks, S., Elding, C., Fenn, T., … Salado, R. (2016). *The costs and impacts of the winter 2013 to 2014 floods*. Bristol: Environment Agency.

Corey, C. M., & Deitch, E. A. (2011). Factors affecting business recovery immediately after Hurricane Katrina. *Journal of Contingencies and Crisis Management*, *19*, 169–181.

Cremades, R., Surminski, S., Máñez Costa, M., Hudson, P., Shrivastava, P., & Gascoigne, J. (2018). Using the adaptive cycle in climate-risk insurance to design resilient futures. *Nature Climate Change*, *8*, 4–7.

European Comission. (2017). Insurance of weather and climate-related disaster risk: Inventory and analysis of mechanisms to support damage prevention in the EU. In X. Le Den, M. Persson, A. Benoist, P. Hudson, M. De Ruiter, L. De Ruig, O. Kuik, & W. Botzen (Eds.). Luxembourg: Publications Office of the European Union.

Flood Re. (2018). *Incentivising household action on flooding and options for using incentives to increase the take up of flood resilience and resistance measures*. Author.

The Geneva Association. (2018). *Climate change and the insurance industry: Taking action as risk managers and investors perspectives from C-level executives in the insurance industry*. Zurich: Author.

Golnaraghi, M., Surminski, S., & Schanz, K. (2017). *An intergrated appraoch to managing extreme events and cliamte risks*. Zurich: The Geneva Assocaition.

Green, R., Bates, L. K., & Smyth, A. (2007). Impediments to recovery in New Orleans' upper and lower ninth ward: One year after Hurricane Katrina. *Disasters*, *31*, 311–335.

Hochrainer-Stigler, S., & Lorant, A. (2018). Evaluating partnerships to enhance disaster risk management using multi-criteria analysis: An application at the Pan-European level. *Environmental Management*, *61*, 24–33.

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*, 179–208.

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.

Insurance Europe. (2015). *European insurance - key facts*. Brussels: Author.

King, A., Middleton, D., Brown, C., Johnston, D., & Johal, S. (2014). Insurance: Its role in recovery from the 2010–2011 Canterbury earthquake sequence. *Earthquake Spectra*, *30*, 475–491.

Kousky, C., & Kunreuther, H. (2014). Addressing affordability in the national flood insurance program. *Journal of Extreme Events*, *1*, 1450001.

Kreibich, H., Thieken, A. H., Petrow, T., Müller, M., & Merz, B. (2005). Flood loss reduction of private households due to building precautionary measures- lessons learned from the Elbe flood in August 2002. *Natural Hazards and Earth System Science*, *5*, 117–126.

Kunreuther, H. (2006). Disaster mitigation and insurance: Learning from Katrina. *The ANNALS of the American Academy of Political and Social Science*, *604*, 208–227.

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*, 741–762.

