(Il)liquid Assets: Risk Management Through Insurance Solutions

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A Comparative Analysis of Failure Mechanisms and Premium Evolution of Flood Insurance in the Netherlands

by

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Cover: North Sea flood of 1953, Korte Nobelstraat te Zierikzee.
Source: National Archives

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Preface

I am pleased to present this thesis, which explores the possibilities of a flood insurance solution covering damage resulting from the failure of primary flood defences. The Netherlands, with its rich history of battling and living with water, and historical difficulty with insuring against it, has provided a unique context for this research.

Throughout the research process, I have been fortunate to receive guidance and support from a wide array of individuals. I am especially grateful to my supervisors, Matthijs Kok, whose years of expertise and insights have been invaluable, Ton van den Bremer, who was able to provide an outsider view on insurance from an economical perspective, and Timo Brinkman, who has provided extensive guidance and stimulated me throughout the process.

I would also like to express my gratitude to the panel of experts who participated in the Expert Judgment Analysis. Their willingness to share their knowledge and experience has been instrumental in shaping the findings of this research.

The challenges encountered while modelling insurance solutions were as educational as they were demanding. The iterative process of refining the models and interpreting the data tested my resilience but ultimately led to a more rigorous and robust analysis.

Finally, this thesis not only represents my journey into understanding the complexities of flood risk management and insurance but also marks the end of my years as a student at Delft University of Technology. I hope that the findings contribute to a better understanding of flood insurance and aid in the development of a more resilient system in the face of natural disasters both in the near and far future.

Olivier Christiaan Platzer
Delft, November 2023

Summary

This thesis investigates potential insurance solutions covering damage resulting from the failure of primary flood defences in the Netherlands. Amidst increasing climate variability, the urgency for a robust multilayer safety framework is undeniably important, especially in a country renowned for its ongoing struggle with water. This research applies a multi-faceted approach, integrating literary research, expert judgment, numerical modelling and comparative analysis to evaluate existing systems and propose new solutions, ultimately aiming to answer its research question: *What is the impact of potential flood insurance solutions covering flood damage resulting from the failure of primary flood defences in the Netherlands?*

The study commences with the introduction of seven failure mechanisms which occur in flood insurance, identified through a comprehensive review of existing literature. These failure mechanisms can lead to increased costs for insurers or contract holders or could lead to the failure of the insurance product as a whole. Therefore, these failure mechanisms are fundamental in evaluating the impact of possible insurance solutions and will serve as the foundation for the rest of this research.

An in-depth qualitative comparative analysis of international flood insurance practices – gathered through literary research – provides a global context and benchmarks for new solutions. After this, an Expert Judgment Analysis is conducted, leveraging the knowledge of multiple experts from diverse backgrounds including the insurance and reinsurance sector, universities and others. This analysis provides a quantitative assessment of the impact of the failure mechanisms on the identified reimbursement schemes from various countries. From both the qualitative and quantitative results of the impact of failure mechanisms on flood reimbursement schemes, seven optional solutions which could potentially be implemented in the Netherlands are introduced. After argumentation, three options are discarded, from which this research will continue to explore the remaining four solutions.

To be able to analyse the financial burden of each solution for the contract holder, a comprehensive insurance premium model is constructed. This model makes use of public sources and mimics the Dutch housing landscape. For each group of homes, the risk is calculated in the form of yearly expected damage, and subsequently, each house is assigned one of four risk classes, based on the amount of risk. This enables the model to construct an actuarially fair premium, which entails pure risk, and an insurance premium, which in addition to the risk, includes the costs of insurance. By making substantiated assumptions, both actuarially fair and insurance premiums for each solution are calculated.

Gathered knowledge is further applied to an in-depth evaluation of each solution, discussing its context, relevant Expert Judgment Analysis results, insurance premium and system structure. All solutions are concluded by a balanced discussion of their advantages and disadvantages.

Finally, this research provides a reflection in which the most desirable solution for the three most important stakeholders – the government, the individual and the insurers – is discussed. The pros and cons of each solution are weighed, and a judgment is made based on the assumed desires of each stakeholder group. In the conclusion, this report presents four possible solutions for flood insurance in the Netherlands: an enhanced Wts scheme (Wts+), mandatory inclusion of flood coverage in home insurance policies, the establishment of a flood risk pool, and the adoption of the Flood Re model. Each solution displays a distinct response to the

identified failure mechanisms and comes with considerable variability with regard to premium development.

The findings of this thesis aim to inform policymakers, insurers, and stakeholders in the Netherlands, contributing to the collective understanding of flood insurance and assisting those who are considering implementing a different system in the Netherlands.

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Introduction

1.1. Background

1.1.1. Flood risk in the Netherlands

For centuries, the people living in the Netherlands – *the low-lying lands* – have been engaged in a constant battle against water to protect their land from flooding. The earliest structures called *terps*[1], were built over 2500 years ago in the northern part of the country. With the introduction of levees during the Middle Ages, people were finally able to keep water out, rendering terps obsolete. The invention of windmills around the year 1400 revolutionised the drainage of lakes and the creation of polders, enabling the people of Holland to reclaim land from water. In more recent times, ambitious projects such as the closure of the Zuiderzee and the construction of the IJsselmeer, the Delta Works in Zeeland, and the reclamation of Maasvlakte 1 and Maasvlakte 2 in the port of Rotterdam have further expanded the country's flood protection measures.

Nevertheless, the Netherlands has experienced significant floods throughout its history. Notable examples include the St. Elizabeth's Flood (1421), the All Saints' Flood (1570), the Christmas Flood (1717), the Zuiderzee Flood (1916), and the devastating Flood of 1953, all of which involved incoming seawater. In more recent times, rivers have also posed significant risks, as seen in the high water levels of the Rhine, Meuse, Waal, and IJssel rivers in 1993 and 1995, as well as the floods in Limburg in 2021 following elevated water levels in the Meuse and its tributaries. These challenges have spurred innovation in flood protection strategies. After the high water levels in 1993 and 1995, Dutch authorities implemented a groundbreaking approach known as *Room for the River*, which focused on creating more space for rivers to store water instead of solely relying on levee height increases.

With 60% of the country vulnerable to flooding from the sea, lakes, and major rivers (Kok et al., 2016), protection against floods is of utmost importance to ensure the habitability of the Netherlands (Figure 1.1). To safeguard the population from water-related hazards, Dutch law incorporates provisions for protection against high water levels through the *Waterwet* (Water Act), which governs the management of water systems, including watersheds, surface water, and groundwater bodies.

Currently, the Netherlands is safeguarded by approximately 18 thousand kilometres of levees, comprising both primary and regional flood defences that protect against flooding at any given point. Primary flood defences shield the land from water originating from major bodies

[1] A terp is an artificial dwelling mound which was built to protect housing and cattle during storm surges, high tides and flooding

such as the sea, large lakes, and rivers. These defences are classified into stretches, each adhering to specific safety standards determined by the probability and potential consequences of a flood event. Figure 1.2 illustrates the primary flood defences and their respective safety standards.

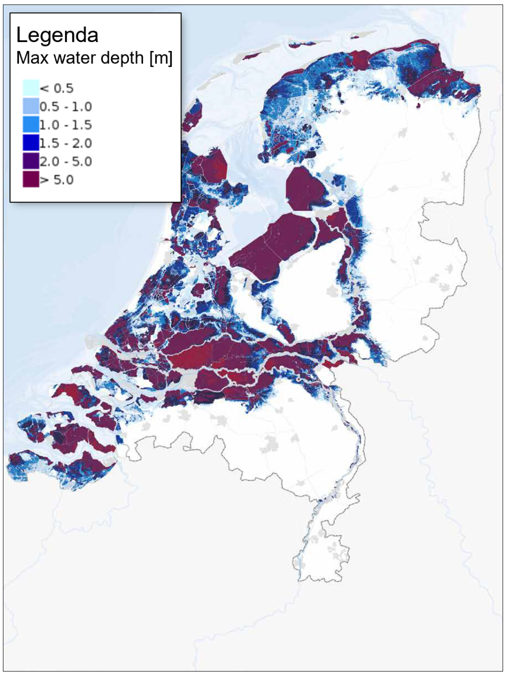


Figure 1.1: Map of the Netherlands indicating flood-prone zones (Kok et al., 2016)

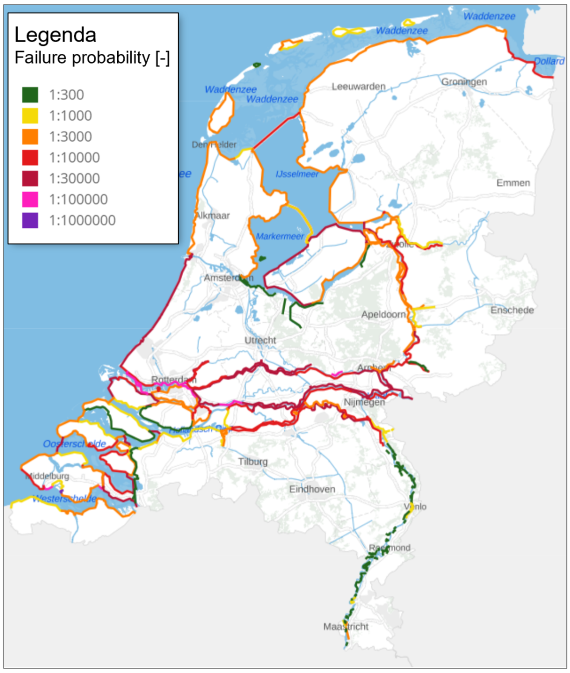


Figure 1.2: Primary flood defences in the Netherlands (Waterveiligheidsportaal, n.d.)

1.1.2. Climate risk insurance in the Netherlands

There is a growing consensus that climate change is leading to more extreme weather patterns, which will result in an increasing frequency and severity of damages to residential homes, commercial properties, and vehicles if no action is taken. An example of such an extreme event in the Netherlands is the hailstorm that occurred on June 23, 2016, causing significant damage in Southeastern Brabant and Middle Limburg. According to the *Verbond van Verzekeraars* (*Association of Insurers* or *the Association*), Dutch insurers received claims worth around €667 million as a result of this storm, mainly related to damage to residential and agricultural businesses (Verbond van Verzekeraars, 2022b, 2023b).

In 2014, the Royal Netherlands Meteorological Institute (KNMI) established four climate scenarios for the Netherlands based on the scenarios provided by the United Nations' Intergovernmental Panel on Climate Change (IPCC). These scenarios serve as a framework for climate-related policy-making by the Dutch government, institutions, and organisations (KNMI, 2015).

The Association of Insurers analysed these scenarios and concluded that insurers are likely to face increased costs due to rising damages (Verbond van Verzekeraars, 2022b). For instance, the Association has calculated that damages in the private sector caused by extreme precipitation and hail – which currently amount to €125 million annually – are expected to double in the coming decades if appropriate measures are not taken. This upward trend will also impact consumers, as insurance premiums are likely to increase to cover higher costs. Additionally, certain risks may become uninsurable if costs become prohibitively high (Verbond van Verzekeraars, 2022b).

In 2023, the KNMI issued a second climate scenario report incorporating new climate-related developments for the Netherlands. At the time of writing, the Association has not yet calculated the new scenario's (KNMI, 2023).

The Association of Insurers and the Ministry of Infrastructure and Water Management have identified seven climate risks and assessed their insurability at present: lightning, drought, hail, floods, rain, snow/frost/sleet, and wind (Verbond van Verzekeraars, 2022a).

Flooding resulting from the failure of primary flood defences has proven to be one of the most challenging risks to insure, primarily due to their wide-ranging and extensive impact. Several factors have contributed to the current situation, where insuring property against flooding caused by seawater, river water, or inland water bodies due to overflow or failure of primary flood defences, or flooding in outer dike areas, is difficult (Verbond van Verzekeraars, 2022c).

1.2. Problem analysis

1.2.1. Problem definition

Climate change is having an increasingly profound impact on our current way of life, with its effects accelerating at an alarming rate. In addition to the rising temperatures, which result in the melting of ice caps and subsequent sea level rise, there will be a surge in the occurrence of extreme weather conditions. These conditions include droughts, severe storms, and increased precipitation, all of which have significant implications for the safety of the Netherlands, particularly in terms of the risks associated with flooding (KNMI, n.d.).

The consequences of severe flooding can vary depending on the effectiveness of disaster management before, during, and after the event. Kok et al. (2016) refers to this approach as *multilayer safety*, which recognises that the impact of a disaster is influenced by three essential pillars: prevention, spatial design, and crisis management. Following the 2021 Limburg floods, Beleidstafel wateroverlast en hoogwater (2022) expanded on this concept by introducing a fourth and fifth pillar: water awareness, and recovery. This report will focus on the fifth and final pillar, recovery.

Multilayer safety framework

1. **Prevention**: implementation of measures to prevent flooding
2. **Spatial design**: strategic arranging of the environment to mitigate the impact of flooding
3. **Crisis management**: adoption of strategies and measures to minimise the consequences of flooding
4. **Water awareness**: grow awareness among individuals to increase responsiveness in the event of a flood
5. **Recovery**: implementation of measures to adequately recover from the aftermath of flooding

The Netherlands, renowned for its rich history of flood protection, has traditionally placed a strong emphasis on flood prevention. While this approach has led to the development of well-designed levees, dunes, and hydraulic structures, it has somewhat neglected the pillars associated with post-disaster management. To achieve comprehensive flood risk management, it is important to account for the potential risks of a disaster which could involve incorporating some form of financial relief. It has to be noted that financial coverage of risk does come at a cost.

Currently, there are two ways for compensation of flood-related damage to homes (buildings and contents), via insurance available and via the Wts.

Firstly, flood damage insurance coverage is available for some types of flood-related damage. When most people think of a flood, images of large inundated areas come up. However, flooding can also occur from direct rainfall or groundwater seepage. Kok (2005) identified seven causes of flooding in (lower areas) of the Netherlands, which are depicted in Figure 1.3. For a long time, only flooding caused by water damage in the house[2] (Point 1 in Figure 1.3), sewage overloading (3), flooding of surface waters (4), and partially, groundwater seepage (2) was insured (Kok et al., 2014). More recently in 2018, the Association of Insurers released a flood advisory report, urging insurers to include coverage against "local flooding" in their building and contents policies (Verbond van Verzekeraars, 2018). As a result, several insurers began offering such policies in various forms. Currently, almost all homes in the Netherlands are covered from flooding due to the failure of regional flood defences, which is point (5) in Figure 1.3. However, for flooding due to failure of primary defences (6) and flooding of areas not protected by levies (7), there is still no possibility of insurance.

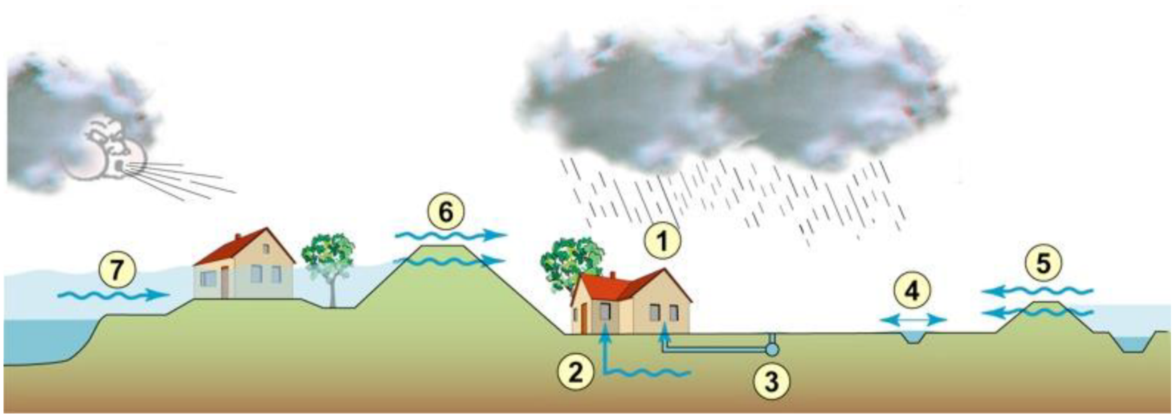


Figure 1.3: Causes of flooding in the Netherlands (Kok, 2005)

Secondly, the government can offer compensation for damage from disasters like floods or earthquakes through the *Disaster Damage Compensation Law* (Wet tegemoetkoming schade bij rampen, Wts), which establishes the regulations for compensation provided by the Dutch government. It is important to note that under the Wts, the Dutch government has full control and determines which damages are eligible for partial compensation. Damage is not fully compensated under this arrangement. Moreover, the Wts does (formally) not apply to flooding from the sea (saltwater flooding). However, in practice, it is unlikely that the government will not provide compensation in case of a large saltwater flood.

A common misconception that is made is that government compensation serves as a form of insurance. The Association of Insurers has observed a significant number of individuals and small-to-medium enterprises incorrectly assuming that the government will act as their financial safety net in the event of a flood, primarily due to the existence of the Wts (Verbond van Verzekeraars, 2020; Van Helmond et al., 2023).

The issues described highlight the relevance of developing an affordable, adequate and comprehensive insurance solution which covers damage caused by the failure of primary flood defences. This report aims to find such a solution by exploring different systems and investigating their advantages and disadvantages.

1.2.2. Why now this study?

Offering flood insurance has been historically difficult. Following the flood of 1953, the predecessor of the Association, known as the Vereniging van Brandassuradeuren, deemed the risk of flooding technically uninsurable due to its catastrophic nature and prohibited its members

[2] This includes all damage caused by water in the house, like leakage during rainfall, but also breaking of plumbing pipes

from providing coverage against it [3] (Kok et al., 2014). However, this ban was lifted in 1998 following objections from the European Union based on competition regulations (Verbond van Verzekeraars, 2018). In 2000, the Association issued a precipitation clause and advised insurers to include it in their policies. This clause covers damage resulting from both direct and indirect precipitation. Direct damage refers to any precipitation that directly contacts or infiltrates the home, either falling from the sky or flowing in from the street. Indirect damage results from localised rainfall leading to the spilling of ditches, canals, quays, and small rivers (Kok et al., 2014; Issuecommissie Klimaat 2017, 2017).

Despite the lifting of the ban, the market deemed insuring homes against damage resulting from larger floods to be too difficult for a long time. Adverse selection, in which people in lower-risk areas are hesitant to purchase insurance, posed a significant challenge, making it difficult to establish a viable insurance pool. Other factors include insufficient awareness, cumulative risk and the presence of government compensations (Verbond van Verzekeraars, 2018, 2020).

In 2005, on behalf of the Advisory Commission Water, Kok (2005) compared four possible ways of insuring flood risks:

1. The government as (co-)reinsurer
2. Mutual Water Flood Insurance Company
3. A separate water insurance
4. Mandatory water coverage in the building and contents policy

The recommendation was to find a unified solution for all forms of flooding, which initiated discussions between the government and insurers in 2007. However, this initiative was halted due to a change in the government administration that year. Subsequently, the topic was put on hold with the onset of the global financial crisis. In 2013, the Association of Insurers proposed an alternative solution: the establishment of the Dutch Reinsurance Company against Flood Damage, similar to the Dutch Terrorism Reinsurance Company. This initiative was rejected by the Authority Consumer and Markets (Autoriteit Consument & Markt) due to its mandatory nature, which violated competition regulations (Autoriteit Consument & Markt, 2013).

As mentioned earlier, initial interest in local flooding policies was limited when they were initially introduced to the market. However, following the 2021 floods in Western Europe, which resulted in the loss of 240 lives and caused €38 billion in damages across Germany, Belgium, the Netherlands, Luxembourg, and France (DeMorgen, n.d.), there has been an increased appetite for these local flood policies (DeMorgen, n.d.; Verbond van Verzekeraars, 2020).

With the recent 2021 flooding of Limburg and the visible impacts of climate change, such as more frequent and more extreme precipitation events, there is renewed momentum to find a solution for compensating flood-induced damage resulting from the failure of primary flood defences. This report aims to identify potential solutions and assess their feasibility. These aspects will be further explained in Chapters 1.3 and 1.4.

[3] This ban excluded certain forms of flooding. For example, drainage capacity problems resulting from large quantities of stormwater or large quantities of melt water

1.3. Research objective

This study aims to address the problem outlined in Section 1.2 by providing a comprehensive solution to the main and sub-questions presented below. The research will be conducted in collaboration with the *Project group floods*[4], comprising representatives from the Association of Insurers and De Vereende Insurance. The main research question is:

What is the impact of potential flood insurance solutions covering flood damage resulting from the failure of primary flood defences in the Netherlands?

To be able to develop an answer to this research question, the following sub-questions will need to be addressed:

1. What are failure mechanisms in (flood) insurance, and how can they be mitigated?

2. How is flood insurance or reimbursement arranged in the Netherlands and other developed countries, and what are potential solutions which could be implemented in the Netherlands?

3. How does the premium evolve for four different insurance solutions?

4. What are the advantages and disadvantages of potential insurance solutions covering flooding in the Netherlands?

1.4. Methodology

This study employs a multifaceted research methodology to investigate potential insurance solutions for covering damage resulting from the failure of primary flood defences in the Netherlands. The approach integrates literature review, expert analysis and premium modelling to evaluate the impact of various insurance schemes. This research is conducted with the assistance of Delft University of Technology and the Dutch Association of Insurers. Both organisations provide input in the form of knowledge, literature and contacts which are applied throughout this research. The ultimate goal is to provide an answer to the research question posed in Section 1.3, for which the sub-questions serve as a foundation.

An extensive literature review is conducted to identify prevalent failure mechanisms in (flood) insurance, which is the aim of the first research question. Scholarly articles are systematically analysed to enumerate these mechanisms, which serve as a basis for subsequent chapters. A thorough understanding of these failure mechanisms is instrumental for the rest of this research.

To answer the second research question, the current status of flood insurance in selected countries is assessed using a combination of online resources and peer-reviewed literature. An Expert Judgment Analysis (EJA) is then carried out with a panel of 10 experts from the fields of insurance, reinsurance, academia, and other relevant sectors who are identified and approached with the help of Delft University of Technology and the Dutch Association of Insurers. Through two rounds, the EJA aims to determine the impact of the identified failure mechanisms on the insurance systems of the examined countries. The selection of experts is based on their expertise and experience in the field. By leveraging the literature and the EJA, a shortlist of seven potential insurance solutions is developed, of which four are selected for further analysis based on defined criteria and argumentation.

[4]The project group has been given a mandate by the members of the Association to develop a flood pool with a solidarity-based character and government participation.

To analyse the financial aspect of an insurance solution, which is the aim of the third research question, a risk-based premium model is designed to calculate actuarially fair- and insurance premiums for selected insurance solutions. The model makes use of publicly available data from the Landelijk Informatiesysteem Water en Overstromingen (LIWO, English: National Water and Flood Information System), the Basisregistratie Adressen en Gebouwen (BAG, English: Basic Register of Addresses and Buildings) and the Schade en Slachtoffermodule (SSM, English: Damage and Casualty module), and of technical reports from research and advisory firm HKV. Data sources for risk assessment are verified for relevance to ensure reliable premium calculations.

Each of the four chosen solutions is evaluated in detail. This evaluation involved an analysis of their performance against the impacts of the identified failure mechanisms and the calculated premiums. A structured approach is adopted to provide a consistent evaluation framework across all solutions and answer the fourth research question.

The concluding chapter reflects on the proposed solutions from assumed perspectives of the government, individuals, and insurers, which aims to provide a handheld for future decision-makers. The methodology for this analysis is guided by insights gained from thesis committee meetings and knowledge gained in previous chapters. By following this approach, the main research question can be answered in the conclusion section, for which knowledge gained throughout this research is exploited.

The research abides by ethical standards concerning the collection and use of expert opinions. All participating experts provided informed consent, and measures were taken to ensure the anonymity of their responses.

1.5. Outline

In the course of this thesis, a systematic analysis of flood insurance and its inherent challenges is performed. Chapter 2 dives into the identification and comprehensive research of the various failure mechanisms observed within flood insurance systems.

Building on the findings from this chapter, Chapter 3 provides an in-depth analysis of the flood insurance systems of five distinct countries: the US, UK, Belgium, Spain, and the Netherlands. Additionally, this chapter explores the impact of the failure mechanisms identified in Chapter 2 on these individual insurance systems by conducting an Expert Judgment Analysis (EJA), evaluating the extent of these effects. Finally, seven possible insurance solutions are introduced, from which three are discarded.

Moving from analysis to application, Chapter 4 introduces a premium calculation model based on the current flood risk for the housing market in the Netherlands. The model aims to estimate the insurance premium of flood insurance, providing perspective on the financial aspects of the research.

Based on the insights garnered, Chapter 5 further analyses the remaining four potential solutions to address the challenges of flood insurance. These solutions are derived from a triangulation of the EJA, the premium model, and a qualitative assessment.

Chapter 6 reflects on the four insurance solutions from a stakeholder perspective and subsequently draws conclusions from the comprehensive research. This report closes off with a discussion of the shortcomings and assumptions, and recommendations for future research.

2
Market failure mechanisms

This chapter presents an outline of general and flood-specific failure mechanisms. The first trio of mechanisms are examined from the vantage point of the insurer, dealing with the challenge of potentially overwhelming or complex cost assessment and coverage, whose failure can result in the collapse of the system. Associated mechanisms involve *risk predictability*, *cumulative risk* and *correlated risks*, which are described in Sections 2.1, 2.2.1 and 2.2.2, respectively.

The subsequent mechanisms -— *risk perception*, *adverse selection*, *moral hazard*, and *charity hazard* -— centre around the incentives and behaviour of the insured. These factors can influence the market's stability and potential for failure. These mechanisms are explained in Sections 2.3, 2.4, 2.5 and 2.5.1, respectively. Of these mechanisms, the last three are more broadly associated with economic failure, and their concepts are explained using the *Market for Lemons* (Akerlof, 1970), *competitive equilibrium theory* (Rothschild & Stiglitz, 1976), and the *principal-agent theory*.

By comprehensively examining and understanding these mechanisms, this chapter aims to answer the first research question: *What are failure mechanisms in (flood) insurance, and how can they be mitigated?*

2.1. Risk predictability

The first failure mechanism addressed in this report concerns the challenge of predicting flood risk, which complicates the insurability of such risks. Accurate assessment of flood probabilities and reasonable assumptions regarding possible flood damages are crucial for insurers to be able to offer insurance contracts with premiums which both cover payouts and entice customers to buy the contract (Botzen & Van den Bergh, 2008).

Empirical evidence from Kunreuther et al. (1995) indicates that the level of uncertainty surrounding the probability of an event and the magnitude of losses directly influences the height of the insurance premium charged. The primary issue with uncertainty arises from the low occurrence of floods, making it exceptionally challenging for insurers to accurately predict them (Seifert et al., 2013). Floods are so-called low-probability, high-impact events, which are inherently more challenging to insure compared to high-probability, low-impact events, like fires (Kron, 2009). This difficulty arises from the interdependency between flood risks. The effect of dependency between risks and a practical example of the difference between fire and flood risk is provided in appendix A.1.

If a flood in an area becomes a medium-probability, medium-impact event, the mechanism risk predictability is (partially) mitigated. This occurs in large areas where multiple floods are likely to occur every year but only impact a relatively small part of the overall area.

2.2. Cumulative and correlated risks

Both mechanisms are related to the interdependence between individual risks (Vrijling et al., 2008). This interdependence can lead to very high total damage costs, surpassing premium levels considered reasonable.

The terms cumulative and correlated risks are used interchangeably in the literature. Therefore, for clarification purposes, the meaning as described in this section will be adopted for the rest of the report.

2.2.1. Cumulative risk

Insurance companies are able to offer coverage on policies that incur damage by maintaining a significant number of non-damaging policies in their portfolio (Barnhoorn, 1995). However, in the event of a large-scale catastrophe, the cumulative damage for the insurance company covering the risk becomes exceedingly high, as a large number of policies suffer damage simultaneously. This situation can lead insurers to default on their payout obligations, ultimately leading to the company's insolvency. Again, this has been described in appendix A.1, which covers the dependency of risks.

Nevertheless, this problem can be overcome. For example, by diversification of the portfolio, the total risk becomes more spread which mitigates the cumulative risk. Moreover, coverage against storm damage poses a significant cumulative risk, but in the Netherlands, where there is a high perception of risk among people, a market for this risk exists (Kok, 2000). This suggests that cumulative risk can be mitigated by increasing risk perception.

2.2.2. Correlated risk

Correlated risk refers to an increased risk of other catastrophes occurring simultaneously with a flood event. For instance, during a storm, there is a high probability of a flood occurring as well. Consequently, in the event of a storm, both storm damage and flood damage contracts are likely to be impacted, placing the insurance company at substantial risk.

Since both cumulative and correlated risks rely on the dependency between contracts, they can be mitigated by diversifying the contracts across various river basins, coastal areas, and polders to achieve independence among groups of policyholders (Kok et al., 2003). Ideally, insurers should include contracts from different countries (or continents) in their portfolio to spread the risks and create independence within their portfolio. Additionally, certain financial instruments, such as catastrophe bonds (CAT bonds), can provide relief to insurers (see A for further reference).

2.3. Risk perception

Risk perception plays a crucial role in the context of flood insurance. Generally, individuals tend to rely on their intuitive judgements when assessing potential hazards. However, these perceptions of risk often differ from expert assessments (Slovic, 1987), leading to situations where the actual risk individuals face may surpass their perceived risk. This discrepancy is significant because it influences individuals' decisions regarding risk mitigation measures.

Savage (1954) highlighted the importance of risk perception in his *subjective expected utility theory*. According to this theory, individuals form subjective probabilities of uncertain outcomes, upon which they decide if and how to take action to mitigate the effects. If people have a low perception of the risk of flooding, they are less likely to opt for flood insurance, making it challenging for a stable flood insurance market to emerge. Countries with a low frequency of flooding, such as the Netherlands for instance, may experience lower demand for flood insurance among their citizens due to their low perception of risk (Seifert et al., 2013).

2.4. Adverse selection

Adverse selection occurs in a market due to the presence of information asymmetry between buyers and sellers, in which one party possesses more information about the goods being sold than the other. This information asymmetry will lead to a disruption in the market, resulting in the failure of the market equilibrium, a phenomenon also referred to as *equilibrium unravelling* (Hendren, 2014). The effects of private information in insurance markets and potential problems were initially described by Akerlof (1970) and Rothschild & Stiglitz (1976). In this section, a brief introduction to adverse selection is provided, followed by a more detailed exploration of its relevance to flood insurance. For a more comprehensive understanding of adverse selection, please refer to appendix A.4.

With adverse selection, information asymmetry occurs between insurance companies and policyholders. While individuals are aware of their own risk levels, insurance companies are not. Consequently, insurance companies treat all individuals as having equal risk, leading to an associated premium that represents the average risk of all individuals. As a result, low-risk individuals may choose not to purchase insurance priced against the average pool, as it would leave them worse off. This phenomenon leads to the unravelling of the market, as described in the *Market for lemons* by Akerlof (1970).

Adverse selection may arise in two forms with regard to flood insurance. First, as proposed by Botzen & Van den Bergh (2008), individuals residing in flood-prone areas are more likely to seek insurance against flooding. Offering a uniform insurance contract to all individuals could lead low-risk individuals to opt out of the market. However, this challenge can be addressed by differentiating between low-risk and high-risk individuals, which can be accomplished through public information such as elevation with respect to sea level. Botzen & Van den Bergh (2008) furthermore state that individuals are unlikely to possess superior knowledge about flood risk compared to insurers, considering the expertise required in assessing climate-related risks, thus limiting adverse selection.

Nonetheless, this report introduces a second form of adverse selection, arising from the disparity in information regarding the potential damage an insured individual may incur. Individuals who are likely to suffer high costs of damage due to flooding, for example by storing data storage equipment in the basement, are more likely to take out coverage than individuals with low risk of high costs. For insurers, accurately determining whether an individual is likely to experience high or low damage costs can be extremely difficult, if not impossible. A potential solution to this issue could involve making insurance compulsory in the building and contents insurance, as is already implemented in other countries like Belgium. This option will be further explored in Chapter 5.

2.5. Moral hazard

Similar to adverse selection, moral hazard arises from information asymmetry. Mas-Colell et al. (1995) distinguished these as *hidden information* leading to adverse selection, and *hidden actions* resulting in moral hazard. With adverse selection, the information asymmetry influences the choice of the contract, while moral hazard involves incentivised behaviour of the individual at risk while already in the contract (Goulão & Perelman, 2014).

This famous concept is also called the *principal-agent theory*, in which the agent is hired by the principal, but information asymmetry and conflict of interest lead to the incentivised behaviour of the agent. A classic example of this is seen in car insurance. When an individual does not take out car insurance, they are incentivised to drive carefully, since they will have to pay for all damages incurred. However, once the individual – *the agent* – has car insurance, the incentive to drive carefully diminishes since they know that the damages they incur will be covered by the insurer, *the principal*. Insurers address this issue by manipulating the agent's incentives through various measures, such as:

1. Deductibles: the agent pays for the initial part of the damage costs
2. Co-insurance: the costs of damage are shared between the agent and the insurer
3. Upper limits on coverage: there are maximum limits on the coverage provided
4. Claim-free years: the agent is rewarded with lower premiums in the next year for having few or no claims

These measures can be divided into those influencing the volume of damage claims (deductibles and claim-free years) and those affecting the value of damage claims (co-insurance and upper limits) (Botzen & Van den Bergh, 2008).

In flood insurance, the potential for moral hazard exists, although it is somewhat limited. Agents cannot influence the likelihood of a flood occurring, but they can impact the amount of damage incurred during a flood. Therefore, an agent with flood insurance coverage may have a reduced incentive to prevent damage caused by flooding. As agents cannot influence the possibility of a flood but only the extent of damage, the relevant mitigation measures are those that influence the value of damage claims.

2.5.1. Charity hazard

A specific form of moral hazard is charity hazard, which affects individuals' willingness to pay for insurance, but it is applicable only when free compensation is provided by the government or other higher institutions. While adverse selection and general moral hazard can occur in various forms of insurance, charity hazard is unique to large-scale catastrophes.

In the event of significant disasters like hurricanes, terrorist attacks, or floods, the government intervenes and offers financial relief to its citizens. This enables communities, regions or entire countries to respond en recover swiftly. However, the presence of governmental aid may lead individuals to underinsure or not insure at all against damage from such large-scale catastrophes, as they expect the government to step in and assist them (Raschky & Weck-Hannemann, 2007). In this case, the government has removed the incentive from its citizens to protect and mitigate, which may lead to high costs for society.

Mitigating charity hazard poses challenges as politicians may use post-disaster compensation to gain political support among citizens (Seifert et al., 2013). However, it was also discussed by Raschky & Weck-Hannemann (2007) and Seifert et al. (2013) that in countries with a low occurrence of floods, like the Netherlands, charity hazard might be reduced among the population due to a lack of familiarity with government-provided financial aid.

In the Netherlands, charity hazard is fueled by the presence of the Wts. A study by the Association of Insurers revealed that 21% of consumers in the Netherlands believe that the government will cover flood-induced damage (Issuecommissie Klimaat 2017, 2017). However, in the case of the Wts, charity hazard is falsely present since the government is only obligated to provide compensation for sweet water floods and only under specific circumstances. As a result, consumers are not incentivized to purchase flood insurance due to the mistaken assumption of government coverage.

This concludes the examination of the seven failure mechanisms described above and answers the research question: *What are failure mechanisms in (flood) insurance, and how can they be mitigated?* These failure mechanisms will be used throughout the entire report, and function as fundamental evaluation parameters for the solutions aimed to result from this research.

In Chapter 3, the reimbursement systems of five different countries will be explored, and scrutinised with respect to the failure mechanisms of this chapter. Following this, an Expert

Judgment Analysis is performed, in which the experts are asked to evaluate the impact of the seven failure mechanisms on each system. Finally, a shortlist of seven possible insurance solutions for the Netherlands is presented.

3
Flood insurance in- and outside of the Netherlands

This chapter offers an extensive analysis of diverse flood insurance systems implemented in five developed countries. In addition to examining the flood insurance system in the Netherlands, it also draws a comparative assessment between the flood insurance systems of the United States, the United Kingdom, Belgium, and Spain. Furthermore, it evaluates the risks of the failure mechanisms identified in Chapter 2 and analyses their relevance to each respective system.

After introducing the different flood insurance systems in Section 3.1, an Expert Judgment Analysis is conducted in Section 3.2 to quantify the impact of the failure mechanisms on each system. The obtained scores from this assessment will be instrumental in the evaluation of potential flood insurance systems in the Netherlands which will be discussed in Chapter 5.

Finally, by leveraging the retrieved knowledge of the failure mechanisms, the different systems, and the insights of the expert panel, a shortlist of seven possible insurance solutions to cover flood damage resulting from the failure of primary flood defences is drawn up in Section 3.3. Three solutions will be discarded, after which this report will continue to explore the pros and cons of the other four solutions concerning the overall structure, failure mechanisms and premium.

Through a thorough examination of the flood reimbursement schemes of other countries, combined with expert insights, this chapter aims to provide an answer to the second research question: *How is flood insurance or reimbursement arranged in the Netherlands and other developed countries, and what are potential solutions which could be implemented in the Netherlands?*

3.1. Country comparison

3.1.1. United States

After a devastating Hurricane in September 1965 (Hurricane Betsy), and given the lack of interest by private insurance markets, the National Flood Insurance Program (NFIP) was established by the American government (Michel-Kerjan, 2010). This program, managed by the Federal Emergency Management Agency (FEMA), covers over $1.3 trillion in assets spread across 5 million flood insurance policies (Horn & Weiber, 2022). Its main objectives are providing access to affordable flood insurance by spreading the risk between government and policyholders and implementing floodplain management standards to mitigate comprehensive flood risk (Horn & Weiber, 2022).

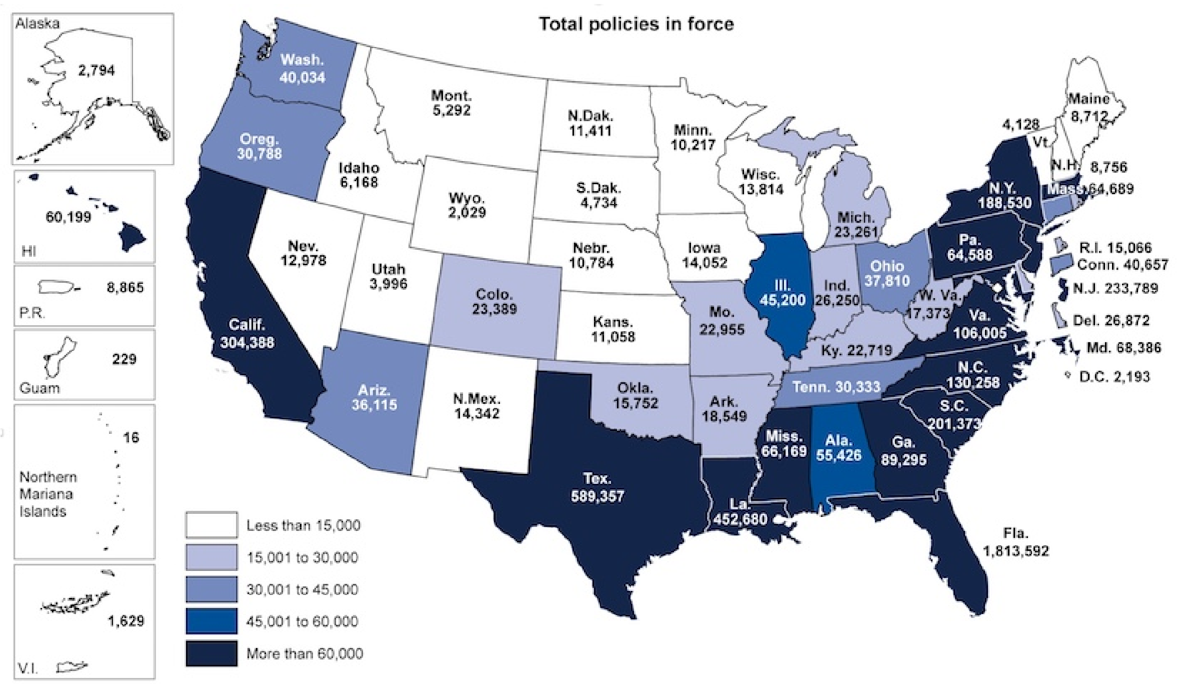


Figure 3.1: Focus area of the NFIP is along the US coastline (GAO, 2016)

The NFIP functions through a distinctive structure in which individuals do not secure flood insurance directly from a private insurance company in the traditional sense. Instead, the insurance provider sells and manages the flood insurance policies and oversees the claims process, but the risk is transferred to the FEMA. This means that while the private insurer handles the administrative duties, the ultimate responsibility for the financial risk and any claims payouts rests with FEMA. In this scenario, the private insurer essentially serves as an intermediary, facilitating the process while the government retains the potential financial liabilities.

The NFIP incentivises communities to reduce flood risk by offering premium discounts to those who invest in mitigation measures, such as elevating homes or building flood barriers. Special Flood Hazard Areas, exposed to a 1/100 or greater annual risk of flooding, are legally required to obtain flood insurance through the NFIP, while areas with lower risk can purchase Preferred Risk Policies with lower premiums.

Currently, the NFIP is $20.5 billion in debt to the US Treasury after it had to borrow heavily to pay claims after significant hurricanes like Katrina in 2005 and Sandy in 2012 (Horn & Weiber, 2022). In addition, the US Congress cancelled $16 billion of debt in 2017, after FEMA had reached its borrowing limit of $30.4 billion. Currently, the NFIP pays interest at a rate of over $1 million per day. According to FEMA, the NFIP will incur an extra $5.8 billion in interest costs over the following ten years, totalling $10.6 billion by the end of 2029 (Horn & Weiber, 2022).

Failure mechanisms in the US system

1. Risk predictability: Although the risk predictability failure mechanism is generally mitigated over large areas, it is still present in the US due to the extremely costly hurricanes the country encounters. Since the NFIP covers the damage from flooding resulting from these hurricanes, this poses a substantial risk to the scheme. However, since hurricanes occur fairly frequently and always during the hurricane season, some mitigation is in place.
2. Cumulative risk: The NFIP's flood policies are mostly taken out along US coastlines and

in the southeast region. This causes a large spread of the risk, reducing the cumulative risk. Figure 3.1 depicts the spread of NFIP policies in the United States.

3. Correlated risk: Correlated risk is not of concern since the NFIP only covers flood risk.
4. Risk perception: Risk perception is very high due to the media attention given to the significant financial costs and loss of lives[1] associated with storms. The heightened awareness positively influences risk perception.
5. Adverse selection: The US system faces adverse selection, but some mitigation is in place. The partially compulsory system with risk-based premiums attempts to offset the effect of adverse selection. However, a full compulsory system would allow for more low-risk premium income which would stimulate the offset of riskier policies. The use of risk maps and offering discounts to policyholders who take risk reduction measures further helps to mitigate this risk.
6. Moral hazard: The presence of compensation does allow for moral hazard to occur. However, the partially compulsory system reduces moral hazard compared to a fully compulsory system. The option to reduce premiums by implementing risk reduction measures and the discount for such measures further mitigates moral hazard.
7. Charity hazard: With a strong governmental presence in the system, charity hazard is present in this case. This is demonstrated by the $16 billion of cancelled debt of the NFIP by US Congress, resulting from a deficit in premium income.

3.1.2. United Kingdom

Flood reinsurance in the UK is administered by Flood Re Limited (Flood Re) through the Flood Reinsurance Scheme (Flood Re, 2022). Its primary objective is to promote available and affordable home insurance for homes at risk of flooding in the UK. The scheme is designed as a transition phase towards a self-sustaining home insurance market that can independently handle flood risks, aimed to be achieved by 2039.

The scheme is intended for homeowners residing in flood-prone areas who are unable to obtain affordable building and contents insurance. While participation is not mandatory, obtaining flood insurance is often a requirement for property mortgages. Under the Flood Re scheme, all flood-related claims are managed through insurers and paid out via the scheme which spreads the risk among insurers. By spreading the risk across the industry, this setup protects insurers from high costs, ultimately leading to reduced insurance prices for homeowners in flood-prone regions.

The scheme is a joint initiative between the UK Government and the insurance industry and was established in 2014. The scheme provides reinsurance coverage for individuals at a subsidised rate. Individuals who are located in high-risk areas take out insurance at a regular home insurer, which decides which risk to cede to Flood Re. To cover underwriting losses, a levy is charged (Levy I) on all UK household insurers, which pass this levy on to all their customers, thus spreading the costs of the individuals who possess the highest risk. The premium collected from insured households, along with the levy from all UK households, has proven sufficient to sustain the scheme. Flood Re maintains financial stability with significant liquid assets and a liability limit. In case a severe flood or multiple flood events take place, and Flood Re is unable to meet its solvency capital requirements, a second levy (named Levy II) can be called against the insurers for an unlimited amount. To incentivize building in non-flood-prone areas, all buildings constructed after 2009 are excluded from the scheme.

It is important to note that Flood Re provides coverage only for residential properties(Flood Re, 2022). Businesses, including smaller entities like SMEs, must secure flood insurance from

[1]Total number of fatalities Hurricane Katrina (2005): 1392 (Knabb et al., 2023)

the open market, which can be challenging.

Failure mechanisms in the UK system

1. Risk predictability: Risk predictability is of lesser concern in the UK system due to the frequent occurrence of floods in the country. Historical records of flood damages enable the Flood Re scheme to more accurately predict yearly costs of flood damage.
2. The reinsurance scheme does mitigate cumulative risk. With all UK insurers offering home insurance participating in the scheme, the risk is spread across the industry, creating a diversified portfolio of policies. This sharply reduces the risk of individual insurers.
3. Correlated risk is low, as the costs of damage from flooding are reimbursed via the scheme while other claims are handled through the regular policy issuer.
4. Risk perception plays an important role in this. The regular occurrence of floods in the UK does have a positive influence on this. Risk perception is of importance in this system, since homeowners are not obliged to take out insurance. And with over a quarter of British homes not having buildings and contents coverage (Butler, 2021), there is still substantial room for improvement.
5. Adverse selection can pose a problem for the Flood Re scheme, as it is specifically designed to provide insurance coverage to homeowners who are at high risk of flooding and may have difficulty finding coverage through regular insurance companies. If the pool of homeowners insured through Flood Re consists primarily of high-risk individuals, it could be challenging for the scheme to cover its costs and remain financially sustainable. To address this issue, Flood Re has implemented a risk-based premium structure, which reflects the true cost of insuring properties in flood-prone areas.
6. The Flood Re scheme could potentially be susceptible to moral hazard if it leads to homeowners in flood-prone areas becoming less proactive about protecting their homes from flooding. However, the scheme is designed to encourage risk reduction by requiring participating insurance companies to offer policyholders advice on how to reduce their flood risk and by offering discounts to policyholders who take steps to reduce their risk. Additionally, the premiums for the Flood Re scheme are based on the risk of flooding in a particular area, so homeowners who live in areas with a high risk of flooding may be more incentivised to take steps to reduce that risk in order to lower their premiums.
7. Since Flood Re is a privately owned public body, consisting of a partnership between UK insurers and the UK government, the charity risk is considered to be low.

3.1.3. Belgium

The Belgian system has gone through an evolution in recent years. At first, a model of national solidarity was implemented through the National Disaster Fund (Bruggeman & Faure, 2018), through which individuals affected by disasters, including flooding, could apply for compensation. However, since 2005, the role of the fund has been reduced.

However, since 2006, flood coverage has been compulsorily included in fire insurance policies offered by private insurance companies in Belgium (FOD Economie, 2020). While not mandated by law, most homeowners in Belgium (approximately 95%) have fire insurance (Mees et al., 2016).

Insurers have the flexibility to set their premium rates, although there is a maximum premium the insurer is allowed to ask. If the maximum premium is applied, insurers have the option to enter high-risk properties into a compensation mechanism called *CANARA*, which acts as the Belgian catastrophe fund and spreads premiums and losses among all fire insurers in Belgium (Mees et al., 2016).

For buildings constructed in high-risk flood areas after September 23, 2008, insurers are not obligated to cover water damages (Mees et al., 2016). If they choose to provide coverage, the maximum premiums set by the government do not apply, and insurers can determine the premium based on their risk assessment.

To discourage construction in flood-prone areas, the National Disaster Fund will not provide compensation for damages if a property cannot find insurance coverage in such areas. This lack of intervention serves as an additional deterrent for building in high-risk flood zones.

Failure mechanisms in the Belgian system

1. Risk predictability: Belgium, though not as flat as the Netherlands, still faces challenges in predicting flood risk due to its relatively small size and infrequent occurrence of floods. This makes it difficult for insurers to accurately assess and predict the expected damage from flooding each year.
2. Cumulative risk: Given Belgium's small size and high population density, a large flood in a densely populated area could result in a significant number of claims from homeowners. The limited geographical spread of policies in affected regions could lead to difficulties in offsetting the claims with unaffected policies. This is mitigated by the fact that all natural catastrophes are insured via fire insurance.
3. Correlated risk: The limited spread of policies in specific regions and the fact that other natural catastrophes fall under fire insurance pose a problem with correlated risk. To mitigate this, adding policies in different regions, possibly in different countries, could reduce dependencies between flood events and other risks.
4. Risk perception: Risk perception poses a lesser issue to the flood insurance market since flood insurance is mandatory in the fire insurance policy, a policy which 95% of Belgian homeowners have taken out. Individuals with a low perception of all risks covered by fire insurance may be less likely to out the bundle.
5. Adverse selection: Adverse selection in the Belgian system is mitigated as the premium is risk-based. However, as Atreya et al. (2015) stated, the premium is in practice often flat, which would incentivize adverse selection. Nevertheless, this is again mitigated through the compulsory nature of the contract.
6. Moral hazard: The compulsory aspect of the contract can stimulate moral hazard, as homeowners may be less incentivised to actively engage in flood mitigation measures since they know they will be compensated in the event of flooding.
7. Charity hazard: Unlike in some other systems, charity hazard is not a significant concern in the Belgian flood insurance system since the compensation is not issued directly from the government. Instead, it is borne by private insurers.

3.1.4. Spain

The Consorcio de Compensación de Seguros (CCS) is a state-owned public business organisation and a subsidiary of the Ministry of Economic Affairs and Digital Transformation. The company serves as a supplementary service to Spain's insurance industry, with a broad range of activities. Most important is the managing of various covers and protection for policyholders, and acting as a repository of information for certain types of insurance (CCS, 2020).

The first and foremost task of the CCS is to provide coverage of extraordinary risks which are not specifically covered by insurance policies issued by private insurers. The coverage of the CCS is included as a compulsory clause in the property damage policies issued by private insurers. Therefore, the CCS does not issue any policy but only compensates claims in case extraordinary risks are in place. These extraordinary risks are natural risks (earthquakes, flooding, volcanic eruptions, meteorites), violent acts (terrorism, rebellion, riot) and action by armed forces or law enforcement in times of peace. Historically, flooding has accounted for the majority of claims, consisting of 69% of total claims in the period 1987-2018 (CCS, 2020). For reference, the total number of claims filed in 2021 due to extraordinary risks totalled 110,036, amounting to €520 million in total costs (CCS, 2021).

The income of the CCS is derived from premiums, surcharges and yields on investments. Premium and surcharge income is collected through a government tax levied on insurance policies. Since the CCS operates under similar laws as private insurers, it must maintain enough capital to meet its solvency requirements.

Failure mechanisms in the Spanish system

1. Risk predictability: In the Spanish flood insurance system, risk predictability is of lesser concern compared to other countries like the Netherlands. The impact of floods is relatively manageable due to the country's geographical characteristics.
2. Cumulative risk: Cumulative risk is also less significant in Spain due to the country's scale. While floods may cause damage in certain areas, many other regions remain unaffected, and the income from those unaffected areas helps offset the losses.
3. Correlated risk: Correlated risk exists in the Spanish system, as heavy rainfall often coincides with storm conditions. However, again, the country's size mitigates this risk to some extent.
4. Risk perception: Risk perception is not a major problem in Spain. The country experiences floods annually, increasing public awareness. Additionally, the compulsory nature of the tax-based premium encourages higher awareness and coverage.
5. Adverse selection: The funding model of the CCS, through a surcharge on all insurance policies in Spain (compulsory nature), eliminates the dependency on policyholders purchasing coverage through the CCS, reducing adverse selection risks.
6. Moral hazard: The compulsory nature of the system stimulates moral hazard, as policyholders may be less incentivised to take proactive mitigation measures, given the certainty of compensation. The absence of regulations promoting risk reduction further contributes to this issue.
7. Charity hazard: Charity hazard is present in this system due to the compulsory nature of this government-orchestrated system.

3.1.5. The Netherlands

In the Netherlands, compensation for flood-related damage can be divided into insured damage and uninsured damage. Insured damage includes damage caused by local rainfall events and flooding of regional flood defences. However, currently uninsured is damage caused by flooding of primary flood defences, which are a combination of dikes, dams, and storm surge barriers protecting low-lying areas of the country from flooding from the sea, lakes, and major rivers. All primary flood defences are designated as such by Rijkswaterstaat. Defences not included are considered regional flood defences. In the evaluation of the Dutch system, the focus is on damage resulting from the failure of primary flood defences, from which compensation is awarded through the Wts.

Compensation for damage caused by flooding of primary flood defences is arranged through the "Wet tegemoetkoming schade bij rampen" (Wts). Under the Wts, individuals and businesses can apply for reimbursement of damage to their property, possessions, and loss of income resulting from natural disasters like flooding. To be eligible for compensation, the damages must be caused by a natural disaster that has been officially declared as such by the government. This is not applicable in case the damage or costs were insurable, preventable or if the compensation can be obtained on other grounds. Additionally, damage is never fully compensated through this arrangement, but is only intended to cover the most severe costs. In addition, the Wts is not applicable in case of flooding from the sea (flooding of salt water).

Failure mechanisms in the Dutch system

1. Risk predictability: The failure mechanism risk predictability does not apply to the Dutch system, since it implies that the difficulty of predicting risks translates to high premiums. However, the Wts is a governmental payout which does not charge a premium.
2. Cumulative risk: While it has a high impact on the Netherlands in general due to its small size, high population density, flat landscape and low position relative to sea level, it has a moderate impact on the Wts specifically. This is due to the fact that since the Wts covers all of the Netherlands, the risk is distributed nationwide which causes substantial diversification. However, diversification is not at the optimum level as this would mean including risks from other countries.
3. Correlated risk: Strongly influences the Netherlands as very high water levels often result from multiple factors, including storms. For example, the disastrous flood of 1953 was caused by a combination of spring tide and a heavy northwestern storm, further raising the water level which resulted in the failure of the flood defences along the southwestern coast of the Netherlands. For the Wts specifically, this would likely not have a lot of impact as damage from a storm can be insured, and the Wts will currently only compensate uninsurable risks. While the effect on the Wts is limited, it does have an indirect impact as it lowers the appetite of insurers towards insuring flood risk.
4. Risk perception: While the Dutch are aware of their history with flooding, it is questionable if their perception of risk is accurate. Research from the Association of Insurers indicated that a substantial amount of people in the Netherlands are unaware of who will compensate for flood-induced damage. Figure 3.2 illustrates the lack of knowledge by consumers on compensation liability for flood-related damage. This is strengthened by the fact that at the time of this survey, flood damage from flooding of regional flood defences was hardly ever covered in building and contents policies. The question of whether the government, which controls the Wts, is fully aware of the risks the country faces is difficult to answer.
5. Adverse selection: Not applicable to the Wts since it is a governmental system applicable to all individuals.
6. Moral hazard: Present in the form of Charity hazard.
7. Charity hazard: Strongly present in the Netherlands as government compensation after a flood reduces the incentive for individuals to mitigate against flood damage. The fact that the Wts does not fully compensate affected individuals somewhat mitigates the effect. The lack of knowledge by consumers on compensation liability, as illustrated in Figure 3.2, demonstrates a lack of awareness regarding who and how they will be compensated.

3.2. Expert analysis

To quantify the impact of the failure mechanisms described in Chapter 2 on the insurance systems/reimbursement schemes from Section 3.1, an Expert Judgment Analysis (EJA) was performed. The primary objective of the EJA is to gain insights into the strengths and weaknesses of each system. Based on these findings, new and improved constructions or mechanisms can be proposed in Chapter 5.

The EJA involved seeking input and expert opinions from relevant individuals with expertise in the field. By leveraging their knowledge and insights, the analysis aimed to provide a comprehensive understanding of how the identified failure mechanisms affect the insurance and

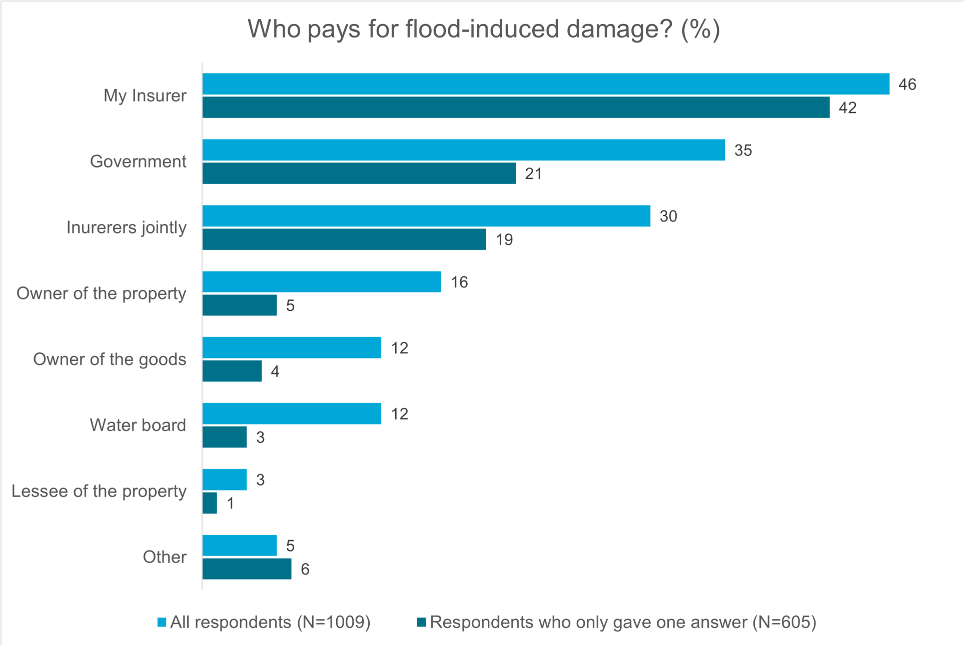


Figure 3.2: Consumer monitor: Who pays for flood-induced damage? (Issuecommissie Klimaat 2017, 2017)

reimbursement frameworks in different countries. This process allowed for a more informed evaluation of the effectiveness of each system and the challenges they may face.

3.2.1. Method

In preparation for the EJA, two methodologies were examined: Cooke's method (also known as the Classical method) and the Delphi method. This section provides a detailed explanation of both approaches.

Cooke's method

Cooke's method uses real data to evaluate the experts and calculate weights to use in combining their probabilities (Clemen, 2008). First, the panel of experts is asked to provide answers to multiple seed questions. The seed questions, with answers already known to the issuer of the EJA, determine how well-informed an expert is, which is expressed in a calibration score. The experts are asked to provide their answers with uncertainty, meaning they are asked to provide the 5th, 50th and 95th percentile of uncertainty regarding their answer. Subsequently, one or multiple target questions are asked to the panel. The calibration scores are used to determine the reliability and informativeness of the answers to the target questions. Soliciting from a broad panel of multiple experts improves accuracy and reduces the influence of individuals. (Cooke & Goossens, 2008)

Delphi method

The second method is the Delphi method. The Delphi method, or Delphi technique, is a method which strives for consensus among its expert panel to elicit certain information. The basic idea of the method is that pooled intelligence improves individual judgment and represents the overall perspective of a group of experts, even when they are not physically present together (De Villiers et al., 2005). Commonly, three versions of the technique are recognised; the *conventional Delphi*, *real-time Delphi* and *policy Delphi* (Linstone & Turoff, 1975).

The conventional Delphi consists of a series of rounds, in which questionnaires are shared with the experts. After each round, the responses are anonymised and shared with the panel, enabling experts to be informed by their peers' views. The objective is to converge the opinions of the experts towards a form of consensus (De Villiers et al., 2005). The real-time Delphi follows a similar approach but is conducted in a single time frame in which experts can continuously view other experts' perspectives and change their answers as often as desired until the timeframe closes. This is generally conducted through an online platform to which the experts log in (Gordon & Pease, 2008). The policy Delphi is a platform for exchanging ideas, aimed at decision-makers who prefer to receive a range of well-informed options and supporting evidence, rather than having a group make a final decision. Important features to consider for all versions are the development of the questionnaire, the definition of consensus, criteria for and definition of the expert panel, sample size and data analysis (De Villiers et al., 2005).

Upon analysing both methods, it was determined that the (conventional) Delphi method was a more suitable approach for research. This decision was based on two factors. Firstly, with the inclusion of seven failure mechanisms and five countries, the number of inquiries already was deemed substantial, with a total of 35 questions. Implementing additional seed questions required for Cooke's method would further increase the inquiries, potentially dissuading experts from participating or leading to rushed responses, which could result in inaccurate judgments. Secondly, Cooke's method aims to obtain decimal answers with a confidence interval, while this research seeks to quantify data more qualitatively since the impact of failure mechanisms on specific systems cannot be precisely quantified. Cooke's method, which aims for decimal answers and confidence intervals, would be more suitable for quantifying data with precision, such as predicting expected precipitation in a year. As a result, the Delphi method was deemed the more appropriate choice for this study.

3.2.2. Implementation

The implementation of the EJA involved several steps, starting with the design of the questionnaire. The document provided to the panel can be found in Appendix C, and is described in this section.

First, a short introduction to the thesis was provided, accompanied by the rationale behind the EJA and the use of the Delphi method. Subsequently, a brief description of the failure mechanisms from Chapter 2 and the insurance systems from Section 3.1 were presented. This step aimed to ensure that all experts had a common understanding and level playing field to assess the different aspects.

Experts were asked to provide their contact details and indicate if they wished their names to be included in the thesis. The participating experts are presented at the end of this section. The questionnaire's first question focused on determining the level of familiarity each expert had with the insurance systems (countries) under consideration. The answers ranged from *most familiar* (++) to *not familiar at all* (- -), with intermediate responses denoted by +, +/-, and -. This familiarity rating served as the weight for each expert's responses.

The subsequent questions asked the experts to assess the impact of the failure mechanisms on the insurance systems. They were asked to rate the impact on a scale from ++ (*very high impact*) to - - (*very low impact*), with +, +/-, and - indicating intermediate impact levels. Experts also had the option to mark *not applicable* denoted by an asterisk (*) if a specific failure mechanism did not apply to a particular insurance system.

After receiving the completed forms, the results were analysed, and a new form was constructed for the second round of the Delphi method. The first-round responses were categorised as weighted and unweighted, with familiarity serving as the weight for the weighted data. This allowed for the calculation of averages and the creation of box-whisker plots for both weighted and unweighted data.

In the second round, experts were given access to their peers' opinions and were presented with the analysed results from the previous round. After filling in their unique expert number which was assigned to them, their responses from round 1, along with the corresponding familiarity ratings, were displayed to them. Figure 3.3 shows the first question of the questionnaire of round 2, which was concerned with the impact of Risk Predictability on the US system. The questionnaire structure for the second round remained consistent for all 35 combinations of failure mechanisms and insurance systems.

A1
US - Risk predictability
Your score

Expert No.	Score R1	Familiarity	Score R2	Rationale R2 (optional)
1	100	4		

Rationales

Expert No.	Score R1	Familiarity	Rationale R1
1	100	4	Systemen in zoals in de VS waarin de risicokaarten zeer slecht zijn geven een sterke negatieve balans. Onderzoek laat zien dat slechte risico informatie en van de grote factoren is Verder wordt het systeem nu pas risk based, wat betekent dat de premies zwaar zijn gesubsidieerd
2	50	0	Knowledge I gained with international insurance programs, with locations in the US, and, in that respect, the outcomes of modelling tools applicable for the US.
3	50	1	Modelling well developed.
4	50	3	The market penetration for flood losses is relatively low in the US. The predictability of flood losses in the communities that have access to the NFIP has proven to be poor, given the massive debt they have built up over the years. To my best knowledge the have always paid out their obligations, but they did not have enough (reinsurance) capacity. The state has been their bank of last resort.
5	100	2	Kan gaan om zeer grote dicht bevolkte gebieden met veel schade per gebeurtenis.
6	?	1	-
7	25	2	Not the key issue related to the NFIP. The key issue is that premiums were/are not actuarially sound (this is being changed) Also, at a portfolio level, the risk is relatively well-known compared to the other countries in the list. The fact that it can readily be seen from past results that the programme is underfunded, illustrates that the risk at a portfolio level is relatively predictable.
8	100	1	There is a voluntary element in the programme. That makes it sensitive to risk predictability.
9	100	2	As I understand in the US insurance for house owners applies only in the T100 zone, and businesses in the T500 zone. Compared to NL the probabilities for exposure are high.
10	75	1	The US is more or less prepared for serious floods. However, on the preventive side they are not taking enough measures. Certain southern parts are vulnerable also taking into account the rise of the water levels worldwide.
Average R1	**72.22**		
Weighted avg.	**76.56**		*Note that the Average R1 and Weighted avg. R1 are taken from **all** experts.*

Figure 3.3: Questionnaire round 2 question A1

Participating experts

- Mr. Beekenkamp, Willem Jan (Allianz)
- Mr. Bobeldijk, Marco (Achmea Non-life Insurance)
- Mr. Bom, Ewoud (Achmea Reinsurance Company)
- Mr. Eijgenraam, Carel (-)
- Mr. Gabriel, Arno (Aon Reinsurance Solutions)
- Mr. Jongejan, Ruben (Jongejan Risk Management Consulting)
- Mr. Kloek, Gijs (Achmea)
- Mr. Kolen, Bas (HKV)
- Anonymous 1 (Dutch insurance company)
- Anonymous 2 (Dutch university)

3.2.3. Results

The EJA evaluated the impact of failure mechanisms on different insurance systems. Two essential features were considered: the spread of the scores, indicating the degree of consensus among experts, and the average of the scores, reflecting the impact of the failure mechanisms on the systems. Therefore, for a failure mechanism to have a significant impact on a system,

Table 3.1: Standard deviation round 1, weighted

Standard deviation round 1						
Weighted	US	UK	Belgium	Spain	NL	Average
Risk predictability	28.60	20.00	20.22	23.57	38.32	26.14
Cumulative risk	36.31	24.49	24.73	18.63	7.00	22.23
Correlated risk	31.21	19.29	27.92	22.44	33.99	26.97
Risk perception	29.93	20.00	33.74	26.68	34.74	29.02
Adverse selection	27.49	24.29	15.00	17.68	39.24	24.74
Moral hazard	39.69	23.11	11.46	11.79	20.00	21.21
Charity hazard	35.56	24.65	19.98	36.98	21.58	27.75
Average	32.69	22.26	21.86	22.54	27.84	25.44

Table 3.2: Standard deviation round 2, weighted

Standard deviation round 2						
Weighted	US	UK	Belgium	Spain	NL	Average
Risk predictability	27.78	14.34	17.62	23.57	30.59	22.78
Cumulative risk	31.72	24.49	19.64	12.50	7.00	19.07
Correlated risk	29.93	18.71	20.83	12.50	32.06	22.81
Risk perception	27.24	14.34	27.72	12.50	31.83	22.73
Adverse selection	23.75	25.82	7.50	12.50	37.01	21.31
Moral hazard	22.26	20.41	11.46	30.62	20.00	20.95
Charity hazard	26.79	24.65	9.32	43.59	12.18	23.30
Average	27.07	20.39	16.30	21.11	24.38	21.85

both a high average score and low spread in the answers are required, indicating that the experts concur on the fact that the impact is high.

The spread of the scores can be measured by calculating the standard deviation of the experts' responses to a specific question. The standard deviation is a statistical measure that quantifies the variability or dispersion of a set of data values from their mean. In this case, the *standard deviation of the population* is used, since the entire set of data is available for the calculation of the standard deviation. The formula for the standard deviation of the population is presented in Formula 3.1, in which σ represents the standard deviation, X_i the individual values in the population, μ the mean of the population and N the total number of values in the population.

$$\sigma = \sqrt{\frac{\sum(X_i - \mu)^2}{N}} \tag{3.1}$$

The standard deviation of the weighted data from round 1 and round 2 are presented in Tables 3.1 and 3.2, respectively. The difference between the two rounds provides insight into the extent to which the expert's opinions converged. This difference is presented in Table 3.3.

Looking at the averages of the standard deviation in round 2, the tables show a large difference in the degree of consensus between the different systems. Interestingly, the average standard deviations of the failure mechanisms are roughly the same. The observed difference in standard deviation depicted in Table 3.3 depicts that, in most cases, the spread between the experts' scores decreased. This indicates that the experts grew towards a consensus, although only slightly in most cases.

Next, the averages of the data points are calculated. Tables 3.4 and 3.5 represent the weighted averages of round 1 and round 2, respectively, while the difference between them is presented in Table 3.6. In these tables, the impact of failure mechanisms on the systems is indicated using colours, with red signifying a high impact and green indicating a low impact. By examining the average impact in round 2, it is evident that the UK, Belgian, and Spanish

Table 3.3: Difference in standard deviation round 1 and round 2, weighted

Difference Weighted	US	UK	Belgium	Spain	NL	Average
Risk predictability	-0.82	-5.66	-2.60	0.00	-7.73	-3.36
Cumulative risk	-4.59	0.00	-5.09	-6.13	0.00	-3.16
Correlated risk	-1.28	-0.58	-7.08	-9.94	-1.93	-4.16
Risk perception	-2.69	-5.66	-6.02	-14.18	-2.91	-6.29
Adverse selection	-3.74	1.53	-7.50	-5.18	-2.24	-3.43
Moral hazard	-17.43	-2.69	0.00	18.83	0.00	-0.26
Charity hazard	-8.78	0.00	-10.67	6.61	-9.40	-4.45
Average	-5.62	-1.87	-5.56	-1.43	-3.46	-3.59

Table 3.4: Average impact round 1, weighted

Average round 1 Weighted	US	UK	Belgium	Spain	NL	Average
Risk predictability	76.56	60.00	72.22	41.67	54.84	61.06
Cumulative risk	71.88	80.00	68.06	41.67	97.86	71.89
Correlated risk	76.56	68.33	63.89	45.83	68.57	64.64
Risk perception	73.44	65.00	62.50	20.83	45.00	53.35
Adverse selection	48.21	41.07	30.00	25.00	42.74	37.41
Moral hazard	67.31	43.75	57.50	66.67	40.00	55.04
Charity hazard	55.77	54.17	54.17	56.25	83.87	60.84
Average	67.10	58.90	58.33	42.56	61.84	57.75

systems scored relatively lower on average, suggesting that the failure mechanisms had a lesser impact on these systems. The difference between round 1 and round 2, as depicted in Table 3.6, further reveals that, on average, experts became more positive about the Spanish system in round 2, while other systems remained fairly consistent.

To visualise the data and understand both the spread and average, a box-whisker plot of the weighted data from round 2 is presented in Figure 3.4. The systems are differentiated by colours (blue for the US, orange for the UK, grey for Belgium, yellow for Spain, and green for the Netherlands), and each cluster of five systems corresponds to a specific failure mechanism. From left to right, the mechanisms are classified as risk predictability, cumulative risk, correlated risk, risk perception, adverse selection, moral hazard, and charity hazard.

To create a box-whisker plot, the data is first divided into four quartiles, each containing 25% of the data. The box in the plot represents the second and third quartiles, and it contains the middle 50% of the data. The top and bottom edges of the box represent the 75th and 25th percentiles, respectively. The whiskers (lines extending from the box) represent the spread of

Table 3.5: Average impact round 2, weighted

Average round 2 Weighted	US	UK	Belgium	Spain	NL	Average
Risk predictability	78.13	56.67	76.39	41.67	60.00	62.57
Cumulative risk	78.13	80.00	69.44	37.50	97.86	72.59
Correlated risk	73.44	70.00	62.50	37.50	67.14	62.12
Risk perception	68.75	68.33	66.07	12.50	47.86	52.70
Adverse selection	45.31	48.21	22.50	12.50	43.57	34.42
Moral hazard	69.23	50.00	57.50	50.00	40.00	53.35
Charity hazard	48.08	54.17	54.17	35.00	90.32	56.35
Average	65.87	61.05	58.37	32.38	63.82	56.30

Table 3.6: Difference in impact round 1 and round 2, weighted

Difference						
Weighted	US	UK	Belgium	Spain	NL	Average
Risk predictability	1.56	-3.33	4.17	0.00	5.16	1.51
Cumulative risk	6.25	0.00	1.39	-4.17	0.00	0.69
Correlated risk	-3.13	1.67	-1.39	-8.33	-1.43	-2.52
Risk perception	-4.69	3.33	3.57	-8.33	2.86	-0.65
Adverse selection	-2.90	7.14	-7.50	-12.50	0.83	-2.99
Moral hazard	1.92	6.25	0.00	-16.67	0.00	-1.70
Charity hazard	-7.69	0.00	0.00	-21.25	6.45	-4.50
Average	-1.24	2.15	0.03	-10.18	1.98	-1.45

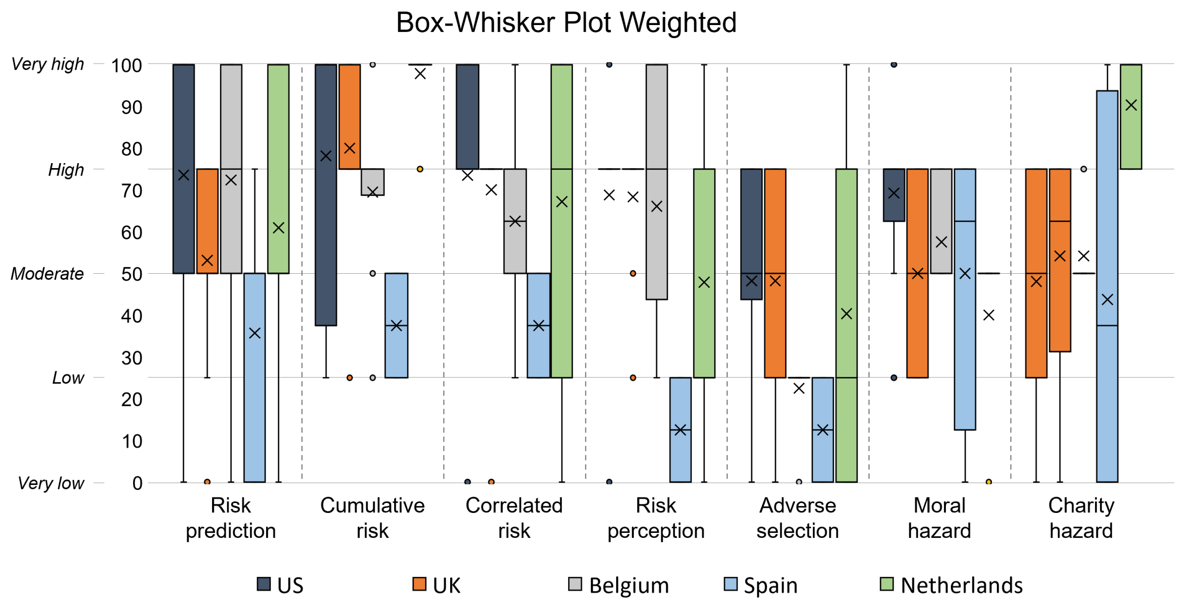


Figure 3.4: Box-whisker plot round 2, weighted

the data. They extend to the maximum and minimum values of the data within 1.5 times the *interquartile range* (the difference between the 75th and 25th percentiles). Values outside of the whiskers are considered outliers and are represented as dots in the plot.

An advantage of the box-whisker plot is that it excludes extreme outliers, which would have a large impact on the standard deviation. A good example is the failure mechanism correlated risk in the UK system depicted in Figure 3.4. The weighted data consists of 14 times a score of 75 ("+") and a single 0 ("- -"). The standard deviation of this dataset is 18.71. However, only a single number differs from the rest. Therefore, as this number does not lie between the 75th and 25th percentile, the spread is very small (0) in the box-whisker plot.

The results of this analysis will be used in the evaluation of different systems which could potentially be implemented in the Netherlands. To assess whether a certain failure mechanism has an impact on a system, attention is given to the spread of answers. If the spread is sufficiently small, the answer can be considered valuable, as the experts agreed on this topic to a certain extent. Next, the magnitude of the impact of this failure mechanism can be evaluated by taking the mean of the responses obtained in round 2 of the EJA. The weighted data, along with the unweighted standard deviation and averages, can be found in appendix C.1 for further reference.

3.2.4. Discussion

The objective of the Expert Judgment Analysis (EJA) was to evaluate the impact of failure mechanisms on the flood insurance systems of the US, UK, Belgium, Spain, and the Netherlands. Out of 17 potential participants approached, a diverse panel of 10 experts emerged, representing various backgrounds, including insurance and reinsurance industries, academia, and individuals familiar with flood damage reimbursement. The experts were asked to rate the impact of the mechanisms on a scale from 0 to 100, with intermediate possibilities of 25, 50, and 75.

During the analysis of the first-round answers, some unexpected challenges arose. Two primary concerns were identified based on the rationales provided by the experts alongside their scores. Firstly, it seemed that several experts answered the questions related to the Netherlands by scoring the impact of the failure mechanisms on a future insurance solution. However, they were supposed to assess the impact of failure mechanisms on the current system in place, namely the *Wet tegemoetkoming schade bij rampen* (Wts). This led to distorted scores for the Netherlands. Secondly, discrepancies were noticed between some rationales and the corresponding scores, particularly in questions related to the failure mechanism *risk perception*. It appeared that some experts rated the level of risk perception in a country rather than scoring the *impact* of the risk perception on the flood insurance system. In this case, a high risk perception in a region would generally lead to a reduced risk of that failure mechanism on the system.

In addition to this, another issue arose with the variability in the sum of familiarity scores. As illustrated in Table 3.8, the sum of the familiarity scores for the US, UK, and Belgium are approximately 17, while Spain and the Netherlands show substantial differences with scores of 7 and 35, respectively. While the total familiarity of the Netherlands is to be expected with a purely Dutch expert panel, the low Spanish familiarity was unforeseen. This variation in the sum of the familiarity scores impacts the weights assigned to different answers. This means that the averages of the answers for Spain carry less weight compared to the other countries. Additionally, not all participants provided an answer to all questions, resulting in very low total familiarity for some data points, especially for the Spanish system. For example, the total weight of the answers of moral hazard in the Spanish system is only 4, while the weight of the same questions regarding the Dutch system is 20 (5x). An overview of weights assigned to each question is provided in Table 3.7.

Table 3.7: Weight assigned to each question

Failure mechanism	US	UK	Belgium	Spain	NL
Risk predictability	16	15	18	6	35
Cumulative risk	16	15	18	6	35
Correlated risk	16	15	18	6	35
Risk perception	16	15	14	6	35
Adverse selection	16	14	10	6	35
Moral hazard	13	12	10	4	20
Charity hazard	13	12	12	5	31

Table 3.8: Familiarity with each system per expert

Expert No.	US	UK	Belgium	Spain	NL
1	4	2	2	1	4
2	0	0	2	0	4
3	1	3	3	1	4
4	3	4	4	1	4
5	2	1	0	1	2
6	1	1	4	1	4
7	2	1	0	0	2
8	1	2	1	1	4
9	2	0	0	0	4
10	1	2	2	1	3
Sum	17	16	18	7	35

3.3. Possible solutions

In this section, seven possible solutions are drawn up, which are inspired by the systems presented in this chapter and the work of the Association and De Vereende. A visualisation of the proposed solutions is depicted in figure 3.5. After discarding 3 solutions for reasons provided below, this report will further explore the remaining 4 solutions. In Chapter 4, assumptions for these structures will be made, upon which a premium is derived, and in Chapter 5, these solutions will be evaluated based on information gathered through the EJA and the premium.

1. **Market-driven insurance**

   Leaving it to the insurance market to construct and offer individuals an insurance contract which covers flood damage resulting from the failure of primary flood defences could be an option. A market-driven solution is commonly practised and currently implemented to insure most risks, like car theft or fire insurance. Insurers sell policies to individuals, which are bundled and subsequently sold to reinsurers. Reinsurers spread their risk by buying in all sorts of insurance contracts from different locations, creating independent sets of contracts and thus mitigating cumulative risk.

   Currently, flooding of regional flood defences and flooding caused by precipitation is offered on the market as part of most building and contents policies. Expanding the policy to include flooding from primary flood defences, and thus covering all flood damage, would seem a logical step. This way, there would be little changes to existing law, and no additional schemes have to be created.

   Below, a failed market-driven insurance contract by Dutch insurance company *Neerlandse* is described in *Failure of market-driven insurance*.

2. **Risk pool with government participation**

   A risk pool with government participation involves the establishment of a single pool comprising insurers, reinsurers, and the Dutch state, arranged in a bottom-up structure. In this system, individuals can opt to include coverage of flood damage resulting from the failure of primary flood defences in their buildings and contents policy if the insurer has joined the risk pool.

Collectively, all participants of the risk pool agreed to cover the maximum damage, which is the cap of the structure. If the total damage is higher than the maximum damage, the participants will be compensated pro rata[2].

3. **State-owned insurance**

   Under a state-owned insurance system, a fully state-owned body provides flood insurance to property owners on a semi-mandatory basis. Semi-mandatory participation entails that a portion of individuals is obliged to take out insurance, and the rest is not. In this case, only high-risk individuals (individuals who face a certain amount of risk, to be determined later) would be mandated to take out coverage for flood damage resulting from the failure of primary flood defences. Other individuals can voluntarily take out insurance.

   The coverage includes a capped amount for damages, beyond which the government's Wts comes into effect. Due to its semi-mandatory nature, the premium charged by this entity to its customers will be risk-based. Implementing a flat premium would deter low-risk individuals who would pay a premium that is higher than their expected loss.

4. **Amended Wts (Wts+)**

   The Wts+ would entail a modification of the current system in place (described in Sections 1.2 and 3.1.5), which operates as a safety net without a vertical cap. In this system, regular home insurers are given the role of claims handler – for which they are compensated – but do not hold any risk (similar to the current Wts). Next, a clear manual which states the responsibilities of all involved authorities and institutions is drawn up, in addition to a transparent set of conditions under which affected individuals are eligible for reimbursement. In contrast to the current Wts, the Wts+ will cover damage resulting from both salt- and freshwater.

5. **Mandatorily included in home policies**

   This approach mandates the inclusion of flood insurance in buildings and contents policies of all home insurers. Insurers cover damage up to a certain amount, after which a modified version of the Wts comes into place. Similar to the Wts+, this modified version of the law does include reimbursement of damage caused by saltwater flooding. This system will be similar to the current system in Belgium, described in Section 3.1.3.

6. **Risk pool**

   Similar to the Risk pool with government participation (solution 2), this approach involves the formation of a risk pool without government participation. Instead, a

[2]For example, if the total covered damage is €1 billion and the total damage of a flood event is €2 billion, all individuals will compensated for 50% of their damage. This is similar to the approach used by the NHT (NHT, 2023)

Failure of market-driven insurance

In 2016, Dutch insurer *Neerlandse* began offering flood insurance to homeowners in the Netherlands. The policy covered all damage from flooding, excluding damage from precipitation, inundation and groundwater seepage (Neerlandse, 2016). The risk was borne by 'one or multiple' underwriters at Lloyds of London, the insurance market. However, adverse selection led to only high-risk individuals taking out the insurance, driving up the price of the premium. Finally, all risk bearers withdrew from the contract, and Neerlandse closed the policy.

This is a real-life example of market unravelling due to adverse selection, described by the *market of lemons* (appendix A.4).

version of the Wts serves as a safety net.

7. **Flood Re**

   In the Flood Re system, regular home insurers can cede the highest-risk policies over to a government-owned reinsurance entity – named Flood Re – at a subsidised rate, a system used in the UK currently (Section 3.1.2. In this system, individuals who have a very high risk of flooding are still able to obtain affordable flood insurance. Insurance is offered voluntarily, and premium is collected in a risk-based manner for all individuals below a certain risk threshold. Individuals above this threshold will pay a subsidised premium. The funds to sponsor this subsidy are collected through a flat levy imposed on all participants.

This research will discard structures 1, 2 and 3 (Free market, Risk pool with government participation and State-owned insurance), and further focus on structures 4, 5, 6 and 7 (Wts+, Mandatorily included in home policies, Risk pool and Flood Re). A more extensive explanation of these structures is provided in Sections 5.1.2, 5.2.2, 5.3.2 and 5.4.2. Argumentation for discarding structures 1, 2 and 3 is provided below.

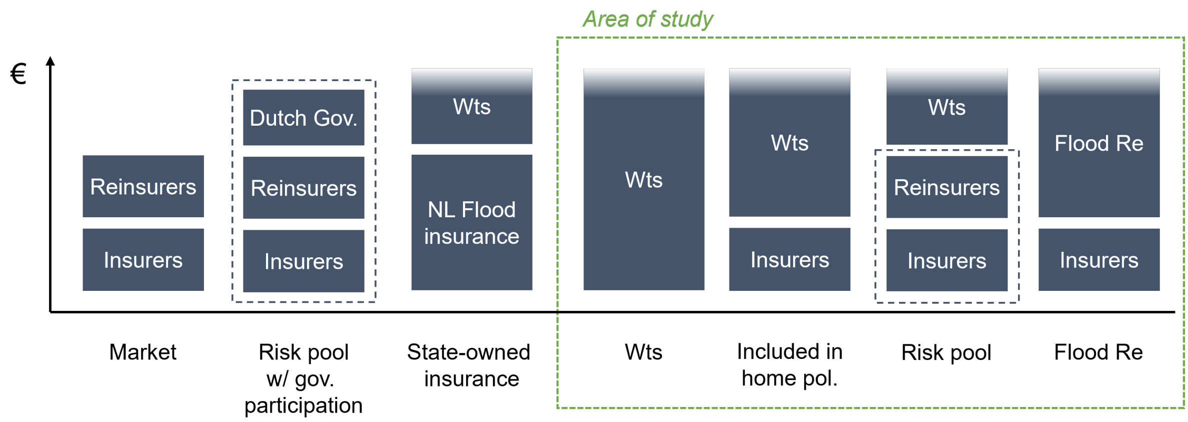


Figure 3.5: Visualisation proposed systems

Market-driven insurance

A market-driven insurance contract which covers damage resulting from the failure of primary flood defences would require little additional regulation and would stimulate competitive pricing, which is in the end favourable for the insured. Additionally, similar to the practice in other insurance contracts, insurers are able to stimulate risk mitigation by awarding premium discounts, resulting in a decrease in overall risk.

However, despite the aforementioned advantages, such a contract is not available at this moment while it does require any additional regulation. Therefore, it seems that a pure market-driven solution without the intervention of authorities is not viable at the moment.

Looking at the *Failure of market-driven insurance* call-out above, it states that the contract offered by *Neerlandse* faced adverse selection, which led to market unravelling, and eventually termination of the product. This phenomenon is described in detail in Appendix A.4, and is the main reason why a market-driven solution has not yet emerged in the Netherlands; low-risk individuals opt out of flood insurance since the risk they perceive is lower than the premium they pay, which further drives the premium for the high-risk individuals, eventually up to a point at which nobody wants to take out insurance any more.

In addition to adverse selection, a market-driven solution has a very high cumulative risk. Insurers need to diversify their (flood) risk geographically, since if they don't, and a flood occurs in an area where they are exposed, a lot of policies will pay out at the same time. Especially for smaller, more locally oriented insurers, it is difficult to diversify this risk.

Finally, since this solution does not involve any government participation, and insurers and reinsurers will have a cap on the maximum amount they disburse, the government is still required to install a safety net structure in case this maximum amount is inadequate. Additionally, this also holds for individuals who do not opt for voluntary insurance.

From the above-mentioned features, it is concluded that the emergence of a market-driven insurance solution without intervention or regulation from authorities is very unlikely and will thus be discarded from this research.

Risk pool with government participation

Setting up a risk pool with government participation is very similar to a solution without government participation, which is also described above. The formation of a risk pool offers the advantage of maximum distribution of risk among participants, thus mitigating cumulative risk. Additionally, knowledge from an existing Dutch risk pool such as the NHT or terrorism pool can be leveraged.

However, by including a layer which consists of reinsurers, a large capital outflow will take place. The insurance companies in the pool will try to reinsure their risk with large international reinsurers, which are able to distribute risk by investing in insurance across the world. However, reinsurance comes at a cost, and thus a large portion of the premium paid will go to foreign reinsurers. If no flood damage occurs, which is the ultimate goal of the government, this capital will not return to the Netherlands. This is unfavourable from the government's point of view.

Additionally, similar to the Market-driven insurance solution, a cap on the covered damage exists. Therefore, the government needs to install a safety net structure in case the maximum amount to be reimbursed is (much) lower than the damage of a flood event.

Finally, due to the voluntary nature of the contract, this solution stimulates adverse selection. As described before, this could lead to an unravelling of the market, and eventually, to the termination of the product.

Therefore, it is decided to discard the Risk pool with government participation and continue with the Risk pool without government participation. In this structure, the government will function as a safety net in the form of the Wts.

State-owned reinsurance

The formation of a state-owned reinsurance company which offers flood insurance covering damage resulting from the failure of primary flood defences is another possible solution. It will prevent a large capital outflow to foreign reinsurers and provide a large incentive to the government to invest in flood protection. Additionally, by having one insurer covering flood damage throughout the Netherlands, cumulative risk is mitigated.

However, forming such a government-owned body will be a comprehensive and possibly expensive process, especially without a precedent in the Netherlands. A lot of additional research is required which will take time and come at a cost.

Additionally, by forming a new insurance entity at which individuals can or have to take out insurance creates a system in which people have two home insurers: one for regular buildings and contents insurance, and one for flood risk. This system will highly stimulate correlated risk. If, for example, a large storm occurs which causes flooding, and houses are damaged by both wind and flooding, it becomes a tedious practice to find out which insurer will have to reimburse which damage. Finding out who pays for what will likely come at a cost.

Finally, by issuing semi-mandatory flood insurance, a portion of individuals will not opt for coverage. This will result in the government having to install a safety net structure for the uninsured, which could be viewed as unfair to insured individuals.

Therefore, in addition to the Market-driven insurance and Risk pool with government participation, it is determined to discard the State-owned reinsurance solution. This research will continue to explore the possibilities of the other four insurance solutions.

This marks an end to the examination of the flood damage reimbursement schemes of the US, the UK, Belgium, Spain and the Netherlands, as well as the impact of the failure mechanisms described in Chapter 2 on the respective systems. Finally, seven potential insurance solutions were introduced, from which it was decided to continue with four: Wts+, Mandatorily included in home policies, Risk pool and Flood Re. This answers the second research question: *How is flood insurance or reimbursement arranged in the Netherlands and other developed countries, and what are potential solutions which could be implemented in the Netherlands?*

In Chapter 4, assumptions for these solutions will be made, from which the premium associated with these structures is calculated. Chapter 5 dives deeper into the pros and cons of the structures concerning the failure mechanisms and the premium.

4

Development of flood insurance premium model

This chapter introduces a simplified property market model intended to provide insight into the development of insurance premiums. The aim of this chapter is to provide an answer to the third research question: *How does the premium evolve for four different insurance solutions?*

The model, serving as an evaluative criterion for solutions introduced in Chapter 3, will be explained by introducing its parameters and functionality in Section 4.1. Following this, the four solutions outlined in Chapter 3 will be introduced through the establishment of assumptions and subsequent premium calculations. Finally, the results of the analysis are summarised and briefly commented on, with a more in-depth evaluation to be conducted in Chapter 5.

4.1. Introduction of the model

To insure more common hazards – like fire or car damage – insurance companies utilise an extensive amount of data, enabling them to anticipate potential damage arising from their insurance contracts. This data positions insurers to calculate a premium which allows them to compensate for such damage. However, the most recent instance of flooding in the Netherlands resulting from the failure of primary defences dates back to the 1953 floods in Zeeland and South Holland. This demonstrates that flooding due to the failure of primary defences is a high-impact, low-probability event. The absence of recent historical data makes it challenging for insurers to accurately predict damage arising from this hazard and consequently, to establish a premium. Despite these challenges, this report introduces an insurance premium model utilising available flood probability data and damage statistics.

The model leverages publicly accessible flood data, which provides flood damage associated with specific return periods -— a conventional method for expressing flood damage. Damage is described across various return periods, such as 100 years, 1000 years, and so on. By connecting these damage events, a damage curve is formed, which enables the determination of the Yearly Expected Damage (YED). The YED, obtained through the integration of the damage curve, represents the average damage anticipated annually and thereby serves as the *risk* associated with an individual contract. Subsequently, each residence within the model is assigned to a specific risk class, facilitating the differentiation of premiums among households. Without this differentiation, a risk-based approach to premiums would be unattainable since all households would be subject to an identical premium.

From the YED, the initial part of the premium, called the Actuarially Fair Premium, is calculated. This premium represents the exact amount an individual should pay on their contract to cover the expected damage of that contract and does not consider any risk distribution or insurance costs. This is also referred to as the risk premium. To account for insurance costs, predominantly composed of the cost of capital, the insurance premium is determined. This premium encompasses both the risk portion and the insurance cost portion of the contract, constituting the final amount an individual pays on its insurance contract. A simplified schematic of the model introduced here is presented in Figure 4.1.

This section introduces a simplified property market, aimed to closely match the Netherlands. In order to employ an efficient and streamlined model, assumptions are made with the intention of minimally impacting the data. It's important to note that results from the model are intended to portray premiums in order of magnitude and to illustrate differences between the premiums of various insurance solutions. For the determination of actual premiums, a deeper dive into the Dutch housing market and flood risks is required and a comprehensive actuarial calculation needs to be performed.

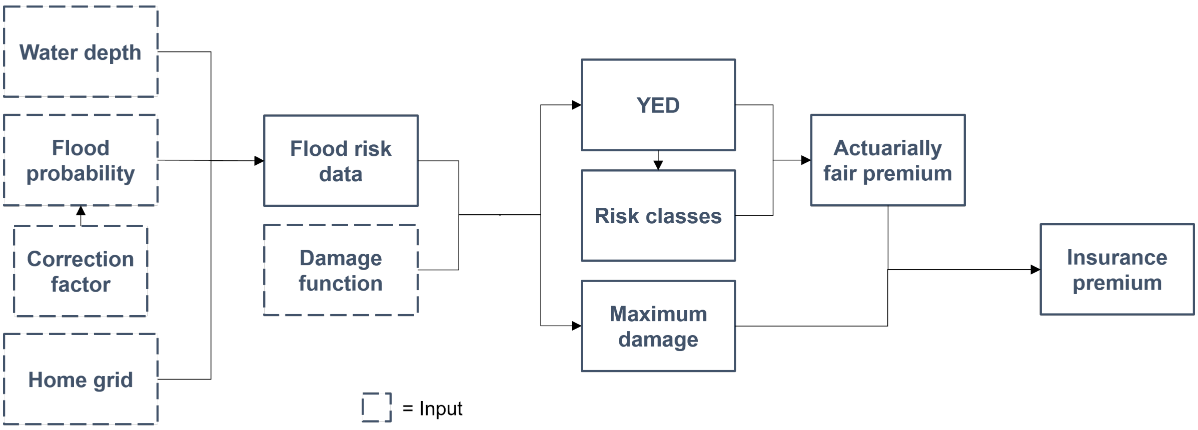


Figure 4.1: Schematic of the premium model introduced in this chapter

4.1.1. Flood risk

To define risk classes and assess the risk of flooding, various input factors are required. Risk is computed by multiplying the probability of an event by the impact that event has on the object of interest (see Formula 4.1). The impact is determined by multiplying the damage function, which is dependent on water depth, by the value of the object, in this instance, a home. To be able to perform this calculation, location-based input for these parameters is required (refer to Formula 4.2). Since the probabilities of flooding are known to be overestimated (Kolen & Nicolai, 2023), a correction factor must be applied to account for this exaggeration (refer to Formula 4.3). This correction factor is also dependent on the location of the object. A more comprehensive explanation of the correction factor is provided at the end of this section.

$$R = P \cdot I \tag{4.1}$$

$$I = f_D(H) \cdot V \tag{4.2}$$

$$P = p \cdot C_f \tag{4.3}$$

In which

R = Annual risk (€/y)
P = Annual probability after correction (-)
p = Annual probability before correction (-)
C_f = Correction factor (-)
I = Impact (€)
f_D = Damage function
H = Water depth (m)
V = Object value (€)

4.1.2. Input

The input for the model consists of a number of parameters which are retrieved from various public sources. For the determination of damage to buildings and contents, a series of maps is used which are combined to determine which houses incur damage X with probability Y. The following publicly available sources have been used as input for the risk assessment:

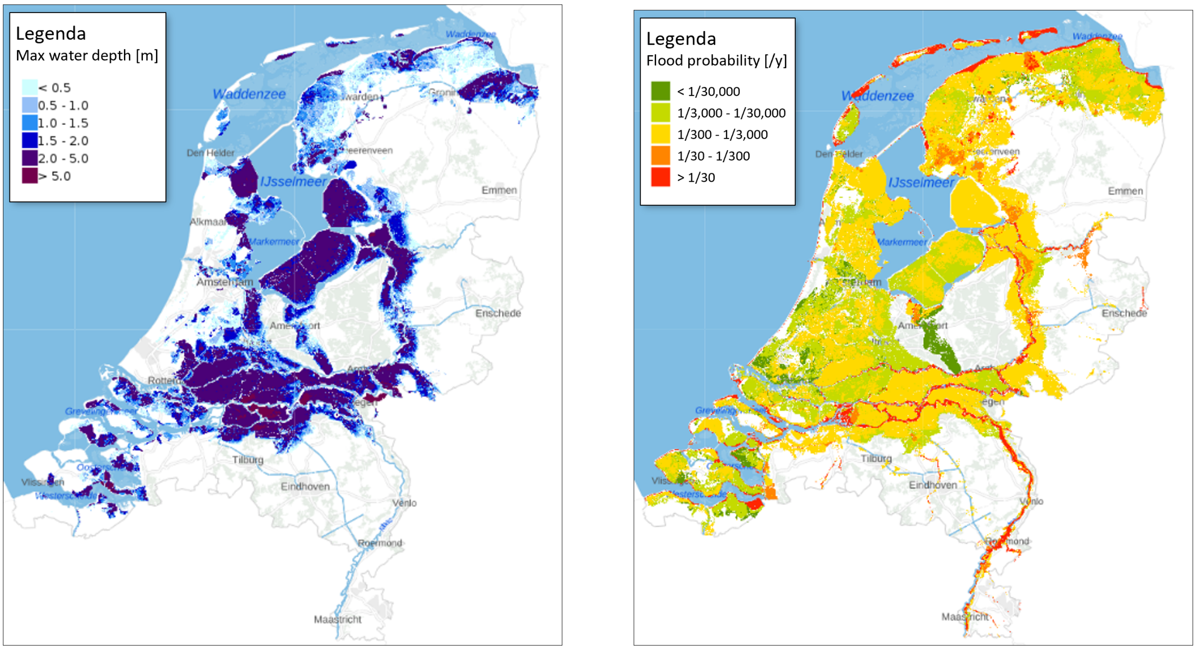
- Water depth - Retrieved from the Landelijk Informatiesysteem Water en Overstromingen (LIWO, English: National Water and Flood Information System) (LIWO, 2023)
- Flood probability - Retrieved from the LIWO (LIWO, 2023)
- Home grid - Retrieved from Basisregistratie Adressen en Gebouwen (BAG, English: Basic register of Addresses and Buildings) (Kadaster, 2023)
- Damage functions - Retrieved from the Schade en Slachtoffermodule (SSM, English: Damage and Casualty module) (Slager & Wagenaar, 2017)
- Correction factor - Retrieved from HKV (Kolen & Nicolai, 2023)

Managed by the Dutch Centre for Watermanagement, LIWO produces flood maps, depicting inundations and probabilities for various scenarios. For this assessment, flood probabilities are distributed into five distinct classes and were all assigned the geometric mean of the probability range. This assignment is a validated assumption when engaging with data on a logarithmic scale (Crump, 1998). The upper value representing a probability of more than once every one hundred years on average is set at 1/100. The lower value representing a probability less than once every ten thousand years on average is set at the geometric mean of 1/10,000 and 1/100,000. The geometric mean is calculated using Formula 4.4 with $n = 2$. The resulting probability classes are listed below. Flood maps retrieved from LIWO are depicted in figure 4.2.

$$\bar{P}_g = \left(\prod_{i=1}^{n} P_i\right)^{\frac{1}{n}} = \sqrt[n]{P_1 P_2 ... P_n} \tag{4.4}$$

Flood probability classes:

1. No damage $\rightarrow$ –
2. $P < 1/100,000 \rightarrow P = 1/3.162 \cdot 10^5$
3. $1/100,000 < P < 1/10,000 \rightarrow P = 1/3.162 \cdot 10^4$
4. $1/10,000 < P < 1/1,000 \rightarrow P = 1/3,162$
5. $1/1,000 < P < 1/100 \rightarrow P = 1/316.2$
6. $P > 1/100 \rightarrow P = 1/100$



(a) Water depth

(b) Flood probability

Figure 4.2: Flood damage and probability maps, retrieved from LIWO (2023)

Leveraging the comprehensive data from the Basisregistratie Adressen en Gebouwen (BAG), a robust understanding of the location and specifics of all properties and addresses across the Netherlands can be obtained. The BAG provides detailed shapes of all Dutch buildings, coupled with accompanying data including the construction year, current status, and designated purpose of use. For this assessment, extraction of data was performed, focusing exclusively on properties throughout the Netherlands that have been designated *residential function* in terms of their purpose of use. This extraction led to a comprehensive database, totalling 5,051,645 houses[1]. Subsequently, LIWO data was combined with the extracted BAG database, creating a unified data set. This combined data set consists of shapes containing houses, each underpinned with corresponding flood risk data. Note that all houses within a single shape share identical water depth and flood probability data, thereby being attributed to the same flood risk. In order to appropriately account for the correction factor later on, each shape is assigned to a specific region in which the shape is located. The regions are Lake area, Coastal North, Coastal Mid, Coastal South, Lower river area, Upper river area Muese and Waal, Upper river area Rhine and IJssel, and Limburg Muese.

Next, to derive the resulting damage from the water depth, a damage function is introduced. Sourced from the Schade en Slachtoffermodule (SSM), this damage function, dependent upon water depth, is applicable to both building structures and their contents. The SSM model, established by Deltares — a non-profit knowledge institute for applied research in the field of water, subsurface and infrastructure (Deltares, 2023) — has been designed for Rijkswaterstaat, a segment of the Dutch Ministry of Infrastructure and Water Management (Rijkswaterstaat, 2023). This model enables the estimation of damage and casualty figures resulting from the failure of primary or regional flood defences. The damage curves, constructed from the data obtained, are visualised in Figure 4.3.

[1] In 2022, the total Dutch housing market contained 8,045,850 houses (CBS, 2023a). The difference in the total number of houses lies in the fact that the BAG counts properties which have multiple addresses as one. Since this mostly concerns buildings with multiple stories, of which only the ground floor apartments have considerable exposure to flooding, it was decided to continue with this number

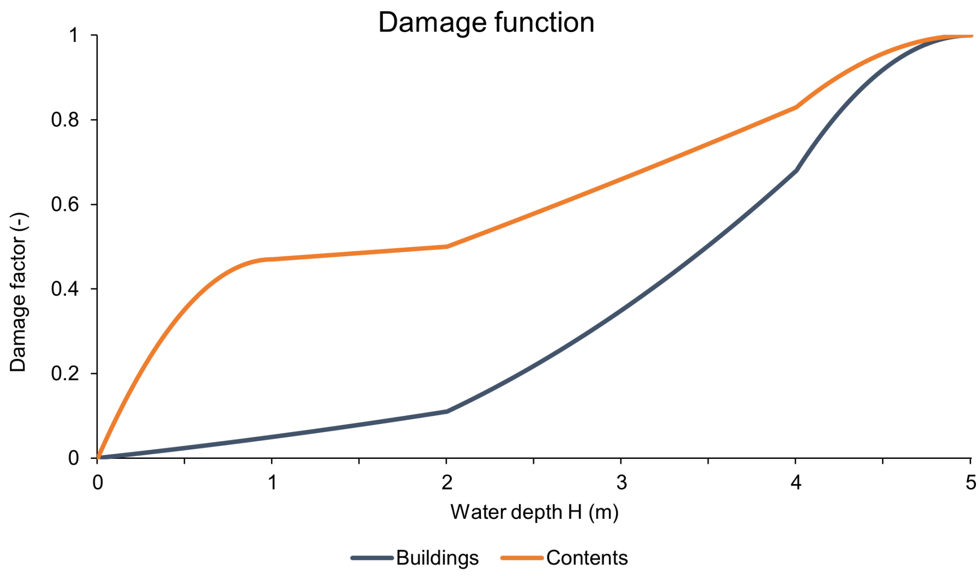


Figure 4.3: Damage functions for buildings and contents, retrieved from the SSM (Slager & Wagenaar, 2017)

Finally, research and advisory firm HKV determined that the flood probabilities issued by LIWO are overestimated, a result of a series of conservative assumptions (Kolen & Nicolai, 2023). The overestimation can be attributed to 1) a cautious approach in evaluating failure probability, 2) a disregard of the effect of *interconnected system dynamics* (Dutch: *systeemwerking*), and 3) a neglect of emergency response measures. Kolen & Nicolai (2023) executed an Expert Judgment Analysis, utilising the Delphi-method, to find a correction factor which can be applied to better describe the failure probability of flood defences. The expert panel in this EJA identified a range by which flood probabilities are overestimated across four distinct types of hinterland. Since this research aims to describe the actuarially fair premium closest to reality, the average of the range is adopted as the correction factor in the model. A more conservative approach would be to select the lower boundary, thereby maximising the probability of flooding.
The following correction factor ranges were identified by Kolen & Nicolai (2023), accompanied by the correction factor used in the model and the regions to which they are applied:

- Lake area: 10 – 15x → 12.5x (Lake area)
- Coastal area: 2 – 5x → 3.5x (Coastal North, Coastal Mid, Coastal South)
- Riverine area: 25 – 40x → 32.5x (Lower river area, Upper river area Muese and Waal, Upper river area Rhine and IJssel)
- Limburg Meuse: 2 – 5x → 3.5x (Limburg Muese)

4.1.3. Distribution of risk classes

The determination of risk classes is accomplished through several steps, beginning with the calculation of the impact, defined by Formula 4.2, using the damage functions found in Figure 4.3. This involves multiplying the damage factors obtained from these functions by the maximal damage applicable to buildings and their contents to determine the damage a house experiences in a specific shape and during a particular return period – this is referred to as the impact. Assumptions are made regarding the maximal damages for buildings and contents, considering them to be the average value for both parameters throughout the Netherlands. The average value of buildings, determined by combining data from the Association of Insurers and the CBS (Bureau for Statistics Netherlands) on the reinstatement value of Dutch properties, is approximated to be €307,733, which is rounded to €300,000 for practical application (Verbond van Verzekeraars, 2023a; CBS, 2023b). Concurrently, data from SEO (an economic research institute) and CBS estimate the average content value in the Netherlands to be €38,759, which is rounded to €40,000 (Pel & Behrens, 2022; CBS, 2014). The probability classes outlined in Section 4.1.2 are adhered to when applying return periods. The final step of calculating the impact is performed using Formula 4.5, which multiplies the damage factor (sourced from the damage function, which is dependent on the water depth) for buildings by the maximal damage applicable for buildings, in addition to multiplying the damage factor for contents by the maximal damage applicable for contents. An illustrative example of the impact calculation across different return periods is provided in table 4.1.

$$I = f_{D,B}(H) \cdot V_B + f_{D,C}(H) \cdot V_C \tag{4.5}$$

In which

I = Impact (€)
$f_{D,B}$ = Damage factor, buildings (-)
$f_{D,C}$ = Damage factor, contents (-)
H = Water depth (m)
V = Object value, buildings (€)
V = Object value, contents (€)

Table 4.1: Table depicting the impact houses occur in a shape for different return periods (exemplary data)

Shape	No. of houses	Region	Impact per house (per return period)				
			$1.0{\cdot}10^2$	$3.16{\cdot}10^3$	$3.16{\cdot}10^4$	$3.16{\cdot}10^5$	$3.16{\cdot}10^6$
1	23	Coast Mid	-	-	€ 17,569	€ 21,947	€ 25,885
2	679	Lake area	€ 25,885	€ 34,230	€ 41,049	€ 41,049	€ 41,049
3	146	Lake area	-	€ 41,234	€ 292,776	€ 307,197	€ 325,923
...							

Next, the Yearly Expected Damage (YED) is to be calculated, represented by the area under the Impact Curve, as highlighted by Bakker (2009). Input for this calculation is provided by the previously determined impact values, which are connected to create the Impact Curve, corresponding to various return periods. In this research, a presumption of a linear relationship between the points is applied. Notably, in a practical sense, a logarithmic relationship might be more fitting, considering the distance between points is multiplied by a factor of 10. Nevertheless, adopting this approach would greatly complicate the calculation process and would require considerably more computing power since a relationship for 5 points across more than 10 thousand shapes would need to be formulated. Thus, for the sake of simplicity and conservation of computational resources, assuming a linear relationship is deemed reasonable. In Appendix B, the difference between a logarithmic and a linear relationship is further explored. It is concluded that a linear approach yields an approximately 41% higher YED than a logarithmic approach. For a more granular relationship between points, additional studies, likely involving numerical analysis, would be required.

Calculating the area under the Impact Curve involves solving the definite integral of the curve. Given the presumption of linearity between impact points, the calculation is simplified to

Formula 4.6. This formula employs the Trapezoidal Rule, multiplying the width between return periods by the average impact. Subsequently, this is multiplied by the associated correction factor —- applicable to the region of the shape -— to determine the Yearly Expected Damage (YED). The YED per shape is calculated by multiplying the YED of a particular shape by the number of houses within that specific shape.

$$\text{YED} = \sum_{i=1}^{n} \left(\left(\frac{1}{T_{i-1}} - \frac{1}{T_i} \right) \cdot \frac{I(T_i) + I(T_{i-1})}{2} \right) \cdot C_f \tag{4.6}$$

The YED being identified for each house and each shape enables the assignment of risk classes to every shape. These risk classes play a pivotal role in distinguishing the premium in a risk-based manner. This research makes use of the classes Very High-risk, High-risk, Low-risk and No-risk, with the YED for the No-risk class being zero. To provide some insight into the data, Figure 4.4 illustrates the number of houses arranged in bins of €2.5, totalling at 5,051,645.

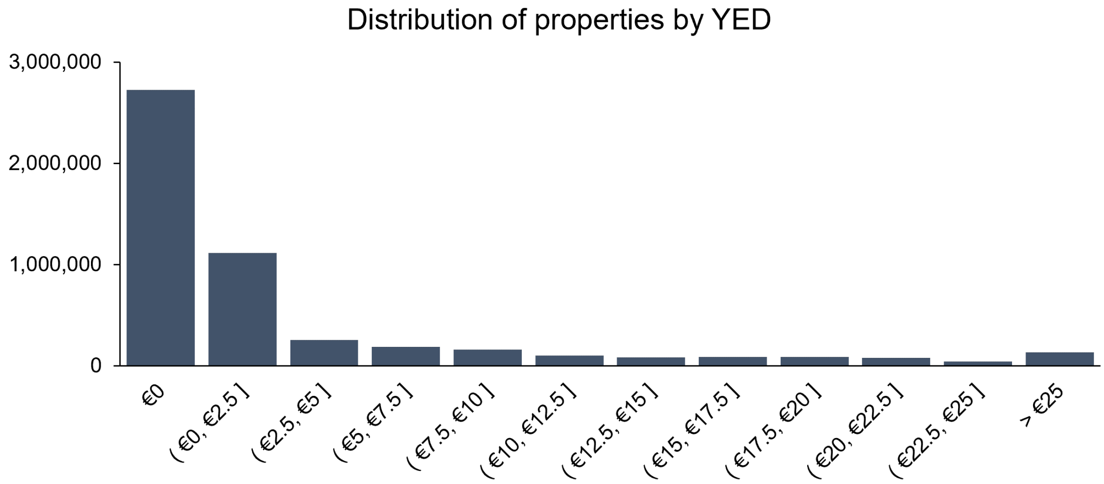


Figure 4.4: Distribution of properties by YED

The establishment of risk classes can be conducted in various ways. This research has opted to strive for a distribution in which the total quantity of yearly expected damage is equal across the three risk classes that possess some level of risk (thus excluding the No-risk class). Determining the boundaries for each risk class for the YED per house, which is derived from the YED per shape, requires an extensive iterative calculation. To maintain simplicity and conserve computing power, the bin sizes have been manually determined, with the goal of forming equal classes in terms of the total YED. The risk classes that result from this method are presented in Table 4.2 and visualised in Figure 4.5.

4.1.4. Maximum damage

The overall premium is composed of two elements: the cost of risk and the cost of insurance. The first, described by the actuarially fair premium, is driven by the risk of the contract holder. The latter, however, is influenced by the quantity of liquid assets an insurer must retain on its balance sheet as per regulatory guidelines. Section 4.2 provides a more detailed explanation regarding the rationale behind this and the nature of this capital. To discern how substantial this is, the maximum possible damage that can arise from an event is explored.

Calculating the maximum damage from an event is a complicated practice in which a set of assumptions has to be made. A straightforward strategy might involve totalling the costs

Table 4.2: Risk classes based on YED

Risk class	Min	Max	No. of prop. ('000)	% of prop.	Total YED ('000)	Average YED
Very high	35	∞	87	1.7	6,753	77.74
High	15	35	337	6.7	6,938	20.57
Low	0	15	1,902	37.7	6,981	3.67
No	-	-	2,725	54.0	-	-

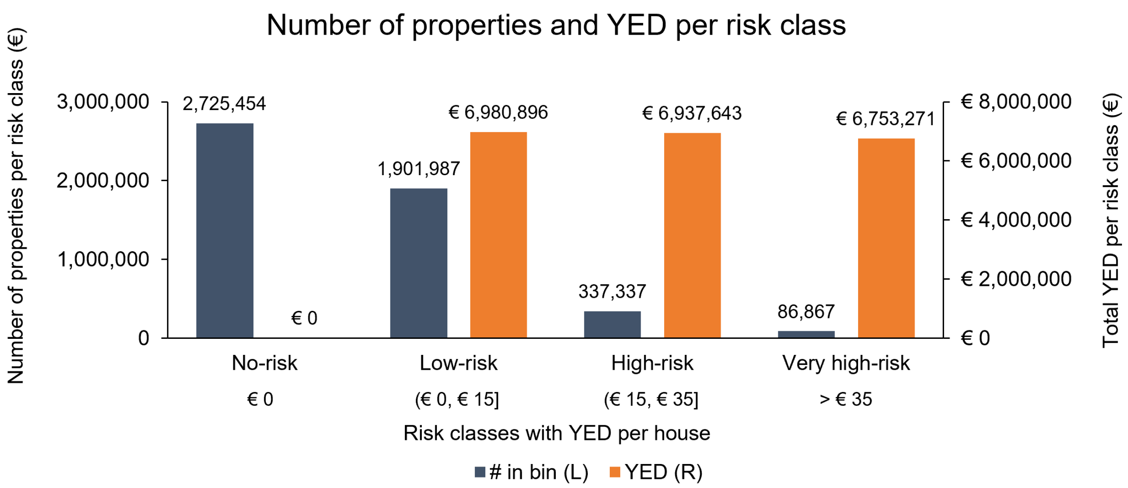


Figure 4.5: Number of properties and YED per risk class

from the most severe event, arguing that this cost represents the absolute maximum the environment has to account for. However, this method might generate a scenario in which the damage is so high and the probability so minuscule that insurers cannot practically depend on this information[2]. To establish differentiation between shapes, it is assumed that every region operates independently of others, thus forming independent events. Operating under this assumption means that the probability of two events occurring in a single year is the product of the inverse of their respective return periods.

To evaluate the validity of this assumption, it is important to explore the dynamics of how residential areas in the Netherlands are impacted by flooding. The country is divided into 58 designated ”dike-rings”; these are essentially low-altitude areas encased by primary flood defences. When an event unfolds, in this case the failure of a primary defence, a breach in one of these rings takes place, inundating the encompassed area. However, provided that no other breaches occur, the remaining 57 rings remain dry. In this assessment, eight distinct regions are identified. Based on the above, it can be concluded that our assumption of independence between regions is still conservative since only 8 regions are used compared to 58 dike rings. In more sophisticated premium calculations, it would be important to consider the impact and interactions of the various dike-rings.

The maximum damage event might consist of a year with multiple events that have a high probability and lower impact, or from a single event with a low probability and high impact. As

[2]For reference, with the current data this would lead to an event at which all of the Netherlands will flood with the maximum amount of impact, resulting in an event which has €170 billion worth of damage (to buildings and contents) and occurs once every $1 \cdot 10^{52}$ years

previously discussed, a minimal probability limit must be established, mandating the insurance industry to maintain the maximum damage amount in available liquid assets. To determine such a limit, the Solvency II directive of the European Union could be used as a reference, which outlines regulations for the insurance industry, including capital requirements. The Solvency II directive states that insurers are required to meet financial obligations for an event with a 200-year return period (European Parliament, Council of the European Union, 2009). However, due to the extraordinary nature of flood risk resulting from the failure of primary defences in the Netherlands, which is characterised by an exceedingly high return period, this limit is deemed insufficient for this exercise. Upon evaluation of the maximum damage for various return periods, the limit was set at a return period of 100,000 years. This assumption is deemed justifiable since, in all proposed solutions, the bulk of the capital requirements will be handled by the government, which generally pays little to no interest on its capital in this assessment (argumentation for this assumption is provided later on).

EU Solvency Capital Requirement

The following states the directive of Solvency II regarding capital requirements (European Parliament, Council of the European Union, 2009):

> *"In order to promote good risk management and align regulatory capital requirements with industry practices, the Solvency Capital Requirement should be determined as the economic capital to be held by insurance and reinsurance undertakings in order to ensure that ruin occurs no more often than once in every 200 cases or, alternatively, that those undertakings will still be in a position, with a probability of at least 99,5%, to meet their obligations to policyholders and beneficiaries over the following 12 months."*

The capital held (economic capital) should suffice to ensure that the company does not become insolvent - in more statistical terms, that "ruin" occurs no more frequently than once in 200 cases, or stated differently, the firm should be able to meet its obligations with a probability of at least 99.5% over the next 12 months. The 99.5% confidence level, or a 1 in 200-year event, is a statistical measure designed to ensure that these firms can absorb significant losses and still meet their obligations.

The maximum damage under a particular probability limit, as mentioned earlier, may not solely arise from a single event inflicting the highest damage. Instead, it might also emerge from multiple events each causing lower damages. To assess this, all combinations of yearly events for the 8 specified regions have been plotted, which involves summing the impact and multiplying the probability for n events, with n ranging from 1 to 8 representing the distinct regions. m marks the different return periods for which the combinations are calculated. This procedure results in a total of $2^n - 1 = 255$ combinations. All these combinations are plotted in Figure 4.6. In this figure, points are colour-coded based on their return period prior to adjustments for the correction factor, which is region-specific. The combined impact and probability are computed using Equations 4.7 and 4.8, respectively.

$$I_m = \sum_{i=1}^{n} I_{T_{n,m}} \tag{4.7}$$

$$P_m = \prod_{i=1}^{n} \left(\frac{1}{T_{n,m}} \right) \tag{4.8}$$

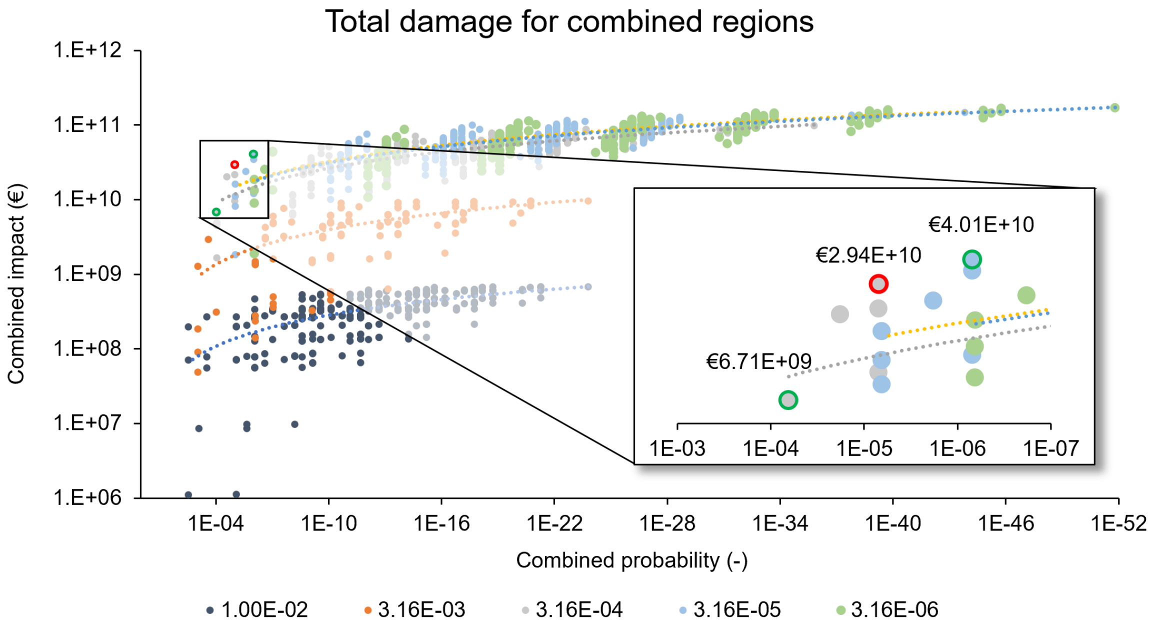


Figure 4.6: Total damage for combined regions

Looking at figure 4.6, and considering the previous limit set at 1 in 100,000 years, interest is drawn to points with a combined probability between $1 \cdot 10^{-4}$ and $1 \cdot 10^{-6}$. From this, three points stand out which are marked by green and red rings in the call-out box of the figure. As maximum damage figure, the point with the red ring has been deemed most useful, as it has a probability which is slightly lower than once every 100,000 years. The choice for this point as maximum damage figure is not necessarily scientifically based, but an essential assumption for the continuation of this method. The sensitivity of this assumption is significant and will be further discussed in Chapter 6. It has to be noted that the choice of which point to use is one of the policy maker, and not of the researcher.

Now, both the YED and the maximum damage are established, which will be utilised to compute the actuarially fair and insurance premiums across various solutions. The subsequent section will introduce the computational methods for deriving the premiums, after which different solutions will be introduced and the final premiums will be calculated.

4.2. Premium calculation

4.2.1. Definition and calculation

Combining the YED and maximum damage enables the determination of the premium calculation. Essentially, the premium for insurance in its fundamental form consists of two components; the expected loss on a contract and the cost of capital to underwrite the contract. In this report, these two components are split into the actuarially fair premium and the insurance premium. For the avoidance of confusion, a short explanation of the types of premiums used will be provided first.

In this context, the actuarially fair premium represents the exact amount an individual should pay to offset the expected loss they will incur, without taking into account risk distribution among other individuals or costs of (re)insurance. In other words, the premium is equal to the expected claims (Autor, 2016), thereby providing an accurate representation of the risk. This is occasionally referred to as the *pure premium* (Frees & Johnson, 2020). However, in order to be able to comment on differences between insurance solutions, and particularly the affordability for individuals, it is important to obtain the final insurance premium figure which individuals are required to pay. Therefore, the insurance premium is derived from the actuarially fair premium. First, in systems in which solidarity is present, a portion of the risk is distributed among other risk classes. Second, the costs of insurance are taken into account, resulting in a multiple which is applied to the actuarially fair premium to derive the insurance premium.

Calculating the actuarially fair premium is a relatively straightforward process. Simply dividing the yearly expected damage of a risk class, identified in the previous section, by the number of properties within that specific class ensures that the total premium amount aligns with the total amount of expected claims.

Now, to determine the insurance premium, the cost of capital to cover the contract has to be determined. The cost of capital refers to the financial burden borne by the insurer to maintain capital, which will be utilised in the event of a payout. To protect (re)insurers from failing in the wake of a substantial payout, and consequently safeguard the public, (re)insurers are obliged to meet certain solvency[3] requirements imposed by governments or other regulatory bodies (e.g. central banks). Investors supply this capital, which inherently carries associated costs (Kielholz, 2000). The cost of this capital is the expected rate of return insurers have to pay for the capital they use. This capital can consist of both equity and debt, but generally, equity is the largest portion of the capital structure. The rate of return is influenced by the demand and supply of capital in general and the risk the business is involved in. In addition to the rate of return on the investments, the insurers incur costs due to taxation and transaction costs (Kielholz, 2000).

However, (re)insurers will also use the capital on hand to make investments which generate returns on top of their premium income. In this evaluation, taxation and transaction costs are not considered, and it is presumed that the investment strategy of the (re)insurers aligns with inflation, thereby omitting both elements from the equation. Assumptions for the cost of capital are made for each respective system. To calculate the insurance premium, the sum of the expected loss and the cost of capital is divided by the expected loss, yielding the Insurance Premium Multiple. Here, the expected loss is the percentage of loss from the total covered amount, referred to as the covered loss. Equations 4.9 and 4.10 introduce the formulas for computing the insurance premium multiple and the expected loss, respectively. Finally, this multiple is applied to the actuarially fair premium to derive the concluding insurance premium.

$$\text{Insurance Premium Multiple} = \frac{\text{Expected Loss} + \text{Cost of Capital}}{\text{Expected Loss}} \tag{4.9}$$

$$\text{Expected loss} = \frac{\text{Yearly expected damage}}{\text{Covered loss}} \tag{4.10}$$

4.2.2. Cost of Capital assumptions

The main driver of the insurance premium is the cost of capital, as described above. In this section, assumptions are made for the CoC figure for the parties involved. The parties involved are Insurers, Reinsurers, Flood Re and the Dutch government.

1. **Insurers**

   For the insurance industry, a cost of capital of 8.30% will be used, derived from data obtained from NYU Stern (Damodaran, 2023). This figure is based on an average of CoC calculations for 17 property and catastrophe insurers located in Europe. Given that the risk is anticipated to be primarily covered by Dutch insurers, this European

[3] Solvency is the ability of a company to meet its long-term debt and financial obligations

figure was deemed reasonable, especially in the absence of a reliable figure specific to the Dutch market.

2. **Reinsurers**

   CoC for the reinsurance industry is assumed to be 6.92%, based on a publication by credit rating agency AM Best, which evaluates the global reinsurance market (AM Best, 2023a,b). Since reinsurance contracts will be sold globally to promote diversification, this assumption is justified.

3. **Flood Re**

   Since the newly formed entity Flood Re will be a public institution, it is assumed that it can access funds at a rate equal to that of the Dutch treasury, and thus the interest paid will be equal to that of a long-term Dutch treasury bond. The current yield on a 30-year treasury bond of the Netherlands at the time of writing is around 3% (DSTA, 2023; Investing.com, 2023). Looking at the yield of the past 25 years, this is considered fairly average.

4. **Government**

   Similarly to Flood Re, the Dutch government can access funds at the rate of treasury bonds. However, in this assessment, it is assumed that the Dutch government will not keep on separate funds in case of a catastrophe, but will issue these funds directly from its reserves in case of a catastrophe, while simultaneously entering the capital markets to replenish its losses. To account for this assumption, the cost of capital is set at 0%.

This concludes the examination of the workings of the model and the introduction of general assumptions. The following section introduces four distinct solutions, which will receive more comprehensive explanations in Chapter 5. Assumptions for each system are made and consequently, the actuarially fair premium and insurance premium are calculated. An assessment of these premiums will be conducted in Chapter 5.

4.3. Solutions

4.3.1. Wts+

Formulating the risk and insurance premium for the Wts+ system is relatively straightforward. This solution results in compensation by the government of the entire damage curve through the Wts. The difference is that insurers will serve as the initial contact for individuals in the event of a large flood. This means that in the event of a flood, individuals with damage can apply for reimbursement through their regular insurer. The insurers, in turn, will utilise funds from the Wts to reimburse their clients. The insurers do not carry any risk in this way.

This structure means that the ”premium” will be in the form of additional taxes which the government will levy on homeowners. The damage is capped at the maximum damage event. Compensation for the handling costs to insurers will be 5% of the actuarially fair premium income per year, which translates to approximately €1 million per year.

Calculating the actuarially fair premium becomes a straightforward step of dividing the total expected yearly damage by the total number of houses in the Netherlands. Since the cost of capital for the Wts is assumed to be 0.0%, no extra costs are incurred to maintain capital, making the insurance premium multiple 1.0x. By employing the insurance premium multiple and accounting for the handling costs compensation to insurers, the insurance premium, detailed in Table 4.5, is calculated.

Assumptions

- Flat premium (tax) for all homeowners covering damage from €0 up to maximum damage event
- Cost of capital of Wts layer of 0.0%
- Compensation for insurers of handling costs of 5% of risk premium per year

Table 4.3: Wts - Covered loss and expected damage

	Layer size (€mm)	YED (€mm)
Wts layer	29,370	21
Total	29,370	21

Please not that €mm equals Euros in millions, and €bn equals Euros in billions. For more abbreviations please refer to the Nomenclature.

Table 4.4: Wts - Insurance premium multiples

Layer	Wts
Expected loss (%)	0.07
Cost of capital (%)	0.00
Premium (%)	0.07
Multiple	**1.0x**

Table 4.5: Wts - Actuarially fair and insurance premiums

	Actuarially fair pr. (€)	Insurance pr. (€)
Wts layer		
All risk classes	4.09	4.30
sum premium income (€mm/y)	*21*	*22*

4.3.2. Included in home policies

Implementing a solution that mandates the incorporation of flood insurance into home policies (like the Belgian system) establishes a two-layer model, involving an insurance layer and a Wts layer. The insurance layer covers damage from €0 up to €1 billion and distributes its premium according to a risk-based structure. Meanwhile, the Wts layer accounts for damage from €1 billion up to the maximum damage event, with premiums for the Wts layer gathered through household taxes (similar to the approach in section 4.3.1). Based on Insurance Europe (2022), it is assumed that the penetration rate of home insurance is 98% among private individuals, which is evenly distributed between risk classes.

The YED is determined by calculating the area under the damage curve for each layer, as detailed in Table 4.6. The YED is divided by the number of houses in each risk class, yielding the actuarially fair premium per individual. For the Wts layer, the YED is divided by the total number of houses, and the aggregate of both layers is used to determine the overall actuarially fair premium per property.

The insurance premium multiple is calculated using formulas 4.9 and 4.10, with the cost of capital for insurers presumed to be 8.30%. Similarly to section 4.3.1, the cost of capital for the Wts is assumed to be 0.0%. Tables 4.7 and 4.8 present the insurance premium multiples, the actuarially fair premium, and the insurance premium.

Assumptions

- Insurance layer covering damage from €0 up to €1bn, risk-based
- Flat premium (tax) for all homeowners covering damage from €1bn up to maximum damage event
- Home insurance penetration rate of 98%, evenly distributed between risk classes
- Cost of capital of Insurance layer of 8.30%
- Cost of capital of Wts layer of 0.0%

Table 4.6: Included in home policies - Covered loss and expected damage

	Layer size (€mm)	YED (€mm)
Insurance layer	1,000	6
Wts layer	27,782	14
Total	28,782	20

Table 4.7: Included in home policies - Insurance premium multiples

Layer	Insurance	Wts
Expected loss (%)	0.63	0.05
Cost of capital (%)	8.30	0.00
Premium (%)	8.93	0.05
Multiple	**14.3x**	**1.0x**

Table 4.8: Included in home policies - Actuarially fair and insurance premiums

	Actuarially fair pr. (€)	Insurance pr. (€)
Insurance layer		
Very high-risk	36.92	527.08
High-risk	3.38	48.25
Low-risk	0.76	10.81
No-risk	-	-
Wts layer		
All risk classes	2.77	2.77
Total		
Very high-risk	39.70	529.85
High-risk	6.15	51.03
Low-risk	3.53	13.58
No-risk	2.77	2.77
sum premium income (€mm/y)	*20*	*105*

4.3.3. Risk pool

The subsequent solution involves establishing a risk pool that encompasses insurers, reinsurers, and the Dutch government – through the Wts – leading to a three-layer model. The insurance layer addresses damages ranging from €0 to €1 billion and allocates its premium based on a risk-oriented structure. The reinsurance layer, while also distributing the actuarially fair premium in a risk-based manner, covers damages from €1 billion to €3 billion. Ultimately, the Wts layer takes responsibility for damages from €3 billion up to the maximum damage event.

Since this solution does not include mandatory inclusion, assumptions of the adoption rate have to be made. Firstly, it is assumed that 60% of households will hold a mortgage (Nederlandse Vereniging van Banken, 2022) and that all mortgage lenders mandate individuals who have some degree of flood risk to take out flood insurance.

In scenarios concerning households without a mortgage, assumptions are speculative due to a lack of reliable data. It is suggested that individuals facing higher premium costs might be less inclined to opt for insurance. Consequently, the adoption rates amongst non-mortgage households are assumed at 10%, 30%, and 90% for Very High-, High-, and Low-risk individuals, respectively. This results in total adoption rates of 64%, 72%, and 96% for Very High-, High-, and Low-risk households, respectively, and an aggregate rate of 90% (excluding No-risk households). It is assumed that No-risk individuals are not required by mortgage lenders to take out flood insurance and that 0% of the No-risk individuals with or without a mortgage choose to obtain flood insurance. Adjustments are made to the size of the Wts-layer in alignment with the adoption rate, resulting in a reduced total covered loss compared to the previously calculated maximum damage.

Calculation of the YED is similar to the approach used before and is presented in table 4.9. The actuarially fair premium for both the insurance and reinsurance layers is computed by dividing the yearly expected damage by the number of individuals within a risk class who have opted for flood insurance.

The calculation of the insurance premium multiple for all layers is similar to the approach used in the preceding solutions. The cost of capital used for the insurance layer is 8.30%. The cost of capital for the reinsurance layer is 6.92%. Similar to the approach of the previous solutions, the cost of capital for the Wts layer is 0.0%.

The insurance premium multiples, the actuarially fair premiums and the insurance premiums are outlined in tables 4.10 and 4.11.

Assumptions

- Insurance layer covering damage from €0 up to €1bn, risk-based
- Reinsurance layer covering damage from €1bn up to €3bn, risk-based
- Flat premium (tax) for all homeowners covering damage from €3bn up to maximum damage event
- Adoption rate of 64%, 72% and 96% among very high-, high- and low-risk properties, respectively, totalling at 90%
- Cost of capital of Insurance layer of 8.30%
- Cost of capital of Reinsurance layer of 6.92%
- Cost of capital of Wts layer of 0.0%

Table 4.9: Risk pool - Covered loss and expected damage

	Layer size (€mm)	YED (€mm)
Insurance layer	1,000	5
Reinsurance layer	2,000	3
Wts layer	22,556	8
Total	25,556	16

Table 4.10: Risk pool - Insurance premium multiples

Layer	Insurance	Reinsurance	Wts
Expected loss (%)	0.50	0.17	0.03
Cost of capital (%)	8.30	6.92	0.00
Premium (%)	8.80	7.09	0.03
Multiple	**17.7x**	**40.9x**	**1.0x**

Table 4.11: Risk pool - Actuarially fair and insurance premiums

	Actuarially fair pr. (€)	Insurance pr. (€)
Insurance layer		
Very high-risk	37.97	671.88
High-risk	3.75	66.35
Low-risk	0.84	14.95
No-risk	-	-
Reinsurance layer		
Very high-risk	10.78	440.42
High-risk	3.83	156.13
Low-risk	0.92	37.71
No-risk	-	-
Wts layer		
All risk classes	1.50	1.50
Total		
Very high-risk	50.25	1,113.79
High-risk	9.07	223.97
Low-risk	3.27	54.16
No-risk	1.50	1.50
sum premium income (€mm/y)	*16*	*307*

4.3.4. Flood Re

The Flood Re solution, as presented here, encompasses a three-tier model: an insurance layer, a Flood Re layer, and a Wts layer, presenting the most intricate solution among those offered in this report.

Under this scheme, it is assumed that all individuals with a mortgage and at some form of risk of flooding are mandated by their mortgage lender to secure flood insurance. The penetration rate for mortgages is set at 60%. Moreover, for non-mortgage holders, the insurance penetration rate assumes values of 50%, 60%, and 70% for Very high-, High-, and Low-risk individuals respectively. This cascades into a total penetration rate of 80%, 84%, and 88% for each risk category respectively. It is also presumed that none of the No-risk individuals opt for flood insurance.

The deviation in penetration rate, when compared to the Risk Pool solution, is derived from the solidarity within this solution, where low-risk individuals subsidise their high-risk counterparts. Therefore, it is expected that a larger number of high-risk and a smaller number of low-risk insurance contracts will be taken out.

As is explained in section 3.1, with Flood Re in the UK, all individuals are able to take out flood insurance with a regular insurer. The insurer can then decide which portion of the risk to cede to Flood Re. Importantly, all residential insurers contribute to Flood Re through a levy, which, when combined with collected premiums, provides the income required to manage Flood Re's assumed risk. This exercise tries to mimic this system in a simplified form.

The assumption is made that the insurance layer provides coverage for damages ranging from €0 to €1 billion. Additionally, it is presumed that all risks relating to individuals in the Very high-risk class are automatically transferred to the second layer, namely the Flood Re layer. This implies that insurers will exclusively cover individuals in the High- and Low-risk classes. All damage related to Very high-risk individuals will be covered by Flood Re. Meanwhile, the Wts layer will manage the remaining damage up to the maximum damage event. The yearly expected damage for each layer is calculated similarly as in previous systems, by calculating the surface underneath the damage curve of each layer. The layer sizes and yearly expected damage are presented in table 4.12.

The premium income from the insurance layer will derive from the yearly expected damage of individuals in the corresponding layer, similar to other systems that involve an insurance layer. The premium is fully risk-based, which implies that the amount of yearly expected damage is divided by the number of individuals in the risk class who have opted for insurance. In calculating the actuarially fair premium, a similar approach is applied to the Flood Re layer. The total sum of yearly expected damage is divided by the number of individuals in the Very high-risk class. Lastly, the entire amount of yearly expected damage in the Wts layer is distributed among all individuals in the environment, as this will be levied as a tax. The resulting actuarially fair premiums are presented in table 4.14.

Next, an intermediate step is taken in which the insurance premium – without solidarity – is calculated. To determine the insurance premium multiples, assumptions regarding the cost of capital have to be made. For the cost of capital of the insurance layer, the same approach as in the previous sections is utilised, resulting in a cost of capital of 8.30%. Following this, the Netherlands 30-year treasury bond yield of 3.0% is employed as the cost of capital for the Flood Re layer, as explained in section 4.2.2. The insurance premium multiples are calculated using Equations 4.9 and 4.10. Ultimately, the insurance premium multiple is applied to the actuarially fair premium to determine the insurance premium of the Flood Re system, excluding solidarity considerations. The insurance premium multiple and the insurance premiums of the Flood Re system are presented in Tables 4.13 and 4.14.

Nevertheless, the actuarially fair premium is distributed among participants in the system to create a solidarity mechanism. This results in lower premiums for Very high-risk individuals and higher premiums for other participants. To derive an insurance premium, an additional step is executed. First, a levy is imposed by Flood Re on all home insurers, which is then distributed among their policyholders. The levy is assumed to be €25.00 per year for all individuals in possession of flood insurance and is indirectly levied by Flood Re in the Flood Re layer. For the computation of the Flood Re layer, it is presumed that *if* the initial total amount of levy income surpasses the total yearly expected damage of the Flood Re layer (that is, the yearly expected damage of the Very-high risk class), a discount is applied to the levy. Moreover, it is stated that if the premium of the Very high-risk class is lower than the premium of one of the other classes due to the levy income, the premium will be set equal to the highest premium paid by one of the other classes. Practically, this will always be the High-risk class. Finally, to account for this effect, an additional discount is integrated, which distributes the additional premium income (accrued in the event that the Very high-risk premium is set equal to the High-risk premium) among all individuals. The resultant combined levy discount is presented in Formula 4.11.

$$LD = \min\left(\frac{YED_{FR} - LI_{total}}{N_{total}} - \max(P_I) \times \frac{N_{VH}}{N_{total}}, 0\right) \tag{4.11}$$

Where

LD = Levy discount
LI_{total} = Total levy income
YED_{FR} = Yearly expected damage Flood Re layer
N_{total} = Total amount of individuals which took out flood insurance
N_{VH} = Amount of Very high-risk individuals which took out flood insurance
P_I = Premium insurance layer

Next, the discount is applied to the premiums in the Flood Re layer in the ultimate step. The premium for the Very high-risk individuals is adjusted based on whether it is equalised to the High-risk insurance layer premium or not. As described above, this is determined by the question of whether the Very high-risk premium is lower than the High-risk premium or not. The premium calculation for the High- and Low-risk classes is more straightforward, consisting of both the levy and the discount. The Flood Re premium for the Very high-risk class is presented in Formula 4.12, while the premium for the High- and Low-risk classes is presented in Formula 4.13. Given that the No-risk class does not take out insurance, they do not contribute any premium to Flood Re. Finally, the total amount of insurance premium to be paid is calculated by summing the insurance layer, the Flood Re layer and the Wts layer. The concluding step is presented in Table 4.14.

$$P_{FR,VH} = \max\left(\frac{YED_{FR} - LI_{total}}{N_{VH}}, \max(P_I) + LD\right) + L \tag{4.12}$$

$$P_{FR,H,L} = \min(L + LD, L) \tag{4.13}$$

Where

LD = Levy discount
LI_{total} = Total levy income
L = Levy
YED_{FR} = Yearly expected damage Flood Re layer
P_I = Premium insurance layer
$P_{FR,VH}$ = Premium insurance layer, Very high-risk class
$P_{FR,H,L}$ = Premium insurance layer, High- and Low-risk class

Assumptions

- Insurance layer covering damage from €0 up to €1bn, risk-based
- Reinsurance through Flood Re for all damage of Very high-risk individuals
- Flat premium (tax) for all homeowners covering damage from €1bn up to maximum damage event of non-Very high-risk individuals
- Adoption rate of 80%, 84% and 88% among very high-, high- and low-risk properties, respectively, totalling at 87%
- Levy is only paid by individuals who take out insurance
- The final premium of a risk class can never be lower than the final premium of a risk class that holds lower risk
- Cost of capital of Insurance layer of 8.30%
- Cost of capital of Flood Re layer of 3.00%
- Cost of capital of Wts layer of 0.00%

Table 4.12: Flood Re - Covered loss and expected damage

	Layer size (€mm)	YED (€mm)
Insurance layer	1,000	3
Flood Re layer	1,975	5
Wts layer	22,373	9
Total	25,348	17

Table 4.13: Flood Re - Insurance premium multiples

Layer	Insurance	Flood Re	Wts
Expected loss (%)	0.30	0.27	0.04
Cost of capital (%)	8.30	3.00	0.00
Premium (%)	8.60	3.27	0.04
Multiple	**28.4x**	**12.0x**	**1.0x**

Table 4.14: Flood Re - Actuarially fair and insurance premiums

	Actuarially fair pr. (€)	Insurance pr. w/o solidarity (€)	Insurance pr. (€)
Insurance layer			
Very high-risk	-	-	-
High-risk	4.14	117.58	117.58
Low-risk	0.94	26.62	26.62
No-risk	-	-	-
Flood Re layer			
Very high-risk	70.94	848.94	207.64
High-risk	-	-	25.00
Low-risk	-	-	25.00
No-risk	-	-	
Wts layer			
All risk classes	1.77	1.77	1.77
Total			
Very high-risk	72.71	850.71	209.64
High-risk	5.91	119.35	144.35
Low-risk	2.71	28.39	53.39
No-risk	1.77	1.77	1.77
sum premium income (€mm/y)	*17*	*160*	*160*

4.4. Summary

An overview of the most important figures of this chapter is presented below. The meaning and context of these figures are discussed in Chapter 5. Table 4.15 provides a summary of the premiums, YED, premium income and the multiple of the premium income over the YED. Figure 4.7 provides a visualisation of the covered damage for each layer.

This concludes the calculation of the actuarially fair and insurance premiums of the four insurance solutions introduced in Chapter 3, and provides an answer to the third research question: *How does the premium evolve for four different insurance solutions?*

Table 4.15 demonstrates that the features and assumptions of the different systems create distinct premium structures, with different associated costs. For instance, it is seen that the cost of insurance for the Risk pool structure is 19x higher than the risk of all individuals, which is a massive difference from the 1.1x multiple associated with the Wts+ structure. These differences will be further highlighted and commented on in Chapter 5, together with the results from the EJA from Chapter 3.

Finally, Chapter 6 will discuss the assumptions made in this chapter and provides recommendations for future research.

Table 4.15: Summary of retrieved premiums

	Wts+	Home policies	Risk pool	Flood Re
Actuarially fair premium				
Very high-risk	4.09	39.70	50.25	72.71
High-risk	4.09	6.15	9.07	5.91
Low-risk	4.09	3.53	3.27	2.71
No-risk	4.09	2.77	1.50	1.77
A *Expected loss (€mm/y)*	*21*	*20*	*16*	*17*
Insurance premium				
Very high-risk	4.30	529.85	1,113.79	209.41
High-risk	4.30	51.03	223.97	114.35
Low-risk	4.30	13.58	54.16	53.39
No-risk	4.30	2.77	1.50	1.77
B *Sum premium income (€mm/y)*	*22*	*105*	*307*	*160*
Multiple (B/A)	**1.1x**	**5.2x**	**19.2x**	**9.2x**
Covered loss (€bn)	29.4	28.8	25.6	25.3

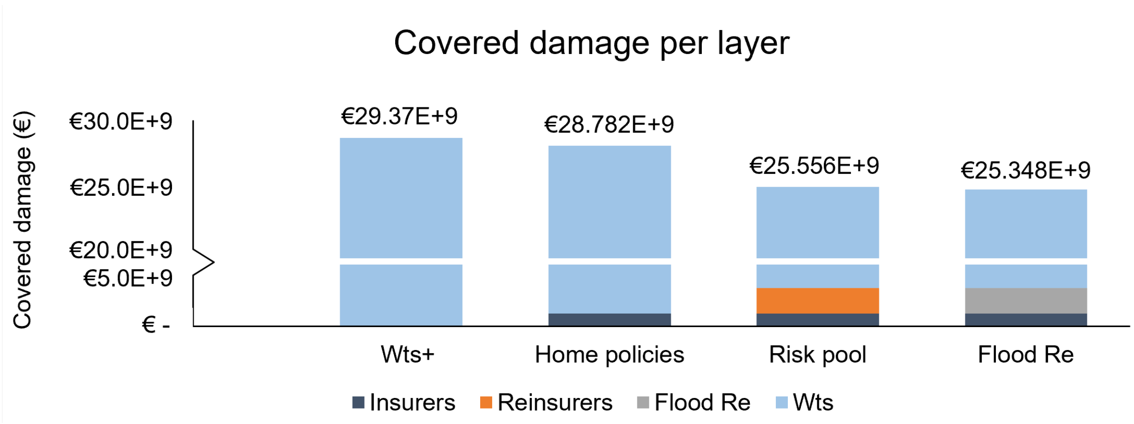


Figure 4.7: Covered damage per layer

5 Application to proposed solutions

This chapter undertakes a comprehensive evaluation of the four solutions introduced in Section 3.3, assessing their robustness against the failure mechanisms previously identified and commenting on the associated insurance premiums of different risk groups. To determine the impact of the failure mechanisms – which were laid out in Chapter 2 – the information gathered from the Expert Judgment Analysis conducted in Chapter 3 is used. The premium derivation performed in Chapter 4 is used to evaluate the financial impact a solution has on the system.

The evaluation of each solution unfolds in a structured manner, starting with an introduction to establish the context, followed by an analysis of the relevant EJA results. Next, a proposed structure is outlined, closed off by a conclusion discussing the advantages and disadvantages of each solution.

By employing this analytical approach, Chapter 5 aims to provide an answer to the fourth and final sub-research question: *What are the advantages and disadvantages of potential insurance solutions covering flooding in the Netherlands?*

5.1. Wts+

The Netherlands has historically been a country where a lot is done to protect its inhabitants from flooding from the sea, lakes and rivers, and is still considered one of the most advanced countries on the subject of flood protection, implementing advanced solutions, regulations and structures to protect the hinterland. The Wts is the current system in place concerning compensation for flood-induced damage resulting from the failure of primary flood defences. As explained in Sections 1.2 and 3.1.5, the *Wet tegemoetkoming schade bij rampen* (Wts) (English: Disaster damage compensation law) prescribes that individuals and businesses can apply for compensation of damage to their property, possessions, and loss of income due to flooding of fresh water, earthquakes or similar major accident. However, they can only apply for a claim if the government decides that the event qualifies as such. The law prescribes a lower limit to these natural disasters, excluding small floods and earthquakes. In addition, the damages caused by the disaster have to be unable to insure or avoid in order to claim disbursement through the Wts. Finally, the amount of disbursement is capped at an amount determined by the Dutch state, and it is important to note that the disbursement is never a full compensation for the damage suffered.

The first solution proposed in this chapter entails a modified version of the current Wts, which is named the Wts+. As will be outlined in Section 5.1.2, insurers will hold the role of claims handler in this system, for which they are compensated, while the government – through the Wts – will hold all the risk. Similar to an insurance contract, the terms under which the insurers provide reimbursement is drafted up to provide a more transparent process. This includes flooding caused by both fresh- and saltwater.

The following sections will discuss the results of the EJA with regard to the Netherlands, lay out the proposed structure of the solution and finally provide a conclusion in which the pros and cons of the Wts+ solution are discussed.

5.1.1. Expert Judgment Analysis

To assess the outcomes of the EJA with respect to the Wts+, a thorough examination of the data relating to the Netherlands is conducted. The existing framework in this country – which is the Wts – is used as a reference.

From Figure 5.1, two mechanisms stand out due to their high scores (high impact) and limited spread: Cumulative risk and Charity hazard. On the other hand, mechanisms such as Risk perception, Adverse selection, and Moral hazard yield relatively lower scores, which indicates a low impact of a failure mechanism. However, it is crucial to consider the extent of their dispersion: since Risk perception and Adverse selection possess considerable spread, only the impact of Moral hazard is taken into account.

As was discussed in section 3.2.4, this research argues that the expert panel occasionally misinterpreted the objectives of certain questions. This interpretation issue also applies to Cumulative risk in the Netherlands. From an insurance perspective, the Netherlands is significantly vulnerable to Cumulative risk, given that flooding is likely to have substantial consequences due to the country's low and flat terrain. This significantly impacts insurers with a substantial exposure to flood-prone areas. However, concerning the Wts/Wts+, the impact of Cumulative risk is mitigated since the government covers all individuals in the Netherlands at the same time, thereby dispersing the risk nationwide.

Furthermore, Charity hazard scores high with relatively limited variability as observed in the EJA results depicted in Figure 5.1. This aligns with this research as the presence of governmental financial protection tends to discourage individuals from proactively mitigating potential damage. This assumption finds resonance in comments made by the expert panel members. It is also noteworthy that within this context, Moral hazard takes the form of Charity hazard.

5.1.2. Proposed structure

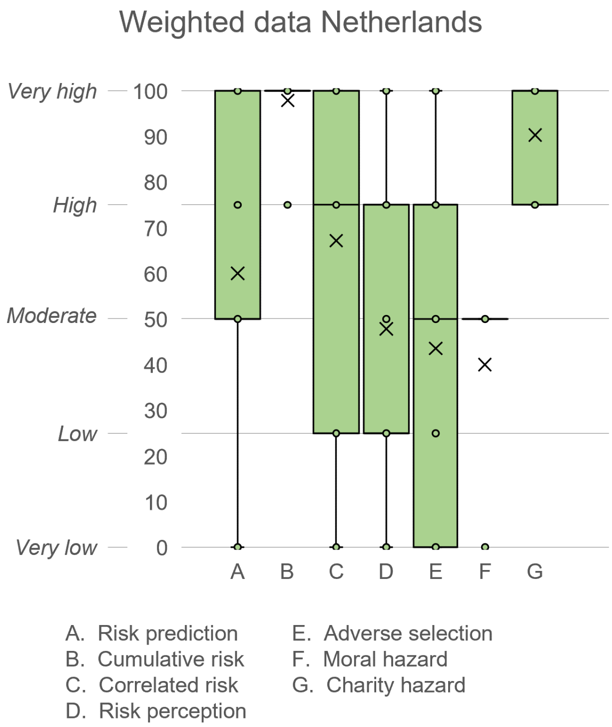
Similar to the structure presented in Section 4.3.1, the design of the Wts+ structure is a refined version of the existing system with an operational role for insurers. As previously discussed, the Wts system offers compensation for damages that are considered uninsurable. The Wts provides financial support to victims of natural disasters, including flooding caused by the failure of primary flood defences. However, the law explicitly excludes compensation for saltwater flooding, which is deemed undesirable.

Another aspect that requires consideration is the absence of a clear structure or process for distributing these funds to the affected individuals. At present, the coordinating responsibility lies with the Ministry of Justice and Security, and the executing role with the Netherlands Enterprise Agency. The Wts allows for customisation based on the (type of) disaster that occurs. It appeared during the aftermath of the 2021 Limburg floods, partly for this customisation argument, that not much had been formally documented regarding the process to be followed (Van Helmond et al., 2023). The lack of a clear structure could lead to a chaotic situation during and after a major flood event, which, in itself, is already a stressful and overwhelming experience for those affected. For instance, in the aftermath of the 2021 Limburg floods, it was not clear who was responsible for certain tasks like mapping the damaged area (Van Helmond et al., 2023).

Netherlands	Average	Mean
Risk predictability	60.00	62.57
Cumulative risk	97.86	72.59
Correlated risk	67.14	62.12
Risk perception	47.86	52.70
Adverse selection	43.57	34.42
Moral hazard	40.00	53.35
Charity hazard	90.32	56.35
Mean	63.82	56.30

Netherlands	Standard dev.	Mean
Risk predictability	30.59	22.78
Cumulative risk	7.00	19.07
Correlated risk	32.06	22.81
Risk perception	31.83	22.73
Adverse selection	37.01	21.31
Moral hazard	20.00	20.95
Charity hazard	12.18	23.30
Mean	24.38	21.85

(a) Average and standard deviation round 2 weighted data, Netherlands and mean of all systems



(b) Box-whisker plot round 2 weighted data, Netherlands

Figure 5.1: Expert Judgment Analysis results Netherlands

Besides a clear manual which states the responsibilities of the involved intuitions, a transparent set of conditions under which affected individuals are eligible for reimbursement is desirable. Van Helmond et al. (2023) concluded that the biggest area for improvement concerns communication and information provision towards affected individuals, businesses and authorities. These stakeholders noted a lack of clarity about what the Wts entails and what to expect. Van Helmond et al. (2023) states that a single point of contact for those affected could contribute to efficient information provision. This is incorporated in the Wts+ structure as insurers will function as the single point of contact.

In this structure, the Wts will be amended such that it covers all damage stemming from the failure of primary flood defences, regardless of whether it relates to salt or freshwater damage. This would necessitate the creation of a comprehensive set of clauses, similar to those in insurance policies, which would specify the types of damages covered, the exclusions, and the conditions under which claims can be made. Moreover, building and content insurance providers will act as intermediaries for claim processing. This means that they serve as the primary contact for individuals who have sustained damages and seek reimbursement, even though they do not bear any of the associated risks. These insurance companies will handle and disburse claims, and will be reimbursed in full by the government via the Wts for the amounts they disbursed. Insurers will be compensated annually for this service, of which the amount is based on a percentage of the yearly expected damage.

Based on the assumptions and computations detailed in Section 4.5, a yearly additional tax of €4.30 is to be levied on all homeowners. This levy is designed to offset the annual expected damage in the Netherlands and to provide compensation for insurers. The relatively low figure, when compared to other schemes, can be attributed to two primary factors. First, the assumption that the Dutch government will not maintain extra reserves for flood risk means that the insurance premium becomes the actuarially fair premium. This is because the insurance premium is driven by the cost of capital, but without capital in the system the cost of this capital virtually becomes zero. This assumption is discussed below in *Zero per cent cost of capital*. Second, the equal distribution of the YED over all homeowners in the Netherlands creates a system with maximum solidarity, meaning that individuals collectively pay for flood insurance, and the amount people contribute is independent of their risk. In financial terms, the sum of the premium income, which serves as a metric for the societal costs of the solution, amounts to €21.71 million annually. This is substantially less than other solutions which will be discussed in this chapter.

> Zero per cent cost of capital
>
> An important assumption made in Chapter 4 is that the government, via the Wts, will not maintain capital reserves for its solvency requirements. Instead, it is assumed that during a significant flood event, the Dutch state would use existing reserves and simultaneously enter the capital market by issuing sovereign debt to cover its costs. To put this into perspective, the covered damage by the Wts will be compared to the Dutch state's budgetary and debt positions.
>
> In Section 4.3.1, it was determined that the size of the Wts layer would account for a total of €29.4 billion in the Wts+ structure. Should the worst-case scenario occur – an event with a return period of 100,000 years – then the entire sum would be allocated for relief and rebuilding efforts among the affected households. To put this in the context of national finances, the Dutch State's total net expenses in 2022 was €351.5 billion (Dutch Ministry of Finance, 2023). This means that such an expenditure would be approximately 8.4% of the annual national budget. Since it is assumed that at least a substantial portion of the expenses will be covered by issuing debt, it is interesting to look at the impact on the sovereign debt level.
>
> As of year's end 2022, the Netherlands had €480.1 billion of outstanding debt, amounting to 51.0% of its Gross Domestic Product (GDP) of €941.2 billion (Dutch Ministry of Finance, 2023). If it is assumed that the damage resulting from a flood would be entirely financed by newly issued debt, this would raise its sovereign debt level to €509.4, or 54.1% of its 2022 GDP. While this increase of 3.1% is substantial, its debt-to-GDP ratio is still well below the 60% aim of the EU, and even lower compared to the EU and Eurozone averages of 83.8% and 91.4%, respectively (Eurostat, 2023). This further reinforces the assumption that the government will not hold extra reserves specifically for the insurance mechanisms proposed in this chapter.
>
> That said, it is important to note that this financial framework only regards residential buildings and contents insurance. In the event of a large-scale flood, the Dutch state would also need to address a host of additional expenses related to public buildings, infrastructure, and economic zones, which would put additional pressure on the capital ratio.

5.1.3. Conclusion

The supplementary income generated from taxes, which can be levied through various taxation methods, is considered affordable at €4.30 per year per household (advantage 1) (Section 4.3.1). This results in a total premium income of €21.71 million per year, which is the most economical of all four solutions, thus having the lowest societal impact from a financial point of view.

Furthermore, with the government as the only distributor of reimbursement, it is incentivised to consistently invest in flood protection measures (2), reducing the potential for significant, unexpected payouts. By being responsible for both investing in flood protection and compensation of flood damage, the government can act according to a cost-benefit analysis of both duties.

Additionally, since the premium is collected via taxation, it ensures universal participation, effectively eliminating the possibility of adverse selection (3). Moreover, due to the passive character of the system (no active participation since it is regarded as a law), the coverage ratio is 100% (4), eliminating the need to install an additional arrangement for uninsured individuals like in other solutions.

Finally, the lack of reinsurers in this system prevents a (large) capital outflow of insurance money from Dutch individuals to foreign reinsurance companies (5). This is a beneficial aspect from a governmental point of view.

On the other hand, mandatory inclusion means that those without any flood risk are subsidising those at risk (disadvantage 1). This could lead to opposition from individuals living in areas without any flood risk as they perceive this extra tax to be unfair. The risk that they have is not represented by the extra tax have to pay. However, this is somewhat mitigated by the fact that the additional tax income can be levied through different methods in a way that individuals do not perceive that they are paying a premium.

Additionally, through mandatory inclusion, there is no incentive for individuals to move to areas with low or no risk of flooding (2) since the risk they have is not represented by the amount of reimbursement. This is unbeneficial in the long term, especially considering rising sea water levels and increasing frequency of extreme precipitation events, as explained in Chapter 1.

Moreover, a system with mandatory inclusion stimulates the risk of moral (charity) hazard (3), as explained in Section 2.5. A common method to mitigate moral hazard used by insurers is to award premium discounts to individuals who actively mitigate their (flood) risk. However, the government lacks the leverage that insurers possess to mandate residents to undertake flood mitigation measures since there is no premium. The inclusion of an insurance layer in the other solutions reduces moral hazard.

Finally, it should be noted that it was assumed that there are no costs of capital involved in the Wts layer, which is an assumption open to debate. This will be further discussed in Chapter 6.

Advantages

1. Affordable risk premium for all individuals
2. Incentive for the government to invest in flood protection
3. No adverse selection
4. 100% coverage
5. No capital outflow to foreign reinsurance companies

Disadvantages

1. No-risk individuals have to pay for the risk of high- and very high-risk individuals which could lead to resistance
2. No incentive to live in areas with low or no risk of flooding
3. Very high risk of charity hazard

5.2. Mandatorily included in home policies

An alternative approach could involve the compulsory inclusion of a clause covering flood damage in building and contents insurance policies offered by insurers, somewhat similar to the current situation in Belgium, as discussed in Section 3.1.3.

It is debatable whether this surcharge should be flat or risk-based. To provide a boundary, the mandatory surcharge discussed here will have a risk-based premium. Risk-based premiums are inherently designed to reflect the level of risk associated with an individual or property. As a result, high-risk individuals may face significantly higher premiums, sometimes to the point of being unaffordable.

The establishment of extremely high premiums was countered in the Belgian system by installing a cap on the maximum premium an insurer can ask to an individual. The additional premium income to cover the risk is collected through home insurers collectively. This system shows similarities with Flood Re, which will be further discussed in section 5.4.

5.2.1. Expert Judgment Analysis

Within the scope of the EJA, the system bearing the closest resemblances to the proposed scheme is found in Belgium, where flood damage is mandatorily included in fire insurance. As can be seen in figure 5.2, high-scoring failure mechanisms were Risk predictability, Cumulative risk, Correlated Risk and Risk perception, of which Risk perception is discarded due to the considerable spread in the responses. On the other hand, Adverse selection depicts a low score with minimal variability, indicating a more positive aspect.

Similar to the situation in the Netherlands, predicting flood risk in Belgium is notably difficult. This complexity arises from the infrequent but high-impact nature of flooding events in the country. Of the five examined countries, the expert panel ranked the Belgian system second highest in terms of Risk predictability, trailing only the US by a slight margin.

> Expert Judgement Analysis: Risk predictability in Belgium
>
> In the Expert Judgment Analysis, Mr Gabriel noted the following with regard to risk predictability in Belgium:
>
> > *“Following the July 2021 flood event, it became evident that the Belgian insurance industry was unable to cover all the costs and had underestimated the potential damage from a major flood. A one-time solution was implemented to indemnify policyholders through the insurance companies, with funding provided by both the governments and the insurance industry. However, to date, no new legislation has been enacted to address this issue, leaving policyholders, the insurance industry, and regional governments at risk in the event of a similar occurrence.”*

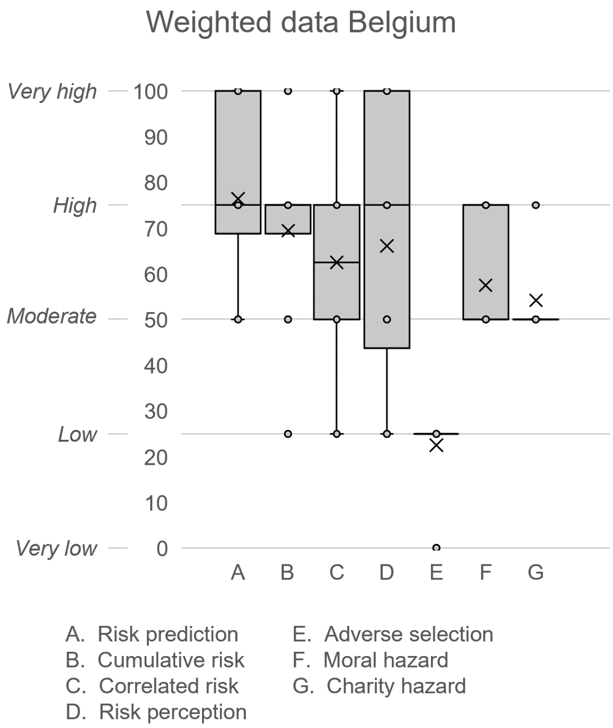
Secondly, the panel indicated a high presence of Cumulative risk and Correlated risk. The experts noted that the Cumulative risk is generally high due to the country’s small geography, making it difficult for the insurance sector to diversify policies and spread the risk. However, experts also recognised that the predominant risk arises from fluvial/pluvial flooding, making the impact relatively manageable when compared to extensive coastal flooding. Consequently, this risk was categorised as ”high-risk” rather than ”very high-risk”. Similarly, Correlated risk scored below ”high-risk”, which was reflected in the panel’s commentary. While mandatory flood insurance inclusion does come with the risk of correlated damage with phenomena such as storm, it was generally deemed moderate since storm is associated with coastal flooding and Belgium mainly risks fluvial/pluvial flood events.

Finally, the risk associated with Adverse selection received a rating below ”low-risk,” which is a logical assessment considering the mandatory nature of the scheme. Admittedly, some degree of adverse selection is in place as taking out fire insurance is not mandatory. However, it should be mentioned again that this requirement is commonly enforced by most mortgage providers, and a significant proportion of individuals opt for fire insurance voluntarily.

Belgium	Average	Mean
Risk predictability	76.39	62.57
Cumulative risk	69.44	72.59
Correlated risk	62.50	62.12
Risk perception	66.07	52.70
Adverse selection	22.50	34.42
Moral hazard	57.50	53.35
Charity hazard	54.17	56.35
Mean	58.37	56.30

Belgium	Standard dev.	Mean
Risk predictability	17.62	22.78
Cumulative risk	19.64	19.07
Correlated risk	20.83	22.81
Risk perception	27.72	22.73
Adverse selection	7.50	21.31
Moral hazard	11.46	20.95
Charity hazard	9.32	23.30
Mean	16.30	21.85

(a) Average and standard deviation round 2 weighted data, Belgium and mean of all systems



(b) Box-whisker plot round 2 weighted data, Belgium

Figure 5.2: Expert Judgment Analysis results Belgium

5.2.2. Proposed structure

The structure of this solution will somewhat mimic the current structure in place in Belgium. Legislation will be amended such that home insurers are mandated to include flood insurance in their buildings and contents insurance policies.

It was assumed that the penetration rate of the mandatory insurance will be 98%, which is the current penetration rate for catastrophe hazards – river flooding and storm surge excluded (Insurance Europe, 2022). For simplicity, it is assumed that after the inclusion of flooding into the insurance contracts, the penetration rate will remain at 98%. In practice, however, it is plausible that the penetration rate will go down when premiums increase due to the inclusion of flood coverage. The Belgian insurance system has addressed this issue by setting a ceiling on the premiums insurers can charge. Any additional expenses are shared among the insurers to maintain affordability. This practice of solidarity will be applied in the Flood Re structure later on, but will not be incorporated in this system. For the remaining 2%, the government will likely have to adopt a safety net structure, similar to the current Wts.

This system adopts a dual-layer model. The first layer, termed the insurance layer, covers damage ranging from €0 to €1 billion and charges a risk-based premium, meaning that the premium of an individual reflects their risk. As detailed in Section 4.1.3, individuals are categorised into one of four risk classes: Very high-risk, High-risk, Low-risk, and No-risk. The risk class an individual is in determines the premium that the individual is charged on their contract within the insurance layer. For the calculation of the insurance premium, a Cost of Capital of 8.30% was assumed.

The second layer, the Wts layer, covers damage spanning from €1 billion up to the maximum damage event. The Wts layer, which is similarly set up as in Section 5.1 from a regulatory point of view, levies premiums on a flat basis through taxation, leading to a uniform premium for all individuals. Given that the government does not maintain additional reserves for potential damage in this layer, the Cost of Capital required for the insurance premium calculation is set at a flat 0.00%.

Based on the assumptions and the calculations made in Chapter 4, the actuarially fair premiums for the Very high-risk, High-risk, Low-risk and No-risk are €39.70, €6.15, €3.53 and €2.77, respectively. Taking into account the Cost of Capital, the insurance premiums become €529.85, €51.03, €13.58 and €2.77, respectively. This includes €2.77 of taxes levied by the government, which will not impact the price of the insurance contract. Taxation to account for the costs of the Wts layer can be arranged in various ways, which is out of the scope of this research.

Following all assumptions, the sum of the premium income of this structure is €105.1 million. Although this is four times higher than the total premium income of the Wts+ structure, it is still considerably lower than the total premium income of the two other structures. This is due to the fact that only €1 billion of covered damage is held in liquid assets over which interest is paid. In the Risk pool and Flood Re structures, as will be detailed in Sections 5.3 and 5.4, interest is paid on approximately €3 billion of covered damage, driving up the insurance premium.

5.2.3. Conclusion

Although implementation and formation of a structure with mandatory inclusion of flood insurance in the regular building and contents insurance policies will require additional legislation, it is considered a moderately difficult approach.

The mandatory nature of the system ensures an almost full coverage of individuals in the system (1). This is a favourable aspect from a government's point of view, as there would likely be reluctance towards a system in which only a portion of the population is compensated post-flood. Consider a situation in which a group of uninsured individuals suffers significant property and possession loss due to extensive flooding. It is unlikely that the government would refrain from offering financial support. Yet, such actions would come with resistance from insured citizens who have always paid premiums and might deter future insurance enrolments. A system in which all individuals are insured would mitigate this issue.

An additional advantage of a system with mandatory inclusion is the minimisation of adverse selection (2). As it is difficult for individuals to leave the system – they have to opt out of home insurance at all – the risk of adverse selection is mitigated.

Moreover, by including insurers in the first layer, they are able to promote mitigation by rewarding discounts to individuals who actively reduce their risk of flooding (3). This incentive could potentially reduce overall premiums and, consequently, the societal financial burden -— benefiting the system as a whole.

Furthermore, the risk-based premium stimulates building and living in lower-risk areas (4), such as the eastern part of the Netherlands, since the premium will be lower for houses in these regions. This would be beneficial in the long term when taking rising sea levels into account.

Finally, compared to the other structures, the total premium income in this system is deemed moderate (5). This is due to only the insurers having to maintain capital in reserves to comply with solvency requirements.

Disadvantages of this structure would include elevated moral hazard arising from the mandatory nature of the structure (1). When all individuals are mandated to have insurance, the incentive to minimise potential damages diminishes, given the assurance of reimbursement. This can, however, be reduced by the promotion of mitigation measures from insurers through rewarding discounts.

Moreover, when this system is implemented in the Netherlands, cumulative risk emerges

(2). Insurers must distribute their risks across various regions to minimise the impact of local events, thus mitigating cumulative risk. Especially for smaller, more locally oriented home insurers, this will be difficult. This effect is reinforced by the mandatory nature of the solution.

Furthermore, while the absence of solidarity in this system might favour low-risk policyholders, it escalates premiums for those at the highest risk level (3). As detailed in Section 4.3.3, the annual insurance premium for individuals with very high risk is €529.85, which is considered to be high compared to the other systems. This could lead to Very high-risk individuals without a home insurance obligation (from i.e. a mortgage lender) not taking out home insurance at all. This would be counterproductive from an insurance perspective.

Additionally, mandating insurers and individuals to enter a contract introduces the possibility of correlated risk (4). In the event of a large storm surge which results in widespread flooding, insurers would find themselves compensating not only for flood-related damages but also for storm-related claims. This situation could lead to very high payout obligations, particularly if insurers lack sufficient diversification.

Advantages

1. Mandatory flood insurance ensures close to maximum coverage
2. No adverse selection
3. Promotion of mitigation measures by insurers
4. Promotes living in areas with low risk of flooding
5. Moderate total premium income

Disadvantages

1. High risk of moral hazard due to mandatory nature
2. Possible high cumulative risk
3. High premium for Very high-risk individuals
4. Possible increased correlated risk

5.3. Risk pool

A more collective solution for managing risks could involve the formation of a risk pool, in which multiple insurance companies come together to create a collective pool to hedge against catastrophic events. In this type of risk pool, there could be three layers. The first layer would consist of insurers, the second layer would involve the reinsurance industry, and the third layer would be covered by the state through a modified version of the Wts. One of the advantages of having a broad field of stakeholders is that everyone involved has an incentive to minimise the amount of damage and maximise gains.

However, pooling also presents challenges, such as the risk of adverse selection, as discussed in section 2.4. If the risk pool includes policyholders with non-homogeneous levels of risk but charges a flat premium, individuals with lower risks are inclined to leave the pool, as the risk they face without coverage is lower than the costs of insurance. Consequently, the low-risk individuals will opt to leave the pool, driving up the premium.

An example of a risk pool in the Netherlands that involves government participation is the *Nederlandse Herverzekeringsmaatschappij voor Terrorismeschaden* (NHT), which serves as a reinsurance company. The NHT operates as a risk pool, with participating insurance companies, reinsurance companies, and the Dutch government collectively covering damages resulting from terrorist attacks (NHT, 2023). The maximum coverage for a single year is set at EUR 1 billion. A market deductible of EUR 7.5 million is in place for all insurers, meaning that if the total amount of claims in a year is less than EUR 7.5 million, the NHT does not pay out. However, the deductible does not apply if the limit is exceeded, resulting in a payout for the total amount of claims. The premium for the NHT is incorporated into all policies of participating insurance companies, including building and contents policies. Figure 5.3 illustrates the structure of the NHT.

The NHT was established and implemented shortly after the 9/11 attacks on the World Trade Center in New York. Until that point, insured damage from acts of terrorism had been relatively manageable. However, the 9/11 attacks revealed that acts of terrorism could result in extreme property losses. The total estimated insured losses exceeded USD 23 billion in 2009 (Wilkinson & Hartwig, 2010), making it the largest loss in the history of insurance until Hurricane Katrina in 2005. Therefore, the implementation of the NHT pool faced little objection due to the high momentum at that time. However, with no recent major floods in the Netherlands, it is likely that the political momentum for such a large-scale implementation of a risk pool may be limited.

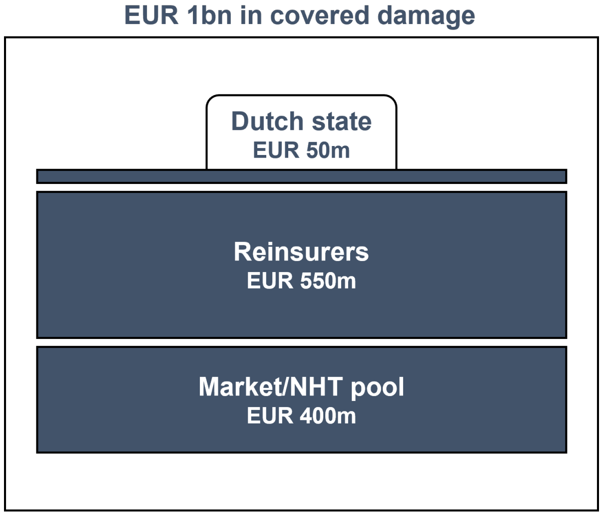


Figure 5.3: Structure NHT

5.3.1. Expert Judgment Analysis

The EJA did not cover a solution with a risk pool as proposed in this section. A good example of risk pools which could be treated is the Dutch *Atoompool* (Atom pool) or the *NHT*.

5.3.2. Proposed structure

The Risk pool solution would consist of a three-layer model, consisting of insurers, reinsurers and the Wts. It is not mandatory for individuals to take out flood insurance in this structure.

As there is no legal requirement for individuals to take out insurance, the penetration rate will be lower than in the previous solutions. The first assumption made is that all individuals with a mortgage on their house are mandated by their lender to take out insurance. Data from Nederlandse Vereniging van Banken (2022) revealed that 60% of houses in the Netherlands have a mortgage. Thus, at least this 60% will have to take out insurance. For the other 40% of households, estimations are made due to the absence of concrete data. As explained in Section 4.3.3, it was determined that the non-mortgage adoption rate of flood insurance is 10% for Very high-risk, 30 % for High-risk and 90% for Low-risk individuals. Consequently, the overall adoption rates for these risk classes are 64%, 72% and 96%, respectively. It was assumed that No-risk individuals are not obliged to take out insurance and that since all individuals act fully rationally, no individuals in this group opt for flood insurance.

The first layer consists of all buildings and contents insurers, similar to the previous solution. Damage from €0 up to €1 billion is covered by a risk-based premium, which is charged to Very high-risk, High-risk and Low-risk contract holders. Following the argumentation provided in

Chapter4, the Cost of Capital is set at 8.30%, consistent with other solutions.

The second layer involves the reinsurance industry, which covers damage starting from €1 billion up to €3 billion. The insurance industry will transfer this risk to reinsurers, which are capable of managing various significant catastrophe hazard risks globally, thereby diversifying their exposure. This method reduces their Cost of Capital, making insurance more cost-effective for them. The Cost of Capital for the reinsurance industry was determined at 6.92% (Section 4.2.2).

Finally, the third layer is comprised of the Wts, similar to the other solutions. The layer will cover damage from €3 billion up to the maximum damage event. The Cost of Capital remains 0.00%, as determined in Section 4.2.2.

5.3.3. Conclusion

Establishing a risk pool in the Netherlands would demand considerable effort due to its three-layer structure. Yet, with the NHT serving as a precedent, both the government and the insurance industry have experience that they can leverage. Formation of this risk pool would involve creating a new entity which manages the distribution of risk. This entity could be overseen by specialised insurers, similar to the NHT, rather than being a standalone company, as is the case with Flood Re.

A big advantage of the Risk pool structure is its mitigation of cumulative risk for insurers (1). Since all insurers will have pooled together, they are all responsible for compensation in the event of a payout. As a result, insurers with a high exposure to flooding are still able to provide home insurance, in addition to smaller, more locally-oriented insurers. This will expand overall coverage.

Additionally, insurers in the first layer are able to promote mitigation measures through premium discounts (2). This will have a lowering effect on the overall risk and consequently decreases the premium of individuals.

Furthermore, due to the high insurance premiums, especially for High-risk and Very high-risk individuals, individuals are stimulated to live in areas with low or no risk of flooding (3). This is also beneficial in the long term, considering the effect of rising sea levels, as detailed in Chapter 1.

Moreover, by including the reinsurance industry in the solution, the system's overall cumulative risk is reduced (4). Reinsurers will buy in large amounts of foreign catastrophe risks all over the world, thereby facilitating a broader spread in their portfolio. This is beneficial for the Dutch system since the risk of failure due to bankruptcy of a participant in the risk pool is reduced.

The downsides of this structure mostly attribute to its capital requirements, which are larger due to the inclusion of a private reinsurance layer. As determined in Section 4.3.3, the insurance premium for individuals in the Very high-risk class is €1,113.79 per year (1). This is over double the insurance paid in the *Mandatorily included in home policies* structure for this risk class, making it by far the most costly structure for this risk class.

Following the high insurance premium, the total sum of premium income becomes €307 million euros per year, compared to a yearly expected damage of €16 million (2). This means that the total premium income is a factor 19.2x higher than the yearly expected damage. Remind that the difference between the premium income and the expected damage represents the cost of insurance, and is not related to the flood risk. Thus, from the total premium individuals pay, only around 5% is to cover the actual risk, and 95% is to cover the costs of insurance.

Another disadvantage stemming from the inclusion of a (significant) reinsurance layer is the substantial capital outflow towards foreign reinsurance companies (3). Large reinsurance companies, the likes of Swiss Re and Munich Re, will charge a premium on the risk they buy in. If no flood occurs, which is the ultimate goal of the government, this capital will not return to the Netherlands. This is unfavourable from the government's point of view.

Additionally, from a governmental perspective, the combination of voluntary participation with elevated premiums raises concerns that higher-risk individuals may opt out of flood insurance. If a flooding event were to occur, the government might find itself compelled to intervene, giving rise to charity hazard (4).

Moreover, since this solution involves voluntary participation, which in combination with high premiums could result in a low penetration rate, a safety-net needs to be implemented for uninsured individuals (5). It is deemed unlikely that the government will leave uninsured to themselves in the event of a large-scale flood. However, this would undermine the credibility of the contract and consequently further pressure the penetration rate of the solution.

Lastly, there is potential for adverse selection in this system, especially due to the high cost of insurance which drives up the premium (6). However, this risk is somewhat offset by the adoption of risk-based premiums. Additional differentiation of risk classes would further mitigate this risk.

Advantages

1. Cumulative effect mitigated by pooling risks
2. Promotion of mitigation measures by insurers
3. Promotes living in areas with low risk of flooding
4. Diversification leading to a better spread of risk

Disadvantages

1. Very high premium for High-risk and Very high-risk individuals
2. Very large sum of total premium compared to yearly expected damage
3. Large capital outflow to foreign reinsurance companies
4. Voluntary nature obstructs maximum coverage
5. A safety net needs to be implemented for uninsured individuals
6. High risk of adverse selection

5.4. Flood Re

An alternative approach would be to establish a system similar to the UK's Flood Re. This would involve the creation of a government-owned reinsurance company, with mandatory participation for all home insurers. As discussed in section 3.1.2, while this option may be complex, it offers several advantages.

In the UK, flood insurance is based on risk assessment. Flood Re specifically aims to provide coverage for high-risk policies that would otherwise be unaffordable. Here's how it works: A high-risk individual obtains home insurance from a participating insurer within the Flood Re scheme. The insurer then transfers the risk associated with the policy to Flood Re. Flood Re charges the insurer a premium based on the assessed risk, and the insurer passes a portion of this premium to the customer. Additionally, all participating insurers contribute to a yearly levy, which spreads the risks and costs of the premiums, making high-risk policies more affordable.

Implementing a system similar to Flood Re would allow for more accessible and affordable flood insurance for high-risk properties. By pooling the risks and costs across the insurance industry, the burden of coverage is shared, enabling insurers to provide coverage at more reasonable rates.

5.4.1. Expert Judgment Analysis

The analysis of the UK's results in the EJA aims to ascertain the impact of different failure mechanisms on the Flood Re system, as the UK already has the Flood Re system in place (please refer to figure 5.4 for the results). Within the panel, the perceived impact of Cumulative risk, Correlated risk, and Risk perception on the Flood Re system was rated as relatively high. On the other hand, the impact of Adverse selection and Moral hazard was considered to be moderate. However, Cumulative risk, Adverse selection, and Moral hazard are discarded due to the high spread in answers.

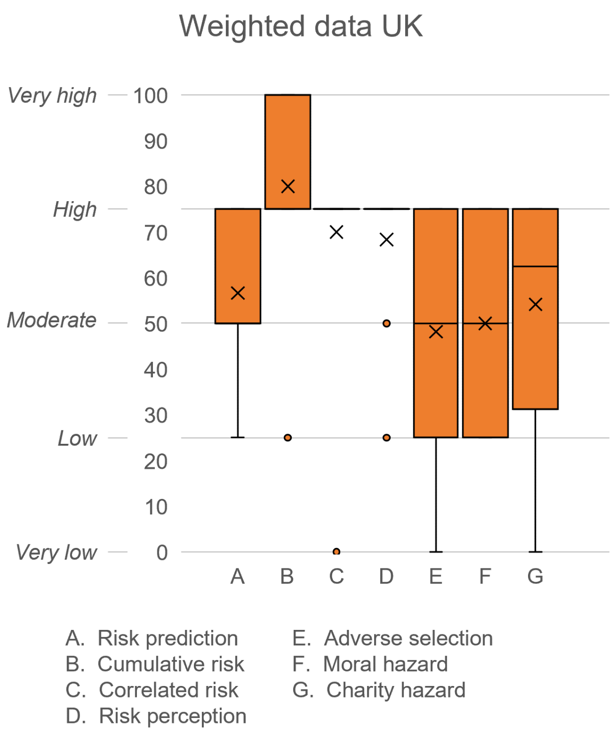
The expert panel as a whole assessed Correlated risk with a rating just below the classification of "high-impact". Notably, there was one outlier who assigned a rating of 0. This outlier argued that since Flood Re exclusively covers flood risk, it remains unaffected by other factors such as storms. While this argument might hold true for Flood Re as an entity, it fails to account for the broader system wherein flood insurance is channelled through traditional insurers, who only offload a portion of the higher-risk policies to Flood Re. Therefore, other factors do exert influence on the overall system. The rest of the experts deemed the risk of storm and coastal flooding substantial and therefore scored the impact high.

As highlighted in section 3.1.2, Risk perception is of importance in the UK system due to the voluntary nature of homeowners opting for flood insurance. This susceptibility to individual perceptions of risk can lead to the decision not to acquire insurance coverage. The design of Flood Re addresses this by offering affordable insurance to high-risk individuals, potentially incentivizing their insurance uptake. The expert panel rated the impact of Risk perception just below the classification of "high", well above the average score of "moderate" for Risk perception.

UK	Average	Mean
Risk predictability	56.67	62.57
Cumulative risk	80.00	72.59
Correlated risk	70.00	62.12
Risk perception	68.33	52.70
Adverse selection	48.21	34.42
Moral hazard	50.00	53.35
Charity hazard	54.17	56.35
Mean	61.05	56.30

UK	Standard dev.	Mean
Risk predictability	14.34	22.78
Cumulative risk	24.49	19.07
Correlated risk	18.71	22.81
Risk perception	14.34	22.73
Adverse selection	25.82	21.31
Moral hazard	20.41	20.95
Charity hazard	24.65	23.30
Mean	20.39	21.85

(a) Average and standard deviation round 2 weighted data, UK an mean of all systems



(b) Box-whisker plot round 2 weighted data, UK

Figure 5.4: Expert Judgment Analysis results UK

5.4.2. Proposed structure

Setting up the Flood Re structure involves a three-layer model which includes the home insurance industry, a newly formed Flood Re entity and the Wts. Similar to the Risk pool solution, there is no legal requirement for individuals to obtain insurance.

As was assumed in Section 4.3.4, and similar to the Risk pool structure, individuals with a mortgage on their house are mandated by their lender to take out flood insurance. Estimates are made for the number of people who do not have a mortgage but opt to take out flood insurance. Given that this system incorporates solidarity —- where individuals at lower risk partly cover the costs for those at higher risk —- it is presumed that a greater number of Very high-risk and High-risk individuals will obtain flood insurance compared to the Risk pool structure. This does result in a lower penetration rate among Low-risk individuals. This resulted in the assumption – presented in Section 4.3.4 – that the adoption rate of flood insurance is 80%, 84% and 88% among Very high-risk, High-risk and Low-risk contract holders, respectively. No-risk individuals are not obliged to take out insurance and do not opt to do so voluntarily.

The first layer is similar to the insurance layer in the *Mandatory surcharge in home policies* and Risk pool structures. The layer covers damage from €0 up to €1 billion, distributing the premium in a risk-based manner. The Cost of Capital is set at 8.30% (Section 4.2.2).

The second layer consists of the newly formed Flood Re entity, which covers the risk of individuals who would have very high premiums in a normal risk pool structure. When individuals take out insurance, whether voluntarily or mandated by a credit provider, they do so through a regular home insurer. The insurer then evaluates which risks to transfer to Flood Re.

Subsequently, to account for the costs of subsidising these policies, Flood Re charges both a premium and a levy, or contribution. The premium is charged to the insurer and is related to the amount of risk. The contribution is flat and is charged to all home insurers. Insurers will pass this contribution to their customers, which will create solidarity in the system, raising the premium of lower-risk individuals, and lowering the premium of higher-risk individuals. For the calculation of the premium in Section 4.3.4, the contribution was set at €25.00.

In this assessment, it is assumed that the insurers will retain the risk of the High-risk and Low-risk individuals up to €1 billion, and cede the risk of all Very high-risk individuals to Flood Re. This results in a total covered damage of €1.98 billion by Flood Re. Given that Flood Re operates as a government entity, it is assumed that it can access capital markets at rates comparable to those of the Dutch state, pinpointed at 3.00%. This is explained in Section 4.2.2.

The third layer will cover the risk not included in the insurance and Flood Re layer through the Wts, similar to the other structures. The Cost of Capital is set at 0.00% (Section 4.2.2).

5.4.3. Conclusion

Establishing a three-layer structure, coupled with the introduction of the Flood Re entity, is anticipated to be the most challenging and time-consuming approach among all proposed solutions. However, the solidarity in this system does pose some certain benefits.

The main advantage of the Flood Re system, when compared to the other systems involving private (re)insurers, is its affordability (1), which arises from the solidarity in the system. Due to an equal set contribution required from all participants, individuals facing the highest risks can still access a relatively affordable premium. As was demonstrated in the Risk pool structure, a three-layer model with risk-based premiums can lead to inflated premiums for the Very high-risk class. In this system, the Very high-risk class pays an insurance premium of €209.41, substantially more affordable than the premiums in the *Mandatorily included in home policies* and Risk pool structures, which are €529.85 and €1,113.79, respectively.

Another advantage is the promotion of mitigation measures by private insurers in the first layer (2), which has the potential to reduce overall premium expenses. Similar as discussed in the *Mandatorily included in home policies* and Risk pool structures, the inclusion of an insurance layer provides the opportunity to award individuals who actively mitigate their flood risk by offering premium discounts. This will stimulate flood risk reduction, ultimately lowering the premium.

Furthermore, due to the risk-based nature of the premium, individuals are stimulated to live in areas with low or no risk of flooding (3). However, due to the solidarity principle incorporated in this system, this effect is less compared to the *Mandatorily included in home policies* and Risk pool solutions. This stems from the fact that, assuming individuals act rationally, the relative difference between the lower and higher premiums stimulates individuals to move to areas which provide a lower insurance premium. Since lower-risk individuals subsidise higher-risk individuals in the Flood Re system, this effect is reduced.

The flip side of a system with solidarity is that lower-risk individuals have a relatively high premium as they will have to support affordability for the higher-risk individuals (1). As a result, the Low-risk class in this system faces an insurance premium of €53.39, which is nearly 19.7 times their annual expected risk. Such a discrepancy can lead to the possibility of adverse selection (2), where those at lower risk might choose to exit the system, thereby elevating costs for those at higher risk.

Additionally, the voluntary nature of the system, while promoting individual freedom, results in a scenario in which not every household obtains flood damage coverage (3). In the long run, should these uninsured households suffer losses, the government may feel compelled to intervene in the form of a safety net structure (4), which could undermine the system's credibility. However, this effect is partly offset by the system's affordable premiums, especially compared to the Risk pool structure.

Finally, if insurance companies do not effectively diversify their risks, they become vulnerable to cumulative risk (5). This effect is especially strong for smaller, more local-oriented insurers, for which it is difficult to spread their risk geographically.

Advantages

1. Solidarity keeps insurance affordable
2. Promotion of mitigation measures by insurers
3. Promotes living in areas with low risk of flooding

Disadvantages

- Relatively high premium for Low-risk individuals
- High risk of adverse selection
- Voluntary nature obstructs maximum coverage
- A safety-net needs to be implemented for uninsured individuals
- Possible high cumulative risk

This chapter has addressed the fourth research question – *What are the advantages and disadvantages of potential insurance solutions covering flooding in the Netherlands?* – by evaluating the resilience and financial implications of the four proposed flood insurance solutions within the Netherlands. Using the analytical groundwork laid in Chapters 3 and 4, it has provided an answer by assessing the impact of failure mechanisms and insurance premiums on the system and contract holders. Chapter 6 will build on this analysis, discussing the viability of these solutions through the perspectives of three key stakeholders: the government, individuals, and insurers, culminating in a multi-faceted understanding of an insurance solution covering flood damage resulting from the failure of primary flood defences.

6 Conclusion

This final chapter delves into a reflection of the solutions that have been introduced and analysed in this study for insurance covering flood damage resulting from the failure of primary defences in the Netherlands. The solutions will be reflected upon from a governmental, individual's and insurer's perspective. The primary aim of this research is not to determine a single 'best' solution. Instead, it involves a comprehensive and multifaceted assessment, taking into account various perspectives and viewpoints. The goal is to encourage thoughtful reflection and constructive conversation, rather than offering absolute judgements or approvals.

Following the reflection, answers are provided to the sub-research questions and main research question posed in Section 1.3. This section forms the conclusion of the research and aims to cover the overall research objective. These conclusions contribute to the collective understanding of flood insurance and could be used by decision-makers who are considering whether a different system should be implemented in the Netherlands or not. Finally, this chapter will concisely touch upon certain assumptions and shortcomings of this research, which could spark new research in the future. Some final words will close off this report.

6.1. Reflection

The goal of this research is not to determine the single best insurance solution covering damage resulting from the failure of primary flood defences but to present multiple solutions with their pros and cons, and how they are viewed from the perspective of different stakeholders. The aim is to inform a decision-maker and assist in the substantiation of their choice. Therefore, this section will reflect on the proposed solutions from Chapter 5 from multiple points of view. This includes a governmental, an individual's and an insurer's perspective. It has to be noted that the motives of stakeholders are assumptions.

To assist the reader, Figure 4.7 and Table 4.15 from Chapter 4 have been re-presented in Figure 6.1 and Table 6.1.

6.1.1. Governmental perspective

From a governmental point of view, it is argued that the primary features of a possible solution are an affordable premium for all individuals and a (nearly) maximum penetration rate, aspects which are both dependent on each other. Additionally, minimising significant capital outflows is also deemed favourable.

While it is easily understood why a government, especially in a welfare state like the Netherlands, would prioritise affordable premiums for individuals, the emphasis on achieving a maximum penetration rate might be less straightforward. As discussed in Chapter 5, having only

Table 6.1: Summary of retrieved premiums (re-presented from Table 4.15)

	Wts+	Home policies	Risk pool	Flood Re
Actuarially fair premium				
Very high-risk	4.09	39.70	50.25	72.71
High-risk	4.09	6.15	9.07	5.91
Low-risk	4.09	3.53	3.27	2.71
No-risk	4.09	2.77	1.50	1.77
A *Expected loss (€mm/y)*	*20.7*	*20.3*	*16.0*	*17.4*
Insurance premium				
Very high-risk	4.30	529.85	1,113.79	209.41
High-risk	4.30	51.03	223.97	114.35
Low-risk	4.30	13.58	54.16	53.39
No-risk	4.30	2.77	1.50	1.77
B *Sum premium income (€mm/y)*	*21.7*	*105.1*	*307.1*	*159.6*
Multiple (B/A)	**1.1x**	**5.2x**	**19.2x**	**9.2x**
Covered loss (€bn)	29.4	28.8	25.6	25.3

a portion of the Dutch population insured against floods could potentially undermine the system's credibility and pave the way for moral and charity hazards. It is the extent of the potential damage a flood has that is at the heart of the dilemma. Provide financial aid to the uninsured in the event of a flood, and charity hazard will arise. Protect the system by refusing reimbursement, and people without insurance will have lost everything. This problem strongly advocates the government's demand for a maximum penetration rate. The callout *Example: Maximum penetration rate* provided below better illustrates this dilemma.

Achieving a maximum penetration rate is straightforward in a system in which participation is mandatory. However, in a voluntary system, the affordability of the insurance contract becomes the primary driver of the penetration rate. Rational individuals who feel that their premium does not reflect their risk – an assumption not unthinkable in a country without major flood damage in the past 70 years – will decide to not take out insurance, thereby reducing the overall penetration rate. This means that a distorted risk perception or inflated insurance costs in a voluntary structure will lead to individuals leaving the system.

From a governmental perspective, the Wts+ structure appears to be the preferred choice. Its guarantee of maximum penetration and extremely low premium meet the primary requirements. Moreover, by excluding (large, foreign) reinsurers, it prevents substantial capital outflows. A downside is that the state will have to tap into either its budget or its reserves for all flood damage that occurs, even minor ones. Furthermore, the *Mandatorily included in home policies* and Flood Re structures would partially align with the government's conditions, making them potentially viable alternatives. Finally, it is beneficial for the government to include an initial layer of insurers which can promote mitigation measures, as this can reduce both the yearly expected damage and the maximum potential damage.

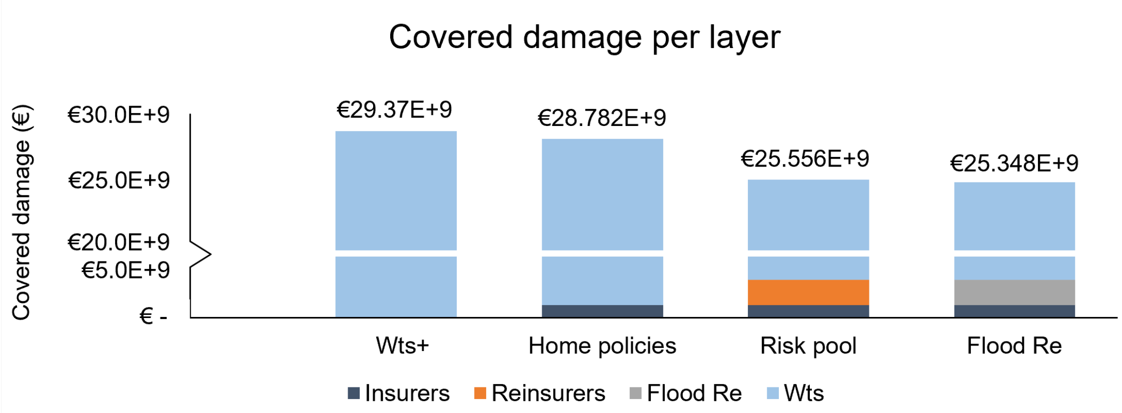


Figure 6.1: Covered damage per layer (re-presented from Figure 4.7)

Example: Maximum penetration rate

The maximum penetration rate demand is illustrated with a fictitious example.

> Imagine a village in which 90% of individuals have taken out flood insurance and 10% have not, and in which a flood occurs that destroys all houses of the villagers. In this case, the 90% will receive immediate reimbursement from the town's insurer for which they have paid premiums over the past years. However, the 10% that has not paid any premium will not be reimbursed by the insurer.
>
> While for the risk of burglary or car damage, one might call it bad luck, it is very unlikely that a government will not provide financial aid to villagers who have lost their home and all their belongings. However, by providing this financial aid, the other 90% will feel aggrieved as they have been paying to cover this risk. The government penalises these villagers from a financial point of view. This provides the government a choice; undermining the insurance system, possibly destroying it, or leaving uninsured villagers in the cold.

6.1.2. Individual's perspective

To comment on the individual's preferences, it is assumed that individuals will act rationally, aiming towards maximum personal gain. Striving towards maximum personal gain translates to individuals demanding an affordable premium, which, in their view, reflects their risk, or ideally, is priced lower than their perceived risk. It is acknowledged that in reality, individuals might be inclined to pay a higher premium to assist others, but this notion has been excluded from this evaluation.

It is important to make a distinction between the risk classes of the individuals. Those at higher risk will favour a system with maximum solidarity, as this would lower their premium, whereas those at lower risk will prefer the opposite. This perspective stems from the essence of solidarity, where individuals with lower risks subsidise the coverage costs for their higher-risk counterparts.

Assuming the ideal system is one in which the greatest number of participants achieves maximum gain, the Risk Pool structure emerges as the most suitable. This is because the No-risk group, making up 54% of the total system as shown in Table 4.2, gets its optimal premium relative to the other solutions. However, when looking at the system as a whole, this is the least favourable option due to its high capital requirements which are paid by the risk-bearing individuals. The sum of the premium income of this system is 14 times higher than that of the Wts+ solution. Still, this would be the least favourite solution of the No-risk class, which represents the majority of the system. By valuing the preferred solution in terms of overall costs, the Wts+ structure would come out on top.

Both options described above are extremes in terms of solidarity. It can be argued that the most favourable solution from the individual's perspective should be somewhere in between. This would require coming back to the assumption that individuals are not willing to pay for the risk of others. The Flood Re structure would provide the optimal outcome in this way, representing a mix between risk-based insurance costs and solidarity towards higher-risk individuals.

6.1.3. Insurer's perspective

To reflect on the proposed solutions from the insurer's point of view, this analysis will primarily consider the financial viability and sustainability of each model. It is duly noted that while insurers – and their shareholders – are driven by profitability, they also operate under a duty of care to act in the best interests of their policyholders, particularly in times of severe risk. Thus, their pursuit of financial health is balanced with responsible business practices. However, this comprehensive financial focus allows for a thorough examination of the solutions, from different perspectives, contributing to the overall analysis of the insurance models. Additionally, financial optimisation involves more than simply targeting the highest possible premiums; it also requires a careful evaluation of broader economic implications, such as the potential for cumulative risk and the effects of adverse selection.

From the insurer's perspective, a structure in which they bear risk is preferred. While the insurance industry participates in the Wts+ structure, it is assumed that they are reimbursed for the costs they make. Therefore, there is no profit to make in this structure. The *Mandatorily included in home policies* structure is the solution which likely provides the most profit for the insurers since it involves the largest addressable market of all insurance-layer-including structures. Additionally, since home insurers are mandated to include flood coverage in home insurance, adverse selection is partly mitigated.

Cumulative risk significantly impacts insurers, as discussed in Section 2.2.1. Without adequate diversification in their portfolio, insurers might face the threat of insolvency, especially when confronted with massive, unexpected payouts like those resulting from floods. The Risk pool structure addresses this by consolidating all risks. Consequently, an insurer with major commitments in a particular region, which is more likely for smaller, locally oriented insurers, is not disproportionately vulnerable to flood risk. In other solutions, ensuring diversification becomes the insurer's responsibility, potentially leading to increased costs. Flood Re provides an alternative approach to minimising cumulative risk. By transferring the Very high-risk individuals to the government-owned and subsidised Flood Re layer, the probability of exceedingly large sudden payouts is reduced for the insurance layer, which is beneficial for the insurer.

To summarise, the *Mandatorily included in home policies* structure will likely be the most preferred solution from an insurer's perspective. Its appeal stems from the large addressable market and the mitigation of adverse selection. However, it is important to highlight that this model presents a greater cumulative risk compared to the other two strategies, a factor that insurers and regulatory bodies should closely monitor.

6.2. Conclusion

Following the reflection provided in the previous section, a conclusion can finally be drawn regarding the research questions posed in Section 1.3. This section will shortly cover all sub-research questions and finally comment on the research objective by answering the main research question.

Research question 1

In Chapter 2, the first research question – *What are failure mechanisms in (flood) insurance, and how can they be mitigated* – was treated. Through an extensive literary review of peer-reviewed articles, this research identified seven potential failure mechanisms which could appear in an insurance solution which covers damage resulting from the failure of primary flood defences: Risk predictability, Cumulative risk, Correlated risk, Risk perception, Adverse selection, Moral hazard and Charity hazard. The failure mechanisms serve as the backbone of this research, so a thorough understanding of these phenomena is instrumental. Of these seven mechanisms, three are most recurrent and are therefore described below.

1. **Cumulative risk** (Section 2.2.1) – Cumulative risk stems from the fact that a flood almost always – and especially in a low, flat area like the Netherlands – affects multiple homes. In case of a major flood in a large urban area, a lot of insurance policies have to be disbursed at the same time. This puts the insurer at risk of insolvency if they have a large exposure in this area. Cumulative risk is mitigated by diversifying a portfolio geographically, thus spreading the risk among different areas.
2. **Adverse selection** (Section 2.4) – Adverse selection emerges following information asymmetry between buyers and sellers. Since the insured is better aware of the risk they are at, or at least perceive this as such, they can decide whether an insurance contract is beneficial or not. Assuming the premium is the average risk of all policyholders, this results in low-risk policyholders leaving the system, driving up the premium. Eventually, all individuals will have left the system since they perceive the premium as higher than their risk.
3. **Moral hazard** (Section 2.5) – Similar to adverse selection, moral hazard stems from information asymmetry. In this case, the insured can influence the amount of damage they incur, while the insurer can not. Concerning flood insurance, this means that an insured individual is not incentivised to mitigate their flood risk, because they know that they will get reimbursed in the event of a flood. Insurers have found several methods to mitigate this risk, such as premium deductibles, co-insurance, upper limits on coverage and claim-free years.

Research question 2

The second research question was investigated in Chapter 3: *How is flood insurance or reimbursement arranged in the Netherlands and other developed countries, and what are potential solutions which could be implemented in the Netherlands?*

First, through a literary review, the flood insurance/reimbursement systems of five developed countries were examined: the United States, the United Kingdom, Belgium, Spain and the Netherlands. Below, a short overview of the three systems which were used for evaluation of the final proposed solutions is provided. In addition to an overview of each system, Section 3.1 comments on the effect of the failure mechanisms on each system.

1. **United Kingdom** (Section 3.1.2) – The UK has introduced Flood Re, which serves as a reinsurance company which covers the highest risk policies. Flood Re covers these policies through a levy imposed on all home insurers in the UK, which means high-risk individuals are able to take out affordable flood insurance.
2. **Belgium** (Section 3.1.3) – In Belgium, flood coverage is compulsorily included in fire insurance policies offered by private home insurers. For the most extreme risks, home insurers can apply to transfer the risk to a federal level, somewhat similar to the Flood Re system.

3. **Netherlands** (Section 3.1.5) – In the Netherlands, flood reimbursement is arranged in two ways, through regular home insurance and through the Wts, of which the latter applies to reimbursement of damage resulting from the failure of primary flood defences. Wts is a law which can be activated if the government qualifies an event as a disaster, and the affected are compensated if they were not able to insure against this disaster.

In addition to a qualitative assessment, an Expert Judgment Analysis was performed to provide a quantitative analysis. A panel of experts with varying backgrounds was assembled, which were able to assess the impact of the failure mechanisms on the five systems. For any assessment to be of value for this research, both a significant score – either high or low – and a low spread were important. Interesting data points from this analysis were *UK – Cumulative risk*, *Belgium – Adverse selection* and *Netherlands – Charity hazard*.

Using knowledge gathered from the five systems and the EJA, the latter part of the research question – potential solutions to be implemented in the Netherlands – could be answered. A list of seven solutions was proposed: Market-driven insurance, Risk pool with government participation, State-owned insurance, Wts+, Mandatorily included in home policies, Risk pool and Flood Re.

From this list, the first three solutions were discarded using the following argumentation. The Market-driven insurance solution was deemed unviable due to the presence of Adverse selection, cumulative risk and an additional need for a safety net. The second solution, a Risk pool with government participation, had the risk of a large capital outflow, the presence of adverse selection and an additional need for a safety net. Lastly, the State-owned insurance had no precedent in the Netherlands, faced high correlated risk and similar to the other two structures, had an additional need for a safety net.

Research question 3

In Chapter 4, the third research question was treated: *How does the premium evolve for four different insurance solutions?* To provide an answer to this question, an insurance premium model was constructed using input gathered through public sources. The model calculates the flood risk, which is also called the Yearly Expected Damage (YED), of groups of homes in the Netherlands and consequently classifies these houses in four so-called *risk classes*. The risk classes used are Very high-risk, High-risk, Low-risk and No-risk. Additionally, from the model, the maximum damage event was determined.

Using the YED, the actuarially fair premium was calculated, which is the premium which purely represents the risk. By applying the maximum damage to the actuarially fair premium, the insurance premium was calculated. The insurance premium is the final premium that an individual will pay on their contract. This calculation was performed for the four remaining solutions from Chapter 3: Wts+, Mandatorily included in home policies, Risk pool and Flood Re.

Research question 4

The answer to the final sub-research question – *What are the advantages and disadvantages of potential insurance solutions covering flooding in the Netherlands?* – was explored in Chapter 5. For each of the four solutions, the principle of the solution was explained, the relevant results of the EJA were discussed and the structure and premium were detailed. Finally, for every solution, this led to a conclusion in which, according to this research, the advantages and disadvantages of each solution are presented. These pros and cons are an instrumental result of this research and were used in the reflection in this chapter.

For reference, the advantages and disadvantages presented in Chapter 5 of each solution are reiterated in Table 6.2 at the end of this section.

Main research question

As stated at the beginning of this chapter, the goal of this research is not to determine the single best insurance solution covering damage resulting from the failure of primary flood defences but to provide an overview of the advantages and disadvantages of multiple solutions, aimed to inform decision-makers. Therefore, this section aims to provide an answer to the main research question: *What is the impact of potential flood insurance solutions covering flood damage resulting from the failure of primary flood defences in the Netherlands?*

To achieve this, the results from the four sub-questions, which culminated in the reflection of Section 6.1, are summarised to highlight the most important and notable aspects of each proposed solution.

For the Wts+ solution, this study identifies several key benefits: the notably low annual premium (tax) of €4.30 for all homeowners, which is considered affordable by this research and favoured from the individual's point of view; a comprehensive 100% coverage ratio that offers a complete solution without necessitating further government intervention; and the retention of capital within the country by avoiding outflows to foreign reinsurers. Nonetheless, a significant drawback of this system is its inability to incentivize residents to live in areas with low or no flood risk, which is deemed particularly concerning in the context of increasing extreme weather events and rising sea levels.

Next, for the *Mandatorily included in home policies* solution, its compulsory aspect guarantees a coverage ratio close to 100%, effectively reducing the problem of adverse selection, which benefits both governmental bodies and insurance companies. However, this compulsion also raises the potential for moral hazard and introduces the issue of correlated risks —- the former of which might be lessened through the provision of premium discounts. Additionally, the inherent high cumulative risk of this approach poses significant challenges for smaller, more locally-oriented insurers for which it is difficult to diversify their portfolio.

The Risk pool solution's main advantage lies in its inherent mitigation of cumulative risk, achieved as insurers distribute the risk of payouts among each other. Additionally, by including an insurance layer, this system allows for the promotion of mitigation measures and encourages living in areas with low risk of flooding. However, the solution imposes a considerable financial load on policyholders, especially those in high-risk categories, resulting in premiums that substantially exceed the annual expected damage. This discrepancy leads to an excessive sum of total premiums and, in turn, a significant outflow of capital to foreign reinsurers. Moreover, the partial coverage will lead to a need for an additional safety net structure, which is not desirable from a government's perspective.

Finally, the Flood Re solution emerges as an interesting alternative, including the principle of solidarity to maintain affordable premiums across different risk categories. In this solution, lower-risk individuals effectively subsidise those at higher risk, which helps to decrease steep premiums for higher-risk individuals, such as seen in the *Mandatorily included in home policies* and Risk pool structures. Yet, a significant consequence is that Low-risk policyholders face disproportionately higher premiums -— nearly 20 times their actual annual risk – which has the potential to drive adverse selection. Moreover, the optional participation in the Flood Re scheme results in incomplete coverage, necessitating further regulatory measures by the government to ensure that adequate safety nets are in place for the uninsured.

This marks an end to the conclusion of this research, which was aimed to provide an answer to the research question: *What is the impact of potential flood insurance solutions covering flood damage resulting from the failure of primary flood defences in the Netherlands?*. The following section will present recommendations, specifically discussing the EJA and examining assumptions made in the premium model.

Table 6.2: Summary of the advantages and disadvantages of the four solutions from Chapter 5

Advantages	**Disadvantages**
Wts+	
1. Affordable risk premium for all individuals 2. Incentive for the government to invest in flood protection 3. No adverse selection 4. 100% coverage 5. No capital outflow to foreign reinsurance companies	1. No-risk individuals have to pay for the risk of high- and very high-risk individuals which could lead to resistance 2. No incentive to live in areas with low or no risk of flooding 3. Very high risk of charity hazard
Mandatorily included in home policies	
1. Mandatory flood insurance ensures close to maximum coverage 2. No adverse selection 3. Promotion of mitigation measures by insurers 4. Promotes living in areas with low risk of flooding 5. Moderate total premium income	1. High risk of moral hazard due to mandatory nature 2. Possible high cumulative risk 3. High premium for Very high-risk individuals 4. Possible increased correlated risk
Risk pool	
1. Cumulative effect mitigated by pooling risks 2. Promotion of mitigation measures by insurers 3. Promotes living in areas with low risk of flooding 4. Diversification leading to a better spread of risk	1. Very high premium for High-risk and Very high-risk individuals 2. Very large sum of total premium compared to yearly expected damage 3. Large capital outflow to foreign reinsurance companies 4. Voluntary nature obstructs maximum coverage 5. A safety net needs to be implemented for uninsured individuals 6. High risk of adverse selection
Flood Re	
1. Solidarity keeps insurance affordable 2. Promotion of mitigation measures by insurers 3. Promotes living in areas with low risk of flooding	1. Relatively high premium for Low-risk individuals 2. High risk of adverse selection 3. Voluntary nature obstructs maximum coverage 4. A safety net needs to be implemented for uninsured individuals 5. Possible high cumulative risk

6.3. Recommendations

This section discusses shortcomings and assumptions made in this research and provides recommendations for future research. The main points of attention will be the Expert Judgment Analysis and the premium model.

Expert Judgment Analysis

The goal of the EJA was to evaluate the impact of the failure mechanisms from Chapter 2 on the systems in different countries from Section 3.1. It was argued that through an EJA, the impact could be better evaluated than by argumentation alone. As was explained in more detail in Section 3.2.4, some issues arose after the evaluation of the answers provided by the panel. Firstly, the purpose of evaluating the impact of these mechanisms on different structures is to apply this knowledge during the development of the solutions introduced in Chapter 5. This implies that the evaluation focuses on the system's structure rather than the context it operates within. Although understanding how a system functions within a specific nation can be insightful, it is not the primary concern of this research.

Secondly, inconsistencies were observed between the rationales provided by experts and their corresponding scores. It seemed that some experts rated the level of risk rather than its effect on the system. For example, when risk perception in a region is high, it typically results in a low negative effect of that risk on the system. Yet, some experts rated the intensity of the risk instead of its impact, distorting the average result.

Third, the differences in the total familiarity of countries introduced challenges. This resulted in a disparity in the weight given to the responses from the panel, posing risks when comparing outcomes. For instance, the total familiarity with the Netherlands stood at 35, while it was only 7 for the Spanish system. When comparing a specific failure mechanism between these countries, it's imperative to recognise that the response of the Netherlands carries significantly more expertise than that of the Spanish system. Overlooking this discrepancy can lead to incorrect conclusions.

Finally, it was interesting to see that experts within the same domain interpret certain industry-specific terms differently. This demonstrates that even among experts in the same field, there is still room for debate, a nuance is highly encouraged by this research.

This research acknowledges the significance of seeking expertise, and as such, recommends this method for subsequent studies. Yet, there are areas for improvement:

- Providing a more detailed explanation of the research objectives might yield more valuable outcomes
- Conducting the EJA with the panel physically present can help avoid simple mistakes
- Incorporating additional rounds in the EJA could result in greater consensus among experts

Premium calculation

For the calculation of premiums of different insurance structures, a model was developed. This model was underpinned by several assumptions. This section highlights and discusses some of the notable ones.

- **Zero cost of capital in the Wts layer**

  The model operates under the assumption that the government will not maintain additional reserves for the Wts layer's reimbursement. As a result, the cost of capital for this layer was considered to be virtually zero. Reasoning for this assumption can be found in Section 5.1.2. If it is believed that the government should hold reserves (or a portion thereof) for the maximum damage, the total premium income would significantly increase. Given the sensitivity of this assumption, future research on this topic is highly recommended.

- **Excluding the effect of mitigation**

  To keep the model straightforward, the impact of mitigation measures was not included. Nevertheless, in systems that incorporate an insurance layer, promotion of mitigation measures could likely reduce the YED and the maximum damage, and consequently, the premium. It is recommended to take this effect into account in future research.

- **Database of 5 million properties**

  As detailed in Section 4.1.2, the database which was used consisted of a total of 5 million properties, counting multi-layered properties as one. counting multi-layered properties as one. This assumption was justified by the fact that the ground-floor apartment in a multi-story building typically sustains the most damage. However, for a more accurate premium calculation, the effect of multi-layered housing should be considered.

- **Maximum damage assumption**

  In Section 4.1.4, a specific return period was selected to determine the maximum damage a system must account for. However, when compared to European regulations, this return period seems overly conservative in terms of capital requirements. One could argue that it is unnecessary to maintain buffers for an event with such a small probability. Lowering this return period will not have an immediate effect on the premiums presented in this research, as the upper range is always covered by the Wts layer, which was assumed to have no capital cost. However, if the zero per cent capital cost assumption were to change in future research, care should be taken in the determination of the maximum damage and corresponding capital requirements.

6.4. Final remarks

As this thesis concludes, the insights uncovered offer a starting point for deeper conversations on flood insurance covering damage resulting from the failure of primary flood defences in the Netherlands. The engagement with experts and the analytical challenges faced have grounded this work in practicality while contributing to the academic discourse. This marks not just the end of my academic chapter at Delft University of Technology but also the beginning of what is hoped to be an ongoing effort to improve flood resilience. I hope that the findings here serve as a handheld for future policy and practice, for which it is intended.

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A

Economic background on market failures

A.1. Dependency of risks

Dependency of risks leads to a much greater variation coefficient in expected damage, which translates to a considerably higher premium. The following derivation of premiums for dependent and independent risks was introduced by Vrijling et al. (2008) and are presented in table A.1, and are followed by an example situation inspired by Kok (2005).

Table A.1: Difference between independent and dependent events in flood insurance (Vrijling et al., 2008)

Variable	Independent	Dependent
Insured spreads damage over	Time	Time
Insurer spreads damage over	Insured	Time
Premium revenue per year	$fNpS$	$gNpS$
Number of payouts per year	$\sim Np$	0 or N
Sum of payouts per year	$\sim NpS$	0 or NS
E (total damage per year)	NpS	NpS
σ (total damage per year)	$\sim S\sqrt{Np}$	$\sim NS\sqrt{p}$
V (total damage per year) (σ/E)	$1/\sqrt{Np}$	$1/\sqrt{p}$

In which

N = Number of insured
S = Damage per insured
p = Probability of an event per year
f = Factor for transaction costs, profit and risk aversion with independence
g = Factor for transaction costs, profit and risk aversion with dependence ($g >> f$)

As was stated by Vrijling et al. (2008), with equal expected payout per year E, variation coefficient V becomes a factor $N^{\frac{1}{2}}$ larger for a dependent event. This is visualised with the following example (Kok, 2005).

A hypothetical village located near a river has 2000 houses, which are all worth EUR 500.000.

1. The probability of a **fire** burning down one house is $1/1000$ per year. The probability of a fire burning down a random house is independent of all other houses.
2. The probability of a **flood** occurring, which destroys all houses, is $1/1000$ per year.

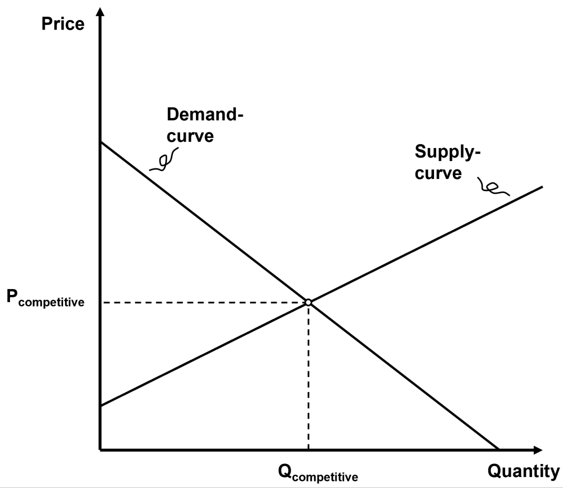
The expected payout E for both situations is NpS = EUR 1,000,000. The variation coefficient V in the event of a fire (independent event) is $1/\sqrt{Np}$ = 0.71, while the variation coefficient V in the event of a flood (dependent event) is $1/\sqrt{p}$ = 31.62. This massive difference in variation coefficient ($N^{\frac{1}{2}}$ = 44.72) puts a lot of uncertainty at the insurer. This will result in the insurer using a substantially larger factor for risk aversion $g >> f$ when charging its premium to customers.

A.2. Catastrophe bond

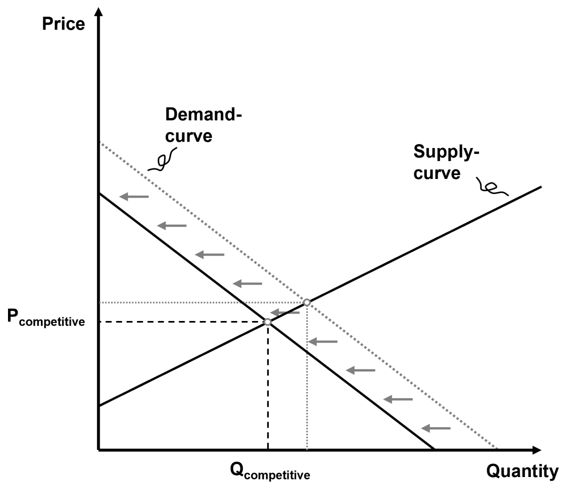
The catastrophe bond (CAT bond) is a high-yield debt instrument issued by insurance companies to mitigate the effects of natural disasters. The CAT bond is designed such that in the event of a natural disaster, like a flood or an earthquake, the issuer of the bond receives funding and the obligation to pay interest and repay the principal is either deferred or forgiven (Murphy, 2020). This transfers the risk of the natural disaster from the insurer to investors. Due to its high impact on investors in case of a natural disaster, the interest paid on the bond is usually fairly high (high-yield).

A.3. Economic equilibria

An understanding of market equilibria will only be provided in basic form. For further understanding of the concept, the literature is recommended (see Debreu (1959) and Varian (1992)). In a market with *perfect competition*, meaning all companies sell identical products, market share does not influence price, companies are able to enter or exit without barriers, buyers have perfect or full information, and companies cannot determine prices, a market equilibrium will occur in which the quantity demanded matches the quantity supplied (Debreu, 1959). The equilibrium price and quantity are called the *competitive price* and *competitive quantity*, and will only change due to a change in demand or supply. This is visualised in figure A.1, with the market in its initial equilibrium in figure A.1a, and a newly formed equilibrium after a change in demand due to a decrease in quantity demanded in figure A.1b.



(a) Market equilibrium



(b) New equilibrium due to a change in demand

Figure A.1: Shift in market equilibrium

A.4. Adverse selection

Adverse selection occurs when there is information asymmetry in a market between buyers and sellers, meaning that one party has more information of the good which is being sold than the other. This information asymmetry will lead to a disruption in the market, resulting in the failure of the market equilibrium. This is also called equilibrium *unraveling* (Hendren, 2014). The effects of private information in insurance markets and potential problems were described by Akerlof (1970) and Rothschild & Stiglitz (1976). In the work of Akerlof (1970), information asymmetry leads to an *equilibrium of market unraveling*, in which the equilibrium exists in a market in which only the worst quality good is traded since all other goods have left the market. According to Rothschild & Stiