7. CONCLUSION

7.1 Reflection on the core research question

Chapter 1 noted that global flood impacts are displaying a strong upward trend due to socio-economic development and climate change, which places growing pressure on society to successfully manage changing patterns of risk. For this reason, there is an interest in increasing societal resilience against natural disasters, like floods, following the call of the Sendai Framework for Disaster Risk Reduction. This is important because Chapter 2 finds that the flood events have a large negative impact on well-being. Climate change potentially increases the number of future flood events, indicating large potential welfare impacts. In particular, Chapter 2 shows that given previous experiences, the well-being impacts of flooding would require over €126,000 of compensation for the majority of French households in flood-prone areas, in order to account for the long-term welfare impacts incurred. This required compensation is more than the annual income of the households. Societal resilience can be improved by reducing the negative welfare impacts of flooding by providing compensation for flood damage and promoting household-level DRR. Insurance can help to meet both of these aims, minimising the long-term impacts of a flood. Insurance provides disaster compensation in return for a premium that can increase disaster preparedness. Promoting household-level DRR is important because such measures can be effective at limiting damage during a flood (Chapter 3). Insurance premiums can offer tangible incentives for DRR by offering premium discounts to policyholders who reduce their risk, at least if they do not provide a disincentive for disaster preparedness due to a moral hazard, which Chapter 4 shows is not the case. Tangible incentives for household-level DRR can be more effective than those based on deductibles (Chapter 4) or subjective risk perceptions (Chapter 5). Furthermore, without a stronger and more active link between flood insurance and risk reduction, flood insurance may become non-viable in the future when flood risk increases due to socio-economic development and climate change, as shown in Chapters 5 and 6.

Given the importance, moving forward, of insurance as a tool to produce more disaster-resilient societies, this thesis asked: How can insurance and household-level risk reduction measures be combined to create a flood-resilient society? Therefore, this thesis asked the following sub-questions:

1. How are flood impacts and household-level flood risk reduction measures valued in terms of welfare? In particular, what are the intangible impacts of flooding and household-level flood risk reduction measures, and how can these be measured and monetised? (Chapter 2)
2. What is the effectiveness of household-level flood risk reduction measures in terms of reducing property damage, and how can this effectiveness be measured while controlling for other factors that influence flood damage? (Chapter 3)
3. Is moral hazard present in natural hazard insurance markets, and is it an impediment to using insurance as an incentive for household-level risk reduction? (Chapter 4)
4. To what degree can direct insurance incentives encourage households to employ flood risk reduction measures? Is there a trade-off between the strength of risk reduction incentives and the affordability of insurance premiums, and, if so, how can it be overcome? (Chapter 5)
5. What is the set of insurance market features that best manages trade-offs between economic efficiency and equity concerns of flood insurance market reforms that are needed in Europe to cope with increasing flood risk as a result of climate and socio-economic change? (Chapter 6).

7.2 Answers to research questions

7.2.1 Question 1: How are flood impacts and household-level flood risk reduction measures valued in terms of welfare? In particular, what are the intangible impacts of flooding and household-level flood risk reduction measures, and how can these be measured and monetised?

The welfare impacts of the flood risk subjective well-being domain (SWBD) have hardly been studied, even though the topic is connected to an expanding field of research using subjective well-being (SWB) to quantify welfare impacts in monetary terms. Chapter 2 expands this literature by estimating the direct welfare implications of both floods and flood preparedness, which were converted into monetary values and disaggregated into tangible and intangible impacts on welfare. This was done by using data collected from surveying about 900 flood-prone households in France. Regression models based on a mediation-style analysis were used to estimate relationships between SWB and flood experiences, perceptions, preparedness decisions, and SWBDs for these flood-prone households. The analysis was based on a mediation approach in order to take into account both direct effects (e.g., of a flood on SWB) and indirect effects (e.g., a flood's effect on a SWBD, which, in turn, has an impact on SWB).

Chapter 2 provides a starting point for monetising tangible and intangible impacts of floods on SWB, and draws four main conclusions. First, the immediate impacts of a flood have a large negative effect on overall SWB that is larger than the influence of the individual SWBDs on SWB. Moreover, the analysis also indicates that there is a degree of adaptation to flood events, since the reduction in overall SWB is nearly halved 12 months after the flood event. Second, flood events can have SWB consequences for people, even if they themselves are not flooded. Third, the employment of individual flood protection measures can increase the SWB of households in communities that are prone to flooding. The fourth main conclusion is that the intangible benefits, or costs, of the flood risk SWBD on overall SWB tend to be larger than the tangible damage suffered or the damage prevented. The average total damage suffered during a respondent's previous flood was €50,000, while a household with an average income requires a compensation of €150,000 to equalise SWB before and after a flood. This would imply an average loss of €100,000 in terms of intangible welfare effects. The same holds for elevating a house above potential flood water levels, which is associated with direct benefits of €8,000 and with intangible welfare benefits of €31,000 (resulting in total welfare benefits of €39,000). Therefore, implementing structural flood preparedness measures at the household-level is an effective way of offsetting welfare losses from living within a flood-prone area. An interesting feature to note is that not all flood preparedness measures may have welfare benefits. For instance, dry and wet flood-proofing measures did not have a robust total effect on welfare as measured through their connection with SWB, but would rather indirectly bring welfare benefits by lowering the direct tangible impacts of floods. Overall, the very large welfare effects of flooding provide an important basis for the use of insurance or other risk management mechanisms to minimize both tangible and intangible flood impacts.