Kunreuther, H. (2017). *Encouraging adaptation to flood risk: The role of the national flood insurance program* (Wharton Working Papers). Philadelphia: Wharton, University of Pennsylvania.
Kunreuther, H., & Michel-Kerjan, E. (2009). *At war with the weather: Managing large scale risks in a new era of catastrophes*. Cambridge, MA: MIT Press.
Kunreuther, H., & Michel-Kerjan, E. (2013). Managing catastrophic risks through redesigned insurance: Challenges and opportunities. In G. Dionne (Ed.), *Handbook of insurance* (pp. 517–546). New York, NY: Springer New York.
Lamond, J., Rose, C., Bhattacharya-Mis, N., & Joseph, R. (2018). *Evidence review for property flood resilience phase 2 report*. Bristol: Flood Re and UWE Bristol.
Linnerooth-Bayer, J., Surminski, S., Bouwer, L. M., Noy, I., & Mechler, R. (2019). Insurance as a response to loss and damage? In R. Mechler, L. M. Bouwer, T. Schinko, S. Surminski, & J. Linnerooth-Bayer (Eds.), *Loss and damage from climate change: Concepts, methods and policy options* (pp. 483–512). Cham: Springer International Publishing.
Maidl, E., & Buchecker, M. (2015). Raising risk preparedness by flood risk communication. *Natural Hazards and Earth System Sciences*, *15*, 1577–1595.
Mas-Colell, A. (1995). *Microeconomic theory*. New York: Oxford University Press.
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.
Michel-Kerjan, E., & Kunreuther, H. (2011). Redesigning flood insurance. *Science*, *333*, 408–409.
Michel-Kerjan, E., Lemoyne De Forges, S., & Kunreuther, H. (2012). Policy tenure under the U.S. National Flood Insurance Program (NFIP). *Risk Analysis*, *32*, 644–658.
Mol, J. M., Botzen, W. J. W., & Blasch, J. E. (2018). Behavioral motivations for self-insurance under different disaster risk insurance schemes. *Journal of Economic Behavior & Organization*. https://doi.org/10.1016/j.jebo.2018.12.007
Montgomery, M., & Kunreuther, H. (2018). Pricing storm surge risks in Florida: Implications for determining flood insurance premiums and evaluating mitigation measures. *Risk Analysis*, *38*, 2275–2299.
Munich Re. (2017). *Natural catastrophes 2016 Analyses, assessments, position. TOPICS GEO*. Munich, Germany: Author.
Mysiak, J., & Pérez-Blanco, C. D. (2016). Partnerships for disaster risk insurance in the EU. *Natural Hazards and Earth System Sciences*, *16*, 2403–2419.
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 Systems Science*, *16*, 2189–2193.
National Research Council. (2015). *Affordability of national flood insurance program premiums: Report 1*. Washington, DC: National Research Council.
OECD. (2016). *Financial management of flood risk*. Paris: OECD.
Osberghaus, D. (2017). The effect of flood experience on household mitigation—evidence from longitudinal and insurance data. *Global Environmental Change*, *43*, 126–136.
Poontirakul, P., Brown, C., Seville, E., Vargo, J., & Noy, I. (2017). Insurance as a double-edged sword: Quantitative evidence from the 2011 Christchurch earthquake. *The Geneva Papers Risk and Insurance - Issues and Practice*, *42*, 609–632.
Potter, S. H., Becker, J. S., Johnston, D. M., & Rossiter, K. P. (2015). An overview of the impacts of the 2010–2011 Canterbury earthquakes. *International Journal of Disaster Risk Reduction*, *14*, 6–14.
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*, 258–277.
Rollason, E., Bracken, L. J., Hardy, R. J., & Large, A. R. G. (2018). Rethinking flood risk communication. *Natural Hazards*, *92*, 1665–1686.
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: Concepts, methods and policy options* (pp. 317–341). Cham: Springer International Publishing.
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*, 33–72. doi:10.1111/rmir.12093

Surminski, S., Aerts, J. C. J. H., Botzen, W. J. W., Hudson, P., Mysiak, J., & Pérez-Blanco, C. D. (2015). Reflection on the current debate on how to link flood insurance and disaster risk reduction in the European Union. *Natural Hazards*, *79*, 1451–1479.

Surminski, S., & Eldridge, J. (2015). Flood insurance in England: An assessment of the current and newly proposed insurance scheme in the context of rising flood risk. *Journal of Flood Risk Management*, *10*, 415–435.

Surminski, S., & Oramas-Dorta, D. (2014). Flood insurance schemes and climate adaptation in developing countries. *International Journal of Disaster Risk Reduction*, *7*, 154–164.

Surminski, S., & Thieken, A. (2017). Promoting flood risk reduction: The role of insurance in Germany and England. *Earth's Future*, *5*, 979–1001.

Thieken, A. H., Mariani, S., Longfield, S., & Vanneuville, W. (2014). Preface: Flood resilient communities–managing the consequences of flooding. *Natural Hazards and Earth System Science*, *14*, 33–39.

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.