Chapter 1: Introduction

1.1 Research background and problem definition

1.1.1 Catastrophe risk and insurance markets worldwide

The global economic losses caused by natural disasters have been increasing significantly over the past few decades, as can be observed in Figure 1.1 (Kunreuther and Michel-Kerjan, 2011; Munich Re, 2013). The average direct economic damage caused by natural catastrophic events between 2001 and 2011 over the world was estimated at $165bn, while the average insured amount in the same period was $49bn. The years 2005, 2011 and 2012 were the most costly years in history for the insurance industry with, respectively, $120bn, $124bn and $65bn of insured damage (Munich Re, 2013). The extreme nature of natural disaster losses poses considerable challenges in connection with the supply of affordable and broad insurance coverage for natural hazards. Recent data shows that on average, only 20 to 30 per cent of total direct damage caused by catastrophic events is being covered by insurance worldwide (Munich Re, 2013). In general, insurance against catastrophic risks is mostly available in developed countries, and is priced at high premiums compared with regular non-disaster insurance (Kousky and Cooke, 2012). Moreover, natural disaster insurance coverage is often subject to various restrictions, such as a cap on overall coverage, limitations on coverage for specific types of damage, and high deductibles for policyholders (see Chapter 2). Several recent costly natural disasters, such as Hurricane Katrina in 2005, the Sichuan earthquake in 2008, the Tsunami in Japan in 2011 and Hurricane Sandy in 2012, have shown that the provision of public funds is needed to (partly) compensate uninsured losses from natural disasters.

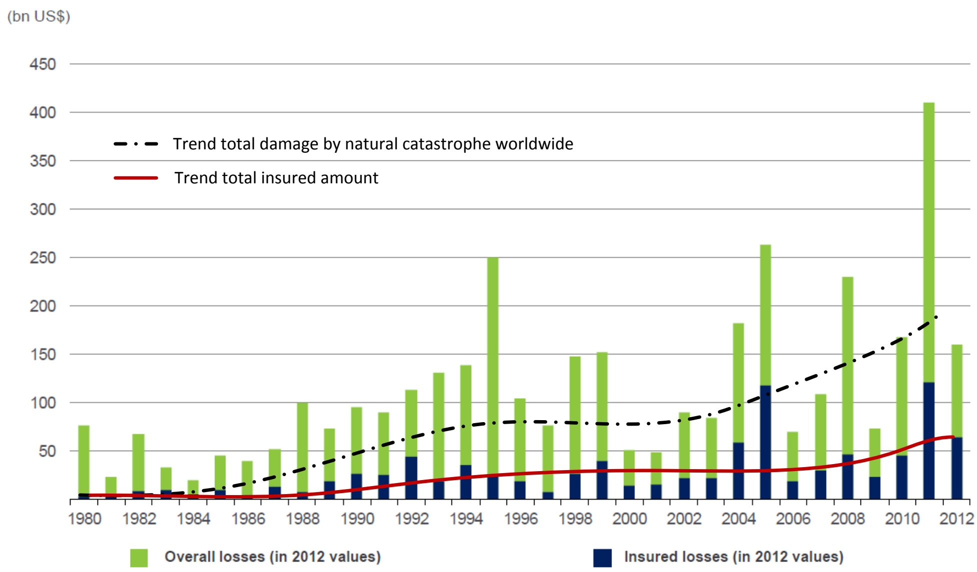

Figure 1.1 Overall and insured losses ca 1 caused by large natural catastrophe events between 1980 and 2012 (in 2012 values)

Source: Munich Re (2013)

1.1.2 Future global climate change and flood risk in the Netherlands

The economic losses and social disruption caused by natural disasters are projected to increase further in certain regions of the world as a result of population and economic growth and climate change in areas at risk from natural hazards (Kron, 2008; Munich Re, 2013). Weather-related events like floods are expected to become more frequent as a result of climate change, which is causing sea level to rise and peak river water discharges to increases in several regions (Field et al., 2012). The growing concentration of population and economic values along the coastal and riverside areas around the globe implies that exposure to natural disasters, like floods and storms is increasing (IPCC, 2007a; Kron, 2008).

Although, in general, this thesis deals with the technical aspects of catastrophe risk insurance, the particular focus is on the Netherlands as a case-study area for examining the management, and, specifically, the insurability, of flood risks. The Netherlands is of particular interest, since it has a high exposure to flooding and is vulnerable to climate change (Aerts et al., 2008). Even though the Netherlands is a low-lying country that is prone to flooding, flood-protection infrastructure has made it one of the best-protected deltas in the world, with very high safety standards. The low-lying areas in the Netherlands are divided in 53 dyke-ring areas, some of which have been reclaimed from former lakes (often called ‘polders’). Each dyke-ring area has its own closed flood protection system of dykes, dams, barriers, and sluices that protect it from floods caused by rivers and the sea. Figure 1.2 shows a map of the Netherlands that depicts the 53 dyke-ring areas and their safety standards, which range between 1/10,000, and 1/1,250.

Various weather-related disasters, with different damage magnitudes and human suffering, have occurred during the last 70 years in the Netherlands. On February 1953, a large-scale flood occurred in the south-western part of the country, caused by a severe storm surge, which caused 1836 deaths, and destroyed around 9 per cent of the total Dutch farmland (De Kraker, 2006; Jonkman et al., 2008). After this catastrophic storm surge, the Dutch created their famous “*Deltaworks*”, which include large-scale engineering measures that resulted in the high flood safety standards shown in Figure 1.2. Nevertheless, a residual flood risk remains, and several floods have been experienced since then, albeit of a less catastrophic nature. In 1993 flooding occurred along the Meuse River, which was caused by extreme river discharges that had a probability of occurrence of about once in 150 years (Jak and Kok, 2000). In 1995 the same part of Meuse River flooded once again. The first phase of a large flood management project that started immediately after the flooding in 1993 to reduce future flood risks was still in progress (Wind et al., 1999). In 2003, owing to the failure of a peat dyke, a local flood occurred in the town ‘Wilnis’, which was most likely caused by a very long dry summer (van Steen and Pellenbarg, 2004).