7.2.2 Question 2: What is the effectiveness of household-level flood risk reduction measures in terms of reducing property damage, and how can this effectiveness be measured while controlling for other factors that influence flood damage?

Chapter 3 noted that the current literature that evaluates DRR measures using survey data is limited and has tended to employ simple evaluation methodologies and small samples, which are vulnerable to biases originating from confounding variables. Confounding variables explain both the outcomes (damage saved) and the employment of a DRR. Chapter 3 sought to remove confounding bias by applying the propensity score matching (PSM) method to a sample of German households living along the Elbe and Danube rivers who were surveyed in response to three flood events. Chapter 3 found that the previous research using mean comparisons of experienced flood damage by people who have, or have not, taken specific DRR measures could result in inaccurate estimates of the effectiveness of a DRR measure. PSM refined these previous evaluations by removing selection bias, and found that several DRR measures are effective at reducing flood damage on an individual level. Chapter 3 detected substantial overestimates of the effectiveness of household DRR if unrefined

estimates are used, ranging from nearly €1,700 to €15,000 per measure. The refined PSM effectiveness estimates find that expected flood damage was between 12.8% and 24.6% lower for people who took a specific DRR measure during flood events compared with otherwise similar people who did not take such a measure (Chapter 5). Assuming independence between measures, the dry and wet flood-proofing measures together lowered risk by 37.4% of the average loss. This value is not an insignificant amount, which highlights the important role that households can play in flood risk adaptation strategies. Chapter 3 indicates that wet flood-proofing is especially effective because of its effectiveness in saving flood damage and the observed high confidence in the statistical significance of this estimate. Employing dry flood-proofing is also found to be effective, although this result is only marginally statistically significant.

Overall, Chapter 3 presents a novel methodological approach for evaluating the effectiveness of DRR measures that refines previous estimates of the effectiveness of DRR and shows that household DRR can play an important role in flood risk adaptation strategies. The next chapters build upon these results by examining how insurance can provide incentives for taking these DRR measures when they are cost-effective.

7.2.3 Question 3: Is moral hazard present in natural hazard insurance markets, and is it an impediment to using insurance as an incentive for household-level risk reduction?

Chapter 4 assessed the presence of moral hazard in two different insurance markets with differing natural hazards, market contexts, and risk cultures using field survey data from Germany and the United States. Moral hazard behaviour occurs when households prepare less for disasters when they are insured. Chapter 4 indicates that flood insurance purchases in Germany are slightly positively related to flood preparedness. Therefore, a significant moral hazard effect was not observed. Moreover, PSM estimated the influence on experienced flood damage in Germany of both adverse risk selection and behavioural changes due to flood insurance through employing fewer preparedness measures. The results show that adverse risk selection can occur, since households with flood insurance experienced a worse hazard during past flood events. Given the problems associated with detecting such traits when an insurance policy is purchased, it is possible that the adverse risk selection detected leads to the presence of adverse selection.

However, flood damage did not differ significantly across households, once bias due to differing adverse risk factors has been controlled for. This lack of a systematic difference in damage was associated with an absence of moral hazard, as the remaining potential source of bias would be due to a change in preparedness before the flood occurred. The presence of moral hazard, therefore, should have generated higher damages between individuals with sufficiently similar adverse risk traits, because they would have differed regarding their level of damage prevention or mitigation efforts.

Taken together, in Germany insurance coverage did not increase the vulnerability of insured households, which is the opposite finding to what the systematic presence of moral hazard would imply. In contrast, individuals with flood insurance in Germany were more likely to have undertaken flood preparedness or information gathering measures than uninsured households. Households with flood insurance may be more risk-averse, since they have collected more information about flood risk and are no worse prepared for flooding.

The evidence from Germany is complemented by a study of flood and wind damage insurance in the United States, for which similar results were found. Moreover, the U.S. analysis found that respondents had little specific knowledge of their deductible amount or believed the amount to be relatively low. This despite the potentially large deductibles that occur in practise in high-risk areas due to insurance policies having separate hurricane and/or wind deductibles. Except for the highest deductible levels, there was no significant influence of deductibles on the policyholder’s ex ante hurricane preparations.

Chapter 4 concludes that, because of the positive joint decision process between taking risk reduction measures and purchasing insurance and the small influence of insurance policy deductibles, the absence of moral hazard is due to the intrinsic traits of the policyholders – such as a high level of risk aversion. The overall findings that natural disaster insurance coverage does not result in significant moral hazard effects in terms of disaster preparedness activities by policyholder suggests that there are opportunities for linking insurance with incentives for risk reduction, as is examined in the subsequent chapters.

7.2.4 Question 4: To what degree can direct insurance incentives encourage households to employ flood risk reduction measures? Is there a trade-off between the strength of risk reduction incentives and the affordability of insurance premiums, and, if so, how can this be overcome?

Chapter 5 notes that several studies have argued that risk-based insurance premiums can incentivize adaptation to changing flood risk, but that few insurance systems provide such incentives in practice. The absence of widespread incentives could result from concerns over informational asymmetries between actors and the overall transaction costs involved in developing such a scheme. Moreover, the potential effectiveness of such incentives has hardly been researched. Chapter 5 presented an empirically calibrated analysis of the effectiveness of risk-based premiums in stimulating policyholder DRR activities, and how such incentives may potentially conflict with affordability of insurance. Chapter 5 investigated if these objectives of economic efficiency and equity can be fulfilled by introducing a compulsory public–private flood insurance system in France and Germany that uses risk-based premiums to stimulate risk reduction. This structure was selected because establishing a wide pool of policyholders can reduce the concerns of adverse selection and produce economies of scale that reduce the size of transaction costs involved with offering insurance. The investigated scheme fits into a policy context of repeated policy proposals in Germany, while the current French scheme could be improved with stronger risk reduction incentives.

There are three main conclusions drawn in Chapter 5. The first is that risk-based flood insurance premiums can substantially differ from non-risk-based premiums and that these differences are highly dependent on the country and market. In particular, the more solidarity-based a system is in practice, the larger this difference in premiums becomes. The second conclusion is that risk-based premiums are effective in promoting cost-effective policyholder level DRR. The premium discounts for DRR correct for underestimation of flood risk by individuals. The strength of the incentive for risk reduction is stronger in higher-risk areas. Chapter 5 finds that, on average, premium discounts for flood-proofing of property could reduce residential flood risk by 12% in Germany and 24% in France in the period 2040–2060, as compared to the situation with no insurance incentives for DRR. The third conclusion is that risk-based pricing hampers the affordability of flood insurance for about 20% of the at-risk population. However, this affordability issue can be addressed by introducing a voucher scheme, which is a form of income support that allows low-income households to pay for flood insurance if they cannot afford it. Even though the total costs for the government to provide such vouchers can be high, the results in Chapter 5 show that the damage reduction incentivized by the risk-based premiums outweighs these voucher costs.

An important policy implication is that offering premium discounts to policyholders who engage in DRR, combined with compulsory purchase requirements, can be effective in stimulating adaptation to changing flood risks, if affordability of insurance is addressed through an income support system such as insurance vouchers.

7.2.5 Question 5: What is the set of insurance market features that best manages trade-offs between economic efficiency and equity concerns of flood insurance market reforms that are needed in Europe to cope with increasing flood risk as a result of climate and socio-economic change?

The core of this thesis argues that insurance can contribute to overall flood risk management. However, despite the large political and academic debate on how to structure an insurance market, there is a limited understanding of how to better link insurance with DRR because of the competing

objectives for insurance to achieve in terms of economic efficiency and equity. Chapter 6 offers insights for this debate by presenting an integrated model of flood risk, the insurance sector, and consumer behaviour that evaluates key features of market structures that have been proposed in the policy debates across the EU. The modelling approach includes a multi-criteria approach to evaluate insurance market structures to account for differing views on the importance of four market outcomes that encompass economic efficiency and equity. Moreover, Chapter 6 assesses what market features could be introduced or maintained over time when flood risk changes as a result of climate change and socio-economic developments.

Chapter 6 indicates a common set of desirable market structures, but does not propose the introduction of a single uniform optimal market structure across the EU. In other words, there is no one-size-fits-all solution. Nevertheless, Chapter 6 indicates a clear reform trajectory that entails a movement towards public-private partnerships in insuring flood risk and greater stakeholder participation in flood risk management. The optimal market structures were found to be based around: a link between risk reduction and insurance, a public reinsurer, purchase requirements, and a limited degree of sharing of losses between high- and low-risk households. These features maintain insurance affordability, while providing sufficient incentives for risk reduction to encourage adaptation to changing flood risk. These features can be broadly implemented and further adapted to suit local contexts.

Chapter 6 shows that household-level risk reduction measures can be incentivized through a stronger link between risk reduction and premiums, even if there is only a partial link between premiums and risk. The advantage of the partial link is to maintain the affordability of insurance for low-income households. However, Chapter 6 also shows that unaffordability remains a concern regardless of market structure, even where the link between insurance and risk is weakest. The most suitable mechanism for correcting for unaffordability was studied in Chapter 5, namely a temporary means-tested insurance voucher. Chapter 6 again supports the results of Chapter 5 by showing that in the aggregate the benefits of stimulating DRR outweigh the costs of unaffordability.

7.2.6 How can insurance-based incentives and household-level risk reduction be combined to create a resilient society?

The thesis's research sub-questions address separate parts of the overall research question. Chapter 2 begins with the finding that there are large welfare (both tangible and intangible) impacts from flooding, highlighting the needs for increased efforts to reduce flood risk. Moreover, that chapter showed that there are substantial welfare benefits from individual risk reduction measures, which provides a rationale for exploring how the implementation of such measures can be improved using insurance. Chapter 3 indicated that household-level DRR can have a substantial impact on the damage suffered during a flood if a household is suitably prepared. Chapter 4 finds that the German and U.S. natural disaster insurance markets are free of moral hazard, showing that voluntary insurance purchase may not have acted as a disincentive to prepare for risk. Taking these results together there is a clear rationale to explore the ability of insurance to promote the use of household-level risk reduction measures.

Chapter 5 provides an indication that insurance incentives via premium reductions can strongly incentivise and promote the use of some of the risk reduction measures described in Chapter 3 in the cases of Germany and France. Even though premiums with a suitable link to risk reduction promote DRR, they remain potentially unaffordable for low-income households in high-risk areas. This unaffordability can be corrected for out-of-general taxation via means-tested insurance vouchers in order to facilitate an adjustment to risk-based premiums. Chapter 6 reconfirms this finding when the model presented in Chapter 5 is extended to cover the high-risk areas (the 1/100yr flood plain) across the European Union.

Chapter 6 also presents and studies six stylized insurance market structures and shows that, as society moves forward in time and risk increases, the general structure of insurance markets will

have to adapt. While there is not a uniform optimal market structure, the common traits of desirable flood insurance systems are: a sufficiently strong connection with risk reduction through limited premium cross-subsidization between higher and lower risk households, and the presence of a public-private partnership through a government reinsurer. Moreover, strengthening requirements to buy insurance may be required in order to maintain high insurance penetration rates. Overall, the research presented in this thesis indicates that as flood risk develops into the future, a stronger partnership across stakeholders focusing on risk reduction is required.

7.3 Discussion of methods

A variety of data, econometric models and other modelling approaches have been applied in this thesis to answer the research questions. This section discusses the main advantages and challenges that were experienced with these methods.

Chapter 2 aimed to examine the influence of flooding and flood preparedness on welfare, for which self-reported happiness or SWB scales were used, which can serve as a basis for monetising these welfare effects. Although this approach is commonly used for estimating the influence of important life events or intangible environmental impacts on well-being, there are few applications to flooding. A novelty of the approach used here is that the analysis separated the tangible and intangible impacts of flooding through monetising the SWB impact of experiencing a flood, and comparing this value to the monetary damage suffered during a flood.

A mediation-style analysis was applied for estimating the empirical model to capture direct and indirect effects of flood-related variables on SWB. This is an extension of the literature, since the analysis moves beyond estimating monetary values for the direct SWB impacts as is usually done. It has been recognized that the SWB approach requires further methodological developments in order to play a wider role in non-market valuation (e.g., HMT, 2011), of which this extension can be seen as an example. An advantage of the mediation-style method is that by examining both the direct effects of flooding on SWB as well as the indirect effects through the SWBDs, more comprehensive insights are obtained into how floods influence an individual's well-being. Moreover, Chapter 2 found that the use of SWBDs as explanatory variables was useful for controlling for many other factors of influence on SWB than the flood-related variables.

Several challenges were encountered in the monetisation of the SWB effects of the variables related to flood experience, flood preparedness, and flood risk perceptions. Due to data limitations, Chapter 2 used average certainty equivalents of the monetised effects of the flood-related variables on SWB and average experienced direct flood losses to distinguish the tangible and intangible monetary equivalents of these variables on SWB. A more refined method would compare individual monetised SWB values with individual direct flood losses. However, the individual direct flood losses were unavailable for all flood events, which is why the analysis had to rely on average values. Nevertheless, the approach in Chapter 2 provides relevant insights into the order of magnitude of tangible and intangible well-being effects of the flood-related variables, such as flood experience.

A second limitation of the methodology employed in Chapter 2 is that the use of SWBD related to the financial situation of an individual in the regression model prevented making a direct connection of SWB to income. Hence, estimates of the relation with SWB and income from the wider literature were used for the monetisation analysis in Chapter 2. This may hamper internal consistency within the study, since using these values from other studies may add uncertainty to the monetisation estimates. Chapter 2 attempted to limit this uncertainty in two ways. First, a meta-regression was applied based on the studies that linked SWB and income, which were sufficiently similar in order to control for idiosyncratic differences between studies. Moreover, a Monte-Carlo approach was used to account for the uncertainty of the relation of income and SWB, which involved taking random draws from the two parameter distributions to characterise the plausible range of outcomes. Moreover, the final estimates of the monetary equivalents of flood impacts on well-being were

compared with such values found in the wider literature for other adverse life events to see if the results in Chapter 2 were plausible, which turned out to be the case.

Turning to Chapter 3, the primary objective was to provide more refined estimates of the effectiveness of household-level DRR measures (Question 2). This was done by applying a novel statistical technique to pre-existing survey data of individual flood impacts and flood preparedness decisions. In particular, Chapter 3 examined the suitability of PSM for deriving estimates of the effectiveness of DRR measures. It turned out that this method proved to be effective in arriving at more reliable estimates of the potential flood damage that can be avoided by specific DRR measures. The main challenge with this approach was its very data-intensive nature in order to capture the relevant confounding variables. These are variables that may influence both the adoption of DRR measures and the effects of these measures in saving damage during a flood event. Moreover, the balancing assumption of PSM must hold in order for the estimated propensity scores to be comparable, which may not always be the case.

Three approaches were taken to overcome these issues as much as possible. The first was that the variables included in the propensity score model were limited to direct indicators of the hazard faced, the level of exposure and a range of indicators regarding vulnerability. The second was to use multiple matching methods in order to check for consistency in the PSM estimates of flood damage savings per DRR measure. The third was that the set of possible confounders was altered for each DRR measure in order to help meet the balancing assumption. In this respect, the use of categorical variables was useful because they provide more flexibility in meeting this requirement.

A variety of statistical methods were employed in Chapter 4 to examine the presence of moral hazard in a voluntary insurance market (Question 3). In particular, probit models were used to establish a relation between insurance and various risk management strategies. Bivariate probit models were applied to determine a possible joint decision process between taking risk management measures and purchasing insurance. Heckman sample selections models estimate the role of deductibles in managing risk through implementing ex ante risk reduction measures. PSM was employed to estimate the difference in flood damage suffered between insured and non-insured households. This was done in order to investigate moral hazard based on different outcomes rather than inputs.

Chapter 4 applied methods that have been well established within the literature investigating moral hazard, although such a systematic analysis of moral hazard was, as yet, lacking for natural disaster insurance markets. A comprehensive assessment was provided by applying the same modelling and variable selection frameworks to several sources of data drawn from very different market and risk contexts, namely the United States and Germany. This approach allowed for arriving at robust insights showing that moral hazard effects are minor, because intrinsic individual motivations imply that many individuals take both flood insurance and other measures that limit flood risk. It should be realized that the methods used in Chapter 4 were suitable for splitting the data samples into a ‘treatment’ and ‘control’ group of individuals with and without flood insurance coverage. This approach works well for examining moral hazard in voluntarily insurance markers. A different approach would be required for examining moral hazard if the purchase of insurance is mandatory since a ‘control’ group would be lacking in that case.

Computational models were developed in Chapters 5 and 6 in order to examine research Questions 4 and 5, for which a comprehensive empirical analysis would be infeasible. These chapters provide novel integrated modelling frameworks of insurer and consumer behaviour by linking flood risk models directly with premium setting by insurers and household-level investments in DRR. Overall, these models are useful for examining effects of policy reforms, such as the influence on household DRR investments and related risk levels of introducing risk-based insurance premiums. Chapter 5 provided a more focused analysis of implications of introducing risk-based flood insurance premiums in a public private flood insurance arrangement for Germany and France. Chapter 6 extended that

model framework to other EU countries, for which the Dynamic Integrated Flood and Insurance (DIFI) model was created. DIFI includes an evaluation module that, on the basis of economic efficiency and equity criteria, identifies desirable reform pathways of flood insurance markets for coping with changes in flood risks due to climate change. DIFI consists of a flexible model structure which allows for examining the desirability of a variety of flood insurance market structures.

Even though the structure of the models used in Chapters 5 and 6 is well embedded in existing literature and empirical information, the calibration of several model parameters was challenging due to limited data availability. In particular, the modelling approaches are constrained by limited data on individual risk perceptions of flood probabilities or the perceived effectiveness of DRR, which are important parameters for the household behaviour modules. An attempt was made to overcome this challenge by calibrating the individual risk perception parameters based on three scenarios of available datasets of individual flood risk perceptions and employed DRR measures by households. Nevertheless, important uncertainties can also be found in other parameters and model assumptions. This is why, in Chapter 6, extensive sensitivity analyses were conducted to examine the robustness of main results to: uncertainty in risk and insurance premium estimates and underlying flood risk projections, alternative assumptions about the costs and effectiveness of risk reduction measures, differing models of flood insurance demand, and different risk management objectives that would alter the relative attractiveness of the evaluation criteria. Furthermore, Chapter 6 relies on a relative multi-criteria assessment of the various market structures rather than on the absolute values of the assessment indicators, which allows for arriving at more robust outcomes.

7.4 Policy recommendations and implications for future research

There are two sets of implications that emanate from this thesis, which are summarized in Table 7.1 and discussed below. The first is policy implications for how flood insurance markets could be restructured in both the present and the future in order to maintain a robust insurance market and a resilient society. The second is a discussion on the general implications for future research.

7.4.1 Policy implications

There are five main policy conclusions from the research presented. The first regards the common expectation by policy makers and insurers that the natural hazard insurance market displays moral hazard and, through adverse risk selection potentially, adverse selection leading to market failure and uninsurability. Contrary to these expectations, the research presented in this thesis found no evidence of moral hazard in the very different voluntary market contexts of the German and U.S. insurance markets. In particular, insurance coverage did not result in households employing fewer risk reducing measures. Rather, there was weak evidence that households with insurance tended to employ more risk reducing measures.

Nevertheless, there is some evidence in favour of adverse risk selection and, as such, stronger mechanisms need to be employed to reduce the potential for adverse selection. The suggested policy mix to overcome this issue is based on risk zoning, in which premiums are differentiated according to risk classes and compulsory insurance purchases. This particular policy mix reduces the importance of the informational asymmetries in risk between the insurer and the policyholder. Moreover, it creates a sufficiently large pool of ‘good’ and ‘bad’ risks, maintaining the equality between premium income and expected indemnity payments.

The second policy implication regards the use of incentives to encourage households to employ additional DRR strategies. This thesis supports on-going discussions for implementing a greater range of incentive mechanisms. Chapter 4 shows that, while deductibles are commonly used to incentivise households to manage risk, very few people know in advance of a natural disaster that they possess a deductible. This suggests that the deductible alone would not be sufficient to promote risk reduction, which is also confirmed by results in Chapter 4 showing that deductibles have only a small influence on implemented DRR measures.

Therefore, this thesis argues in favour of the use of risk-based pricing and premium discounts to incentivize households to adapt to changing risk in an ex ante, cost-effective manner. Chapter 5 shows that risk-based premiums can be an effective mechanism for reducing risk by overcoming a lack of disaster preparedness by households who underestimate the natural disaster risks they face. However, this is not the only policy mechanism that may be suitable. For instance, in the United States, the Disaster Savings and Resilient Construction Act would provide a tax incentive for building in a disaster-resilient manner, which may encourage non-insured household to conduct risk-reduction activities. The general conclusion is that these incentives should not be based on a disaster occurrence, as is the case with incentives originating from deductibles. Instead, tangible incentives, such as premium discounts or tax credits, are more suitable, in order to provide policyholders with a concrete financial reward for reducing risk.

The third policy implication is that while risk-based premiums are potentially successful at promoting DRR, this incentive can come at the expense of insurance affordability. Even if risk-based insurance is affordable, the premiums can also counteract the potential strength of the insurance incentive by rendering DRR measures unaffordable when a household's disposable income is lowered through paying high premiums in high-risk areas. Both types of unaffordability can be addressed by providing means-tested vouchers or subsidies, since they reduce the burden on household budgets of purchasing disaster insurance or implementing DRR measures. It is likely that the insurance premium voucher should take priority. The insurance premium voucher would allow for the risk transfer element of insurance to take place, while weakening the unaffordability constraint for risk reduction measures.

Table 7.1 Core implications emanating from this thesis

Finding	Policy Implication	Research Implication
Absence of moral hazard in Germany and the U.S., but adverse risk selection is present, which in turn may lead to adverse selection as commonly understood.	Strengthen the incentives for insurance companies to promote policyholder-level risk reduction. Base premiums on risk classes and/or introduce compulsory insurance to overcome the potential for adverse selection.	Investigate the possibility of moral hazard in compulsory rather than voluntary insurance markets.
Tangible incentives (i.e., premium discounts), are more effective in stimulating risk reduction than deductibles.	Introduce interest-free loans, tax credits, premium discounts or otherwise fixed incentives for household retrofitting to stimulate DRR.	Develop models to compare the ability of other tangible incentives to encourage DRR, such as minimum risk reduction standards to be eligible for insurance.
The risk reduction potential of risk-based premiums outweighs the burden such premiums place on low-income households.	Introduce a short-term voucher programme to ease the transition and burden of risk-based premiums.	Further development of the debate over how to define and measure the affordability of insurance. Investigate innovative mechanisms for managing the unaffordable part of insurance.
Intangible (non-monetary) benefits of flood preparedness and costs of flooding are large.	Intangible impacts should be more often included in the cost-benefit analysis of large scale flood protection projects that limit disaster risk. The benefits of DRR should be viewed holistically rather than focusing on solely direct economic benefits.	Investigate other regions to see how transferable these results are. Try to develop stronger experimental (or semi-experimental) econometric strategies to check the robustness of the findings.
Flood insurance reforms towards a public-private partnership are desirable based on a compromise between solidarity based insurance systems and semi-voluntary-based insurance systems.	Strengthen insurance purchase requirements. Offer public reinsurance for natural disasters similar to terrorism insurance.	Involve stakeholders in order to determine an appropriate set of weights for the MCA analysis applied in Chapter 6 to further refine specific reform directions for a country.
Continued evaluation of characteristics of flood insurance systems is required.	There is no silver bullet insurance system, since when the risk situation changes and develops new solutions may be required.	Constant evaluation of stakeholder preferences and objectives. Constant review of flood risks and effective strategies to manage flood risk. Expand the DIFI model to include general disaster insurance and include more data driven behavioural rules.

However, it must be acknowledged that the vouchers offered for insurance premiums should be temporary in order to facilitate adjustment to the implementation of risk-based premiums, rather than acting as a direct subsidy which could over time attract new residents to high-risk areas. Potential subsidies or vouchers for risk reduction measures, on the other hand, do not create this problem; as such measures directly reduce vulnerability.

The fourth policy implication applies more broadly to flood risk management. Government investment in protection infrastructure or risk management plans as a whole tends to be based on a cost-benefit analysis, where a project is conducted if the total discounted benefits of flood protection exceed total discounted costs of this protection. However, these cost-benefit analyses often disregard the intangible benefits of flood risk reduction. Chapter 2 shows that the welfare impacts of the intangible impacts from flooding or household preparedness can outweigh the importance of the direct damage suffered. Intangible benefits and costs should be integrated into the decision processes that govern risk management investments, but usually such values are not part of cost-benefit analysis of flood risk management strategies. Such flood risk management decisions that do not take into account intangible benefits are likely to result in a socially inefficient level of investments. Moreover, the importance of intangible impacts of natural hazards should be considered when assessing the cost of increasing natural disaster risk that can result from climate change.

The fifth implication is that, while this thesis tended to focus on Europe, the results and policy recommendations can be useful in the on-going policy discussions about reforming natural disaster insurance markets outside of Europe. An important finding is that adverse risk selection may be present while moral hazard is not, as the analysis in Chapter 4 also showed for the United States. Therefore, resources should be allocated to studies developing methods to provide more spatially refined risk estimates. This supports policy reforms such as recent flood insurance reform acts concerning the National Flood Insurance Program in the U.S. and moving toward risk-based rates, such as the Biggert-Waters Flood Insurance Reform Act of 2012.

Moreover, policies aimed at increasing the uptake of flood insurance among both low- and high-risk groups could be useful for creating a large risk pool and limiting (potential) problems with adverse selection. For example, the Homeowners Flood Insurance Affordability Act of 2014, and the Flood Insurance Market Parity and Modernization Act of 2016. These acts are aimed at improving the financial sustainability of the NFIP, which has high debts held by the U.S. Treasury. Some of the issues that these reforms try to address are improving the actuarial soundness of the program by moving towards risk-based premiums, strengthening purchase requirements to overcome the observed low penetration rate outside high-risk areas, and providing stronger incentives for DRR. These reforms have similar characteristics to the set of reforms appropriate for most European countries. Moreover, in many regions around the world, natural disaster risks are increasing, which can trigger debates about insurance solutions to cope with changing risks for which the results in this thesis may serve as a useful staring point.

7.4.1.1 Political economy of the policy implications

The policy implications can have a substantial impact on how European insurance markets for floods and other extreme weather events are structured in some countries. This is because as Chapter 6 notes there are a range of approaches taken in Europe to provide flood insurance, although there are similarities. For example, Spain provides insurance through a public institution at a flat rate; France provides insurance through private institutions at flat rates, but with a high degree of public-private collaboration; while the UK and Germany are reliant on private insurers with different levels of coverage. These differing approaches have developed because different countries display different risk profiles and priorities in the past, leading to their idiosyncratic development (Surminski et al.,

2015) according to the preferences of the local residents. Therefore, this formation can be seen as the result of public policy choice.

However, even though the approaches taken have developed idiosyncratically, it must be acknowledged that not all stakeholders (i.e. households, governments, insurers) view the role of insurance in the same manner. These differing views can prove problematic in policy debates. For instance, risk based premiums can provide strong risk management incentives but also create concerns regarding unaffordability (Chapter 5), which differing stakeholders can view with differing levels of importance. An example is that very high risk households could value mechanisms limiting the unaffordability of their insurance much more highly than lower risk households who benefit more from risk based premiums. Additionally, over time the views of stakeholders can diverge regarding relevance of certain actions or behaviours as can be seen through the evolution of the 'Gentlemen's agreement' to Flood Re in the United Kingdom. Therefore, how different stakeholders can view the various market outcomes has substantial impacts on how markets develop. On the whole when presented with this concern, this thesis presented these differing views as different risk management objectives. Therefore, rather than directly modelling the preferences of a wide range of stakeholders we focused on differing sets of indicators for the relative importance of the modelled insurance outcomes. These different risk management objectives are generated by the different preferences that the stakeholders have towards risk, welfare transfer, the role of the state etc.

Therefore, when investing the suitability of market structures we should take these different objectives into account. A comparative analysis of schemes is required, such as presented in Chapter 6, the extent to which a scheme is able to achieve a reasonable trade-off between the various outcomes. This heterogeneity of approaches can help us to better understand what systematic market features work or do not work in achieving this trade-off across difference preferences (with the varying weights associated with each outcome acting as a proxy). Chapter 6 supposed a range of different objectives and then looked for the market features that were most commonly highest scoring across the range different risk management objectives. In comparing the optimal stylized market structures found in Chapter 6 to an inventory of extreme weather insurance presented in a forthcoming external report for the European Commission[1], we see that many of these features are already in place in what can be considered best practice countries in terms of their provision of extreme weather insurance overall.

Even though this thesis used the MCA approach as a proxy for the different preferences towards insurance markets, there is still the potential for many political difficulties in applying this thesis's policy implications. This is because there is a distinction to be made in if flood insurance, and by extension all extreme weather insurance, is a private or a social good. Seeing insurance as a 'private good' means insurance is a method for protecting an individual financially from extreme weather events based on their own wishes. While, seeing insurance as a 'social good' means that insurance is a method of protecting society as a whole by limiting the individual financial impacts, thereby preventing economic damage from extreme weather events. In this view insurance should be accessible for all, or there is a strong overall desire that many people are covered.

Different stakeholders can view insurance to be located at different points along the spectrum of a private to a social good, with resulting implications on how the 'optimality' of the reforms can be seen. The closer a view is towards the 'private good', the weaker the support for the limited cross-subsidization is likely to be, compared to a view closer to the 'social good'. Perceptions that the impacts that floods can cause on those directly affected are substantial and widespread can point to the view of extreme weather insurance as a social good. That such perceptions are heterogeneous is

[1] Insurance of weather and climate-related disaster risk: Inventory and analysis of mechanisms to support damage prevention in the EU, approved for publication on August 2017. Consultation for the European Commission Directorate-General for Climate Action, Unit A.3 – Adaptation. Partnership between Ramboll (Xavier Le Den, Matilda Persson, Audrey Benoist) and IVM (Paul Hudson, Marleen de Ruiter, Lars de Ruig, Onno Kuik).

further reinforced by the common observation that the subjective and objective flood risk perceptions can be widely divergent.

The proposed set of policy directions tends towards the view that flood insurance should be treated as a social good. Therefore, the political acceptability of the identified market features is dependent on how wide-spread the political support for risk based or flat premiums is; the degree to which people are willing to support each other; the extent to which there are economies of scale in minimizing expected flood damage; and how idiosyncratic flood risks are. The problems of the divergence of lay-, and expert risk perceptions can further compound these problems in the political arena, as the relevance of the flooding risk is seen differently between different stakeholders.

These political problems can influence how market structures can be seen to be optimal based on their acceptability to the overall electorate across the various countries. This acceptability is based on the combination of preferences that individuals have towards these matters and the potential welfare consequences of the proposed reforms over the status quo. However, treating flood insurance as a social good there is room for abstracting away from individual level preferences. This allows suitable market structures, or risk management strategies, to be investigated independently from risk attitudes. Chapter 2 noted that an individual's risk perceptions depended on their lifetime of experiences and how recent these experiences are. This temporal dimension to risk perceptions creates a volatile political atmosphere where there can be short bursts of intense focus on flood risk management, and periods where peoples subjectively low risk beliefs inhibit action. The potentially cyclical nature highlights the need for policy discussions that move away from risk attitudes.

This process may take a long time to accomplish as the varying views are combined into an overall objective for managing flood risk via insurance. Flood Re is an example of such a complex processes of compromise across the relevant stakeholders, which captures many of the aspects of an 'optimal market' as identified in Chapter 6. The differing risk management objectives of the stakeholders show that there would be room for more open and transparent engagement of, and collaboration with, the various stakeholders involved in the risk management process.

7.4.2 Research implications

This thesis has answered several research questions, but further research on this topic is needed, since as long as there are changing risk profiles or preferences there will be a need to constantly re-evaluate and assess society's approaches to managing flood risk. Additionally, the limitations of each chapter as well as the discussion presented in the previous sub-section offer a natural starting point from which new research can build.

The empirical methods use data from cross-sectional datasets obtained from surveys of households in flood-prone regions in Germany and France that were structured to reveal the past flood experiences of households and currently taken self-protection actions. There is still room for the improvement of data collection methods. Data could be improved upon by developing panel or longitudinal datasets that have longer temporal dimensions. Panel or longitudinal datasets would add a stronger temporal dimension to the available data. The improvement of the temporal dimension of datasets would greatly enrich the analyses that can be conducted within the field of natural hazards research. Datasets with a temporal dimension would allow for a greater variety of statistical techniques to isolate causal effects or to investigate changes in flood preparedness over time as risk, risk perceptions, or incentives alter. The research in this thesis investigated changes in flood preparedness over time calibrated on cross-sectional datasets, while the temporal dimension may be an important factor of influence on this preparedness. For instance, households may delay investing in household risk reduction measures even if there are strong insurance incentives in order to see if the insurers will continue to provide the premium discount. Calibrating the model parameters on datasets with a stronger temporal dimension would enrich the aspects of these models that look into household behaviour regarding high-impact/low-probability risk and altering

behaviour over time. Moreover, it may open up more avenues of research than are currently possible.

Increased recording or systematic surveying after a disaster could also be suitable for investigating the tangible and intangible impacts of flood experiences or risk reducing measures. Moreover, the use of panel data with more detailed loss recording can allow for an individualised investigation of impacts of flooding on subjective well-being. Further individualisation of the results could be achieved through applying multi-level approaches that would allow specific parameters to be estimated for each 'level'. For example, combing a multi-level regression model and a panel dataset would allow for estimating separate parameters for each respondent, which may result in an estimated certainty equivalent of subjective well-being impacts that correspond closer to the respondent in question.

Chapter 4 dealt with moral hazard, which is a very commonly mentioned problem with natural disaster insurance markets. Moral hazard is often regarded to be a problem in natural disaster insurance markets because the premiums charged by insurance companies would no longer reflect the actual risk facing the household if moral hazard occurs. Chapter 4 investigated moral hazard in two effectively voluntary insurance markets, finding that it was not present since those people who are motivated to insure are also motivated to protect themselves. Investigating moral hazard is possible in voluntary insurance markets because it is possible to compare the protection behaviour of those with and without insurance.

However, Chapter 6 notes that not all disaster insurance markets are voluntary. Some markets have various forms of purchase requirements, meaning that all households must buy insurance including those who are motivated to protect themselves and those not motivated to do so. These non-voluntary markets could also display moral hazard. Investigating moral hazard in non-voluntary insurance markets may be more difficult, but no less important. The premiums in non-voluntary insurance markets have been noted to be very weakly connected to risk and not all of the insured have the tendency to display intrinsic characteristics that prevent moral hazard form occurring. Therefore, research could be conducted to see if mandatory natural disaster insurance schemes are more vulnerable to moral hazard than voluntary insurance markets. This is an especially important avenue of future research, because one of the key policy implications of this thesis is the introduction of compulsory forms of flood insurance. It may be that any possible presence of moral hazard in compulsory insurance markets could be corrected for by introducing deductibles (although awareness of the deductible may be low as Chapter 4 indicated) or through the incentives offered by risk-based premiums or other external incentives. Future research could examine if these mechanisms are required or would be sufficient to address the presence of moral hazard when all households must buy insurance.

Another area for future research concerns investigating the success of DRR measures for different flood characteristics (e.g., floods of smaller overall magnitudes) so that a more complete picture of the effectiveness of DRR can be provided. The results of this chapter indicate that DRR measures were effective in limiting damage during a large flood event, while damage reductions may be different during flood events of a smaller magnitude.

Future research can also seek to apply PSM to a wider range of natural hazards. In general, there are few independent empirical studies about the employment of natural disaster risk reduction measures and their effectiveness, which implies that the evidence base for these estimates is small. In addition, future research could focus on establishing an improved evidence base for estimates of natural disaster risk reduction measures that are in place in different regions and how effective these are in limiting flood damage.

Yet another direction for future research would be examining the effectiveness of social psychological interventions that governments, NGOs or insurance associations could undertake to

improve disaster preparedness. These instruments could be important complements to financial incentives for reducing disaster risk, since preparedness involves more than employing risk reducing measures. For instance, early warning systems may only be effective if people know how to correctly respond to the warning or trust the warning giver. Moreover, a high degree of preparedness or risk awareness as a whole can help decentralised risk management, because location decisions may be altered when the agent does not want to bear the risk of living in a flood-prone area. Examples include public service announcements and mail campaigns that provide, in simple language, information or reminders about natural disaster risks and the benefit of purchasing natural disaster coverage. For example, Chapter 4 highlighted that studies of the effectiveness of communication about flood risk show that communication messages can be effective in increasing risk awareness and demand for flood risk reduction measures and flood insurance.

The core model discussed in Chapters 5 and 6 accounted for possible individual misperceptions of flood risk. The model assumed that households base decisions on flood-preparedness by trading off costs and benefits of flood-proofing measures. This could be seen as a limitation of this chapter's approach when households make decisions on other grounds. Allowing for alternative decision-making frameworks could be a fruitful area for future research. In addition, there are several uncertainties regarding the applied input data and modelling approach (e.g., household-level risk perceptions). In future work, the calibrated flood risk perception distribution could vary over time, and allow for greater spatial diversification if wider longitudinal studies are conducted by expanding the DIFI model to include factors other than objective risk. For instance, time periods with long gaps between floods will likely contribute to reduced flood risk awareness, while periods immediately after a flood can result in perceptions that imply overestimation of objective risk.

Our modelling approach is useful for examining average effects of insurance market reforms on individual flood preparedness behaviour, which can provide a useful starting point for future research that aims to predict this behaviour in a more detailed manner, such as for a specific region at a particular point in time.