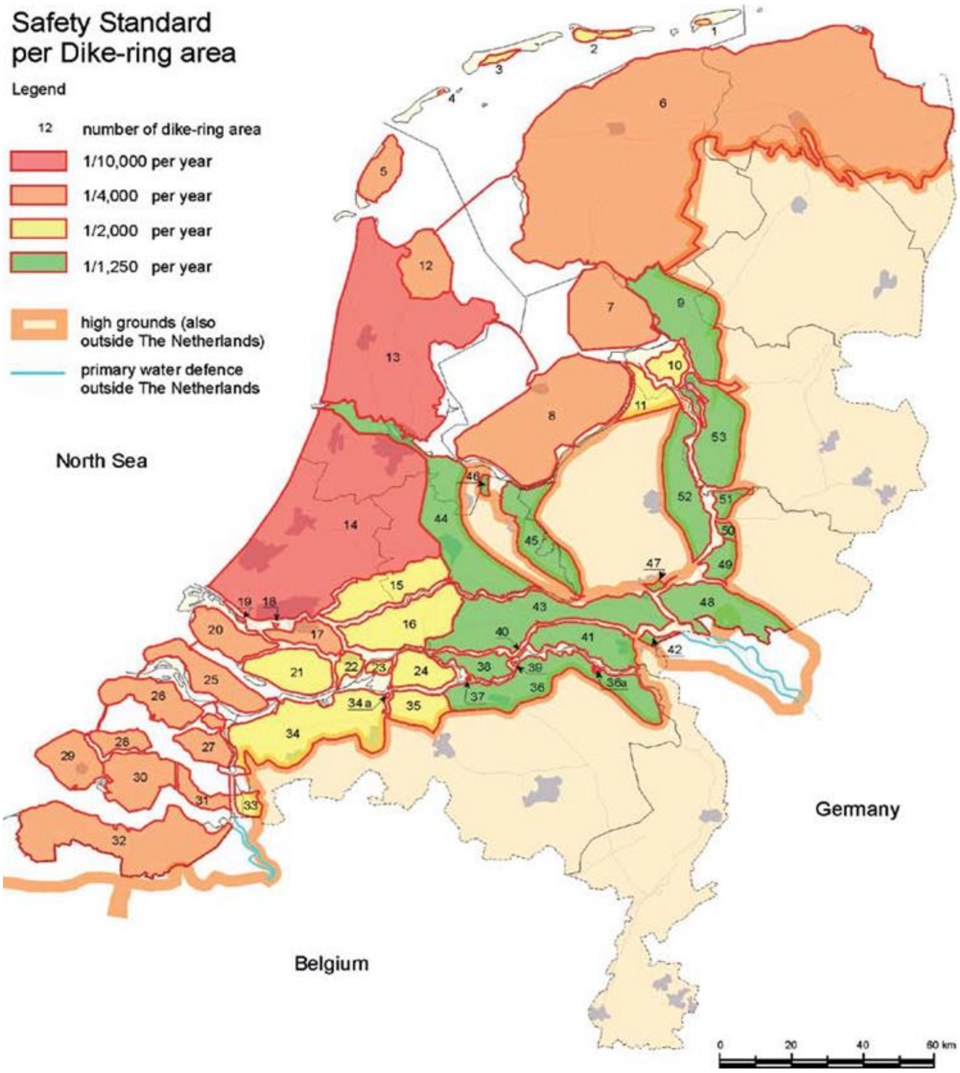

Figure 1.2 Safety standards of dyke-ring areas in the Netherlands

Source: (Klijn et al., 2004)

Global warming caused by greenhouse gas emissions may increase flood risks in the future because of sea level rise and an increase in (extreme) precipitation and possibly an increase in the frequency and severity of storms in certain regions (Field et al., 2012). The global temperature has increased by 0.76°C since 1900 causing a sea level rise of approximately 20 cm. The International Panel of Climate Change (IPCC) projects a rise in global average temperatures between 1.1°C and 2.9°C in 2100 under a low emission scenario, while the rise could be between 2.4°C and 6.4°C under a high emission scenario (IPCC, 2007b). The Royal Dutch Meteorological Institute (KNMI) provides different projections of future changes in climate and their potential consequences for flood risk in the

Netherlands under four different climate change scenarios[1] for the years 2050 and 2100 (van den Hurk et al., 2006). Since 1900, the mean temperature in the Netherlands has risen by 1.2°C, which is higher than the mean temperature increase that has been observed worldwide. According to the KNMI, the projected increase in temperature under the 'warm' climate change scenario will lead to a sea level rise of between 15 and 35 centimetres by 2050, whereas this rise could be in the range between 30 and 70 centimetres by 2100. As a result of climate change, the annual maximum river peak discharges are expected to rise between 3 and 19 per cent, which may have a significant impact for the future flood risk in the Netherlands (Middelkoop et al., 2001; Vellinga et al., 2001). For example, a study by Aerts and Botzen (2011a) shows that the potential average flood damage in the Netherlands may increase by 200 and 260 per cent compared with current potential flood damage under, respectively, scenarios of low and high economic growth and 24 cm of sea level rise by 2050. In addition to increasing the potential flood damage, climate change may substantially increase the future flood probability in the Netherlands (Aerts and Botzen, 2011a). Obviously, these projections of climate change in the future are surrounded by large uncertainties, but nevertheless they point towards the need to implement policies to adapt to the projected increase in flood risk.

1.1.3 Flood risk insurance in the Netherlands

Accelerated sea level rise, would have a significant impact for the flood security in the Netherlands because of its low-lying geographical position. Various research projections of flood damage in the future predict an increase in frequency and severity of floods (Aerts and Botzen, 2011a; te Linde et al., 2011; van den Hurk et al., 2006). The main focus of the current flood risk management policy in the Netherlands has been to lower the probability of the flood hazard by means of prevention via an extensive flood protection infrastructure (Aerts and Botzen, 2011a; Vis et al., 2006). However, because of the projected socioeconomic development[2] in floodplains and anticipated climate change, the need for a comprehensive long-term strategic planning for flood-risk management has arisen. New policies may include adaptation measures, which prevent flooding through the strengthening of flood

[1] The four different climate change scenarios are moderate, moderate+, warm, and warm+ (van den Hurk et al., 2006).
[2] Although, in general, the term 'socioeconomic development' refers to the process of social and economic development, throughout this thesis it has slightly different meaning. Here this term refers mainly to the costs of a disaster as a function of GDP per capita and population growth over time.

protection infrastructure and measures that reduce flood damage. Additional strategies may be considered, such as setting up financial arrangements for compensating residual flood risk, such as flood risk insurance (Botzen and Van den Bergh, 2008; Kabat et al., 2005; Katsman et al., 2011).

Currently, insurance coverage for flood damage is excluded in most general property and casualty (P&C) insurance policies in the Netherlands, except for the catastrophe insurance policy introduced in 2012 (see Section 1.1.4) (Botzen et al., 2010b). Compensation for disaster losses, with the exception of losses caused by saltwater, in the Netherlands can be provided by the Dutch government on an ad-hoc basis through the Calamities and Compensation Act (called the '*Wet Tegemoetkoming Schade bij Rampen en Zware Ongevallen*' − "WTS"). This arrangement was established in 1998 in response to the flood events in 1993 and 1995 that caused, respectively, total damage of about €115 and €64 million (Jak and Kok, 2000). The WTS provides compensation for damage caused by natural disasters (uninsurable risks) to property-owners and businesses under certain conditions. For example, the maximum compensation amount is never higher than 70 and 65 per cent of the damage, for homeowners and businesses, respectively, and the corresponding deductible amounts are €1,000 and €10,000 (MBZ, 1998). Prior to the establishment of the WTS, the Dutch government initially proposed to extend private home insurance with coverage for fresh flood water damage. This proposal was, however, rejected by the Association of Dutch Insurance (ADI), for the reason that insurers may not have sufficient financial capacity to cover losses caused by catastrophic events, such as floods (Kok et al., 2005).

Given the projected increase in flood risk caused by socioeconomic developments and climate change, it has recently been suggested that some form of (public-private) flood insurance could be more efficient in compensating flood victims for potential flood damage in the future (Botzen and Van den Bergh, 2008; Jongejan and Barrieu, 2008). Various studies on future flood risk in the Netherlands have suggested that it is especially important to integrate policies and incentives for risk reduction in natural disaster insurance systems and, thereby, promote climate change adaptation (Botzen et al., 2009a; Botzen and Van den Bergh, 2008, 2009b). For example, an empirical study has shown that many Dutch homeowners would be willing to take flood risk mitigation measures in exchange for a premium discount on a flood insurance policy, which could substantially reduce aggregate damage during a flood (Botzen et al., 2009). Moreover, surveys have examined the demand for Dutch households for flood insurance using utility models (Botzen and Van den Bergh, 2009a), the contingent valuation method (Botzen and Van den Bergh, 2012b), and choice experiments (Botzen et al., 2013). A main result of these studies is that the willingness-to-pay (WTP) for flood insurance in the Netherlands is, on average, higher than the expected value of flood damage that homeowners may face (Botzen and Van den Bergh, 2009a).

In view of the anticipated effects of climate change and socioeconomic development on flood risk in the Netherlands, it has been argued that the WTS will be inadequate to cope with catastrophic damage in the future (Seifert et al., 2013). There are five main shortcomings of the WTS arrangement. First, the WTS is an ad-hoc compensation system, and it is uncertain whether or not, and how much, of the flood losses will be compensated. In fact, compensation depends on the political will and public opinion at the moment of a flood event. The Dutch government has to recognize and declare a flood event as a national disaster, before the WTS comes into effect. However, there are no clear rules for such a declaration, and about how much compensation is granted to those affected by floods. Even if compensation is given, experience shows that the necessary time for claim handling could be unacceptably long (ADI, 2013). Second, the WTS does not contribute to raising awareness of flood risk, and it fails to provide incentives to property-owners to implement measures that mitigate flood damage (Botzen et al., 2010b). For example, the WTS does not levy (risk-based) premiums, nor does it provide a financial reward to people who flood-proof their houses by, for example, the elevation of newly-built homes in flood-prone areas. Third, the WTS is financed solely through ad hoc available public money and, because it does not collect premiums, it cannot build structural (cumulative) reserves. Fourth, the WTS compensation very dependent on the financial possibilities for compensating losses at times of a flood disaster, and the political decisions made at the moment of the flood event. Fifth, the WTS is paid out of taxes, and no spreading of flood risks occurs with the (international) insurance sector, which is costly for taxpayers when a severe flood event happens.

1.1.4 Recent developments in the availability of flood coverage in the Netherlands

The aforementioned shortcomings of the WTS have initiated discussions between the Dutch government and private insurance companies about introducing flood insurance in a public-private (PP) partnership, in which both insurers and the government cover part of the flood damage. Such a PP flood insurance system may provide a better solution to cope with future flood risk in the Netherlands in the light of the potential effects on flood risks of climate change and socioeconomic development, and given the vast concentration of population and economic values within most dyke-ring areas (Aerts and Botzen, 2011a, b). Recently, the DAI advocated for a collective basic insurance coverage for flood risk. The proposal entailed the compulsory inclusion of flood coverage in general building and content insurance policies, and the mandatory participation of Dutch primary property insurance companies in a flood insurance pool (ADI, 2012; Botzen and Aerts, 2012). This pool would cover all flood-related claims up to a maximum value of €5 billion financed by the premiums for basic P&C policies paid by households and businesses. To enlarge the coverage capacity, such a system could be extended with reinsurance. In addition, the government may provide compensation for flood damage above the limit of the pool, which may be necessary in case of extreme flood losses. Property-owners have the freedom to buy insurance coverage from commercial insurance companies for the damage above the basic threshold. The DAI believes that only a compulsory insurance scheme could be an affordable solution to insure flood risk in the Netherlands. A compulsory flood insurance system may keep insurance premiums for specific dyke-ring areas affordable by spreading risks over a large number of policyholders, and overcome problems with adverse selection[3] which may arise if only high risk individuals demand flood insurance (see Chapter 2). The proposal of the DAI was rejected in June 2013 by the Dutch Authority for Consumer and Market (ACM) for the reason that such a compulsory scheme would violate the Competition Law (MW) in the Dutch market (ACM, 2013). Interestingly, the ACM classifies flood damage as an insurable risk. This suggests that flood victims may not be eligible for financial compensation under the current WTS arrangement which, according to the law, may only provide compensation for damage which is not "insurable in a reasonable manner" (ADI,

[3] Adverse selection is a term used in economics, insurance and risk management, and refers to a market situation where unintended results happen when suppliers and buyers have access to different information about products and markets (Akerlof, 1970; Mark, 1968).

2013). Despite ACM's disapproval, the ADI still remains a proponent of including flood coverage compulsory in general P&C insurance policies (ADI, 2013).

The reason why the ACM has defined flood risk as an insurable risk is that, since 5 September 2012 Dutch homeowners can buy (limited) commercial flood insurance from the Lloyd's cover-holder 'Neerlandse'. This flood coverage is offered by Neerlandse as part of a catastrophe risk insurance which provides a bundled coverage for earthquake, terrorism, and flood risks. The premiums of this flood coverage are differentiated according to the flood risk faced by the policyholder. Policyholders who take certain measures that limit potential flood damage are eligible for premium discounts. Although this catastrophe insurance can be seen as a good first attempt to offer insurance against flood risk in the Netherlands, it has many limitations. The catastrophe insurance coverage provides only limited coverage for a relatively high premium compared with regular insurance. As an illustration, according to the Dutch Consumer Association (DCA), some of the homeowners will have to pay a premium of even more than €200 per month for the flood coverage, which is significantly higher than the collective average premium of €21, as estimated in Chapter 4. The flood coverage provided by Neerlandse is only available for homeowners, and not for tenants or individuals who live in unprotected floodplains. Moreover, limits exist on the number of flood policies that can be sold within a dyke-ring area, since overall insurance capacity is limited. A maximum coverage amount per policy of €75,000 per event exists, which will be sufficient for many cases. However this amount could be easily exceeded in case of extreme flood events, especially in those areas lying significantly below potential sea and river water levels. In comparison with the coverage amounts proposed by the ADI, which are €250,000 and €25,000, respectively, for property and content damage, this limit of €75,000 is relatively low. Overall, it can be concluded that the flood coverage included in the catastrophe insurance policy is a good step forward in that it gives homeowners the option to insure against flood risks. However, its relatively high price and limited coverage availability imply that it will not achieve a broad national coverage for flooding in the Netherlands.

1.1.5 Potential societal functions of catastrophe risk insurance

The economic losses of natural disasters can have huge consequences for individual property-owners and businesses, especially when these exceed their financial capacity. In such cases, an ad hoc public compensation system like the WTS may not be appropriate to help those affected, as it has many shortcomings, as mentioned above. Either a commercial or a public-private flood insurance system can overcome these shortcomings, and could have six main advantages compared with the current WTS regulation in the Netherlands. First, flood insurance could provide more certainty of compensation according to policy conditions than uncertain government compensation. Second, insurance companies may be more efficient in providing flood coverage than the government. Insurance and reinsurance companies have the tools, knowledge, financial capability, and also the commercial objective to cover regular risks for a competitive price, as long as the risks are not too extreme, and the probability and the potential damage caused by the insured event can be estimated with some certainty. Third, in general, the premiums levied by insurance companies are risk-based, which may help to increase individuals' awareness of catastrophe risk. Moreover, flood insurance with risk-based premiums helps insurance companies to spreading flood risks across many individual policyholders, classes of businesses or specific groups of individuals with a similar risk exposure (Freeman et al., 2004). Fourth, flood insurance can be used as an instrument to stimulate a large number of policyholders to simultaneously take risk-reducing measures to lower the total flood damage and insured costs by providing them with different incentives, such as rewarding policyholders who flood-proof their homes with premium reductions and/or lower deductible amounts (Board on Natural Disaster, 1999). Fifth, in contrast to the WTS, through an insurance system against natural disasters, insurance companies can put pressure on the government to take specific long-term structural adaptation and risk-reduction measures to reduce the economic costs of flooding. For example, in return for the provision of flood insurance coverage, insurance companies may require that the government commits to a long-term strategy of investments in flood protection infrastructure. The current private flood insurance in the UK is based on such commitments from the government (ABI, 2009). Sixth, in contrast to the WTS, an insurance system is based on free market principles, and does not depend on (only) public financial means. For example, an insurance system finances compensation payments through (partly) risk-based premiums and builds reserves, and makes use of international capital and reinsurance markets for financing, and for diversifying, catastrophe losses. Therefore, a (public-private) flood insurance arrangement allows for spreading risks between the public and private (international) insurance sectors, which means that post-disaster expenses arising from floods are not solely paid by taxpayers.

1.1.6 Challenges facing the insurance sector in managing catastrophe risk

Although it has been possible to reduce the number of natural disaster casualties throughout the last decades in the industrialized countries as a result of better forecasts and early evacuation, the magnitude and frequency of property damage and social disruption have increased considerably (Hallegatte et al., 2011; Kahn, 2005). The economic losses caused by natural disasters are generally large, and individuals and regular primary insurance companies will hardly be able to cover them alone, owing to their limited financial capacity.

Insurance is a mechanism to transfer risk of loss from one entity to another entity that spreads risks across many policyholders. The theory of insurance is commonly based on the assumption that individual losses are independent of each other, and, therefore, in the event of damage the cumulative losses will remain low and stable (Michel-Kerjan, 2001). However, this general insurance theory does not apply to catastrophe risks because of highly correlated risks across policyholders, which is also the reason why, in practice many insurance arrangements against catastrophe risk need some form of government support (see Chapter 2). Offering a broad private insurance coverage against natural disaster risks is often complicated because of several issues. First, the difficulty of assessing the probabilities and potential damage of natural disaster events in view of the limited availability of historical data on natural disaster risks, remains one of the main challenges for the estimation of potential claims per policy and the related (re)insurance premium. Second, insurers normally prefer not to be exposed to one large loss caused by a single event, because such a loss may exceed their financial capacity (Mehr et al., 1980; Sturm and Oh, 2010). However, catastrophic losses are highly dependent, and are thus, positively correlated across policyholders, because they usually happen all at once and affect a large group of policyholders within a specific area. This is also one of the main reasons why catastrophe risks are generally considered to be uninsurable (Jaffee and Russell, 1997). Third, rare but potentially large catastrophe losses may force solvency-constrained insurance companies to hold large reserves that have to be sufficient to cover a high loss percentile of the total damage with a reasonable degree of certainty (Kousky and Cooke, 2012). However, holding such large reserves entails considerable capital costs. In order to cover such costs, (re)insurers may demand an extra surcharge on the premium, which may be several times the expected value of damage (see Chapters 2 and 3). A related issue is that reinsurance premiums for catastrophe risk are relatively high compared with primary insurance premiums, which makes the primary insurers reluctant to offer coverage for catastrophes since it would require them to spend a large portion of their premium on reinsurance coverage (Froot, 2001; Kousky and Cooke, 2012). Fourth, information asymmetries, such as adverse selection and moral hazard[4], can pose problems in catastrophe risk insurance markets (Botzen and Van den Bergh, 2008; Gollier, 2005). For example, adverse selection may impede the spreading of risks if mainly high-risk policyholders purchase insurance against catastrophe risk, while low-risk policyholders demand less insurance protection. In the case of private catastrophe insurance, it may be difficult for insurers to spread the catastrophe risks across a large number of policyholders if the insurance is not mandatory and public awareness of the catastrophe risks and related demand for catastrophe coverage is low. This may result in low market penetration and relatively high premiums. Therefore, it is usual that, after natural catastrophes, public resources must be used to compensate a part of the damage or to provide some form of disaster relief.

1.1.7 Public-private partnership for flood risk insurance

A well-designed flood insurance arrangement should be affordable and financially viable, and be able to ameliorate, and limit, the impacts of socioeconomic development and climate change on flood risks in the future. Experience shows that a collaboration between public and private sectors, and homeowners, can be fruitful in managing and providing adequate compensation for large catastrophic events, by achieving a broad diversification of risks, and providing incentives for risk

[4] Moral hazard is a common problem in the insurance field that arises because of asymmetry in information to control behaviour after purchasing an insurance contract (Akerlof, 1970; Mark, 1968). For example, a policyholder who has purchased flood insurance may take less action to prevent flood damage which may be unobserved by the insurer and imply that this policyholder causes a higher loss for the insurer than was anticipated when the insurance contract was established.

reduction (Botzen et al., 2010a). Most of the existing catastrophe insurance systems in developed countries, such as those for flooding, earthquake and terrorism risks, have been developed with some sort of involvement of the government. This government involvement often entails the provision of compensation for extreme losses through public reinsurance or a state guarantee (see Chapter 2). This government support is useful to stimulate the provision of insurance coverage for catastrophe risks, because insurers consider the extreme part of catastrophe damage as uninsurable. Insurers either exclude extreme losses from coverage or demand very high premiums for covering them in the absence of a financial guarantee or support from the government. Therefore, in practice Public-Private (PP) partnerships have been established whereby private insurance companies and governments provide compensation for catastrophe damage with varying degrees of roles and responsibilities for the involved participants (Kunreuther and Michel-Kerjan, 2007; Paudel et al., 2012; Seldon, 1997). In a PP insurance system, the government and the private sector cooperate in risk-sharing or selling insurance policies with the aim of achieving high market penetration and making optimal use of the expertise and capacity to carry the risks of both sectors. In contrast, the government role in a fully private system is very limited, i.e. it has only a regulatory role. One of the main advantages of the governments' participation in a PP flood insurance arrangement is that relatively high reinsurance premiums can be avoided if a risk neutral agent like the government covers part of the extreme flood damage (see Chapter 4). In such an arrangement, primary insurance companies can cover a middle-sized layer of flood losses which is financed using (semi) risk-based premiums. Given the shortcomings of the WTS arrangement in the Netherlands (Section 1.1.3), it would be worthwhile to explore the possibilities to introduce a PP flood insurance arrangement in the Netherlands, as has been proposed by earlier studies (Botzen and Van den Bergh, 2008).

1.2 About this thesis

The main aim of this thesis is to explore, and study, catastrophe risk and the corresponding (re)insurance modelling techniques, from both statistical and actuarial perspectives, and how these can be applied to solve a real-world problem. Flood risk in the Netherlands has been chosen as a real case study, which examines whether the low-frequency-high-impact flood events can be (re)insured through a public-private insurance scheme. The main advantages of such a scheme with respect to other alternatives are studied, such as a solely private insurance arrangement. This case study has practical relevance because flood risk is generally excluded from property insurance coverage, and it has been proposed to introduce a PP insurance system to cover the low-probability high-impact flood risks in the Dutch river delta (Aerts and Botzen, 2011a; Botzen and Van den Bergh, 2008). In addition, private (re)insurance companies are usually reluctant in offering insurance against flood damage, especially, because of potentially high correlated insured amounts and the lack of reliable risk assessment methodologies. Moreover, climate change with a high sea-level rise in combination with socioeconomic development can make the Netherlands even more vulnerable to severe floods. In such a situation, a PP insurance scheme could provide a good solution for covering flood damage in the Netherlands, as long as it is accompanied by adequate policies and incentives that limit flood risk. Although the focus of this thesis is on the Netherlands, the developed and applied statistical and actuarial models can also be applicable to various other catastrophe risks and related (re)insurance products in other countries.

This thesis fits in an emerging literature on the opportunities provided by, and the obstacles of, introducing a broad flood insurance coverage in the Netherlands. In particular, the main advantages and difficulties in establishing flood risk insurance in the Netherlands, along with the main shortcomings of the current public compensation arrangement (WTS), are discussed in detail by Botzen and Van den Bergh (2008), Jongejan and Barrieu (2008) and Aerts and Botzen (2011a).

A main solution for the compensation of flood damage in the Netherlands proposed by these previous studies is to introduce a multi-layer public-private flood insurance system (Botzen and Van den Bergh, 2009). The functioning of such public-private partnerships in insuring catastrophe risks in other countries has hardly been studied. Also, the desirable allocation of flood risk among stakeholders in a public-private (PP) flood insurance arrangement in the Netherlands and the consequences of this for the price of flood insurance have not yet been studied. This thesis aims to fill these gaps, and, thereby, provides a novel contribution to the existing literature on this topic. For this, different aspects of such PP schemes need to be studied, such as to qualitatively assess how existing insurance or compensation arrangements for catastrophe risks in different countries perform, and what lessons can be learned to either improve the existing systems or to establish new arrangements. In addition, different actuarial statistical models are proposed to study the stochastic character of flood risks, and to estimate expected flood damage and the related (re)insurance premiums for the 53 dyke-ring areas in the Netherlands. Finally, this thesis will provide an insight into the practical allocation of flood risk between the three main stakeholders (homeowners, insurers and the government) using the Pareto optimality principle, with the aim of keeping an optimal balance between costs and (re)insurance purchases, especially from the perspective of the property-owner and the insurer.

Moreover, studying future risk is important in order to provide flood risk insurance at an affordable price[5], and to cope with the impacts of anticipated climate change and socioeconomic development on future flood risk in the Netherlands. Future flood events and their inflicted damage, are surrounded by large uncertainties, and cannot be described with a single probability and flood damage estimate. However, most of the existing studies estimate a single flood probability and damage amount for low-lying areas in the Netherlands (i.e. Aerts, 2008; Wouters, 2005) and, thereby, fail to account for the stochastic nature of flood risk in their damage assessment process. Estimates of the complete probability distributions of flood damage in all low-lying areas in the Netherlands are necessary to provide a good insight into the uncertainty of flood risk, which is required for estimating flood (re)insurance premiums. Therefore a particular focus of this thesis is on the estimation of flood damage density curves and the corresponding (re)insurance premiums, using different stochastic actuarial methods and simulation techniques, for the 53 dyke-ring areas in the Netherlands. It should be noted that behavioural aspects of the introduction of flood insurance can have endogenous effects on flood risks, such as location decisions and changes in flood preparedness in response to insurance premiums, which are not quantified in this thesis.

1.2.1 Objective and research questions

In order to address the research gaps identified in the previous sections, the overall research question can be formulated as follows:

[5] The term 'reasonable price' in this thesis refers to a premium for flood insurance, which is close to the expected value of flood damage.

How can a multilayer public-private partnership be designed to provide flood risk insurance in the Netherlands, at an affordable price?

To answer the key question, the following five sub-questions are researched:

Sub-research questions:

The sub-questions can be formulated as:

1. What are the main strengths and the shortcomings of representative existing catastrophe (flood and earthquake) risk insurance (compensation) arrangements in different countries? What policy recommendations can be made based on practical experience that could be useful in establishing new or improving existing, flood insurance/compensation arrangements at an affordable price?

2. What statistical and actuarial modelling techniques may be recommended for estimating the full probability density functions of flood damage, and assessing the corresponding (re)insurance premiums, in view of the lack of sufficient empirical loss data for all low-lying dyke-ring areas in the Netherlands?

3. What are the differences in flood (re)insurance premiums, when insurance against flooding is provided either by a risk-neutral agency, like the government, or by a risk-averse commercial (re)insurance company?

4. What would be the desirable level of risk-sharing between the three main stakeholders in a public-private insurance system that strikes a balance between the benefits and the costs of (re)insurance purchases, and provides incentives for homeowners to take measures for flood risk reduction?

5. What are the main advantages of a public-private insurance arrangement, in which property-owners, insurers and the government can participate, compared with a private flood insurance system?

6. What would be the impact of the anticipated climate change and socioeconomic development on flood risk in the Netherlands, and what does this imply for the design of a flood insurance arrangement?

1.2.2 Thesis overview and applied methods

This thesis is divided in two main parts, as shown by the schematic overview in Figure 1.3. The first, qualitative part consists of a comparative study on representative insurance or compensation schemes for catastrophe risk in various countries, with a particular focus on earthquake and flood damage (Chapter 2). These insurance or compensation arrangements are grouped in three different categories, namely: private (i.e. flood risk insurance systems in Germany and the UK); public (i.e. Switzerland (CIM), and Spain (CCS)); and public-private (i.e. US (NFIP), Belgium (WN) France (CatNat)), and earthquake risk insurance in California (CEA), Japan (JERC) and Turkey (TCIP). The different aspects, like general characteristics (i.e. types of stakeholders and their roles and responsibilities), funding (i.e. insurance coverage and (re)insurance premium levels), and mitigation and adaptation strategies of these systems, are studied and compared with the objective to provide recommendations for policy makers that could be useful in establishing new, or improving existing, insurance arrangements for natural disasters.

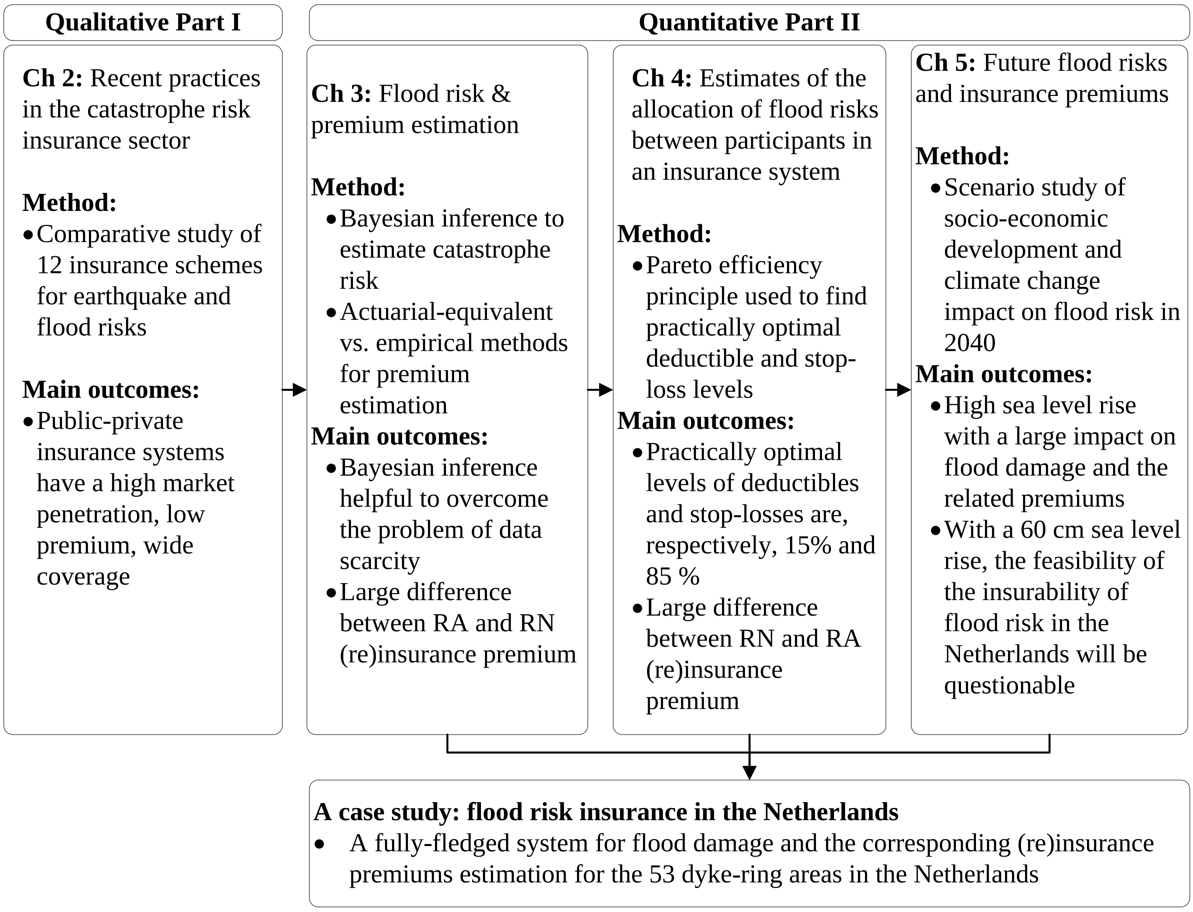

Figure 1.3 Schematic overview of the contents of the thesis

The second, quantitative, part of the thesis examines important quantitative aspects of flood risk insurance in the Netherlands. It proposes different statistical and actuarial models for estimating flood risk and the corresponding insurance premiums in a private or public-private flood insurance system. In addition, Part II calculates efficient and practical levels of deductible and stop-losses for, respectively, property-owners and insurance companies, and the potential impacts of socioeconomic development and climate change on flood risks and insurance in the Netherlands.

In particular, Chapter 3 proposes a Bayesian technique for flood damage estimation in view of the lack of empirical data on flood risk, which provides good insights into the probabilistic nature of flood damage for each of the 53 dyke-ring areas in the Netherlands. The Bayesian Inference (BI) is often used in actuarial science to study the stochastic character of risk events, and to estimate the related damage and (re)insurance premiums in view of a lack of historical loss data. The low-frequency-high-impact character of flood events in the Netherlands, and the resulting scarcity of empirical loss data, makes it virtually impossible to estimate potential damage with some degree of certainty based on simple analyses of historical loss data. In such cases, BI can be a helpful tool as it combines different data originating from different sources to update risk probabilities and to assess related damage amounts. The proposed model in this chapter combines additional flood loss information through a Gamma conjugate prior probability distribution with an assumed loss process described by a Pareto density distribution to estimate the updated posterior parameter of a flood damage density function. Subsequently, the Monte Carlo technique is used to simulate flood damage for 250,000 flood events for each of the 53 dyke-ring areas. The simulated loss data are then used to estimate the flood density curves and the corresponding (re)insurance premiums using two different practical methods (actuarial equivalent and empirical method) that each account in different ways for insurer's risk aversion and the dispersion rate of loss data. The actuarial equivalent method includes an extra surcharge on premiums for the insurer's aversion to catastrophe risk and the large risk variance, and is based on the method proposed by Kaas et al. (2004). The empirical premium estimates are based on the methodology proposed by Kunreuther et al. (2011), which takes a modest rate for insurer's aversion to (fat-tailed) catastrophe risk into account, based on empirical estimates of insurers pricing of catastrophe risk.

Subsequently, in Chapter 4, a multilayer public-private (PP) flood insurance system, in which the insured, the insurer, and the government can participate, is proposed and applied for the case study of flood risk in the Netherlands. A Pareto-efficient allocation model is introduced for estimating the maximum (re)insurance coverage amount within a desirable range of deductibles (own-risk for property-owners) and stop-loss (own-risk for insurers), and for providing insights into flood-risk allocations between the stakeholders in a multilayer insurance system. This model considers that the insurers and the property-owners have different social and financial interests compared with the government, and therefore try to strike a balance between costs and benefits. The insurers and the insured can achieve their objective by minimizing the (re)insurance premiums they have to pay, thus minimizing their level of indemnity, while limiting their own risk to a predefined level. But, minimizing insurance and reinsurance coverage may imply that the insured and the insurer have to carry additional risk. Therefore, the insurer and the insured have to strike a balance between the (re)insurance coverage and expected risk exposure, in such a way that expected worst-case losses can be limited. Under the assumption that flood insurance can be provided by risk-averse (RA) (i.e. commercial (re)insurance companies) or by risk-neutral (RN) agencies (i.e. the government), the corresponding insurance and reinsurance premiums are estimated and compared. This provides a good understanding of the potential benefits of introducing a PP insurance scheme, because it shows a clear difference between the (re)insurance premiums that may be charged when flood insurance is provided by a risk-averse (i.e. commercial insurance companies) or by a risk-neutral agent like the government.

Chapter 5 studies the impact of socioeconomic development and climate change on potential flood risk and the corresponding (re)insurance premiums by 2040, for each of the 53 dyke-ring areas in the Netherlands. The methodology followed in this chapter extends the research work in Chapters 3 and 4 to the study of future flood risk and its impact on a hypothetical PP insurance scheme for the Dutch situation. Under four combined scenarios of climate change and socioeconomic developments for 2040, this study estimates probability density curves of flood damage and the corresponding flood (re)insurance premiums for the each of the 53 dyke-ring areas. Evidently, future estimates of flood risk are highly uncertain, which is why a broad spectrum of scenarios is used in Chapter 5. The socioeconomic scenarios represent the spatial land-use changes and socioeconomic growth for the year 2040 in the Netherlands, and are labelled as Regional Communities (RC) and Global Economy (GE) (Janssen et al., 2006). GE represents a scenario which is accompanied by strong international economic integration. In contrast, RC is a stable socioeconomic scenario, with a low socioeconomic growth rate. Two additional projections are developed for flood damage for the year 2040 that correspond to a 60 cm sea level rise in both the GE and RC scenarios. This captures the impact on flood risk of an extreme climate change scenario with a 60 cm sea level rise in combination with both GE and RC socioeconomic scenarios. To derive these additional projections, an extrapolation of an exponential regression is applied to the existing data from Aerts et al. (2008). The methodology proposed in this chapter consists of three main parts. First, probability density curves of flood damage are estimated for the current situation using the Bayesian technique and Monte Carlo simulation, as described in Chapter 3. Second, future information on socioeconomic development and climate change from Aerts et al. (2008) and Aerts and Botzen (2011a) is used in order to make projections of future flood risks. The (re)insurance premiums are estimated for both, the RA (private insurance) and the RN (public-private insurance) insurance agencies, and the differences are analysed and discussed in terms of flood risk insurance availability in the long-term in the Netherlands.

Finally, Chapter 6 provides conclusions per chapter, and recommendations for further research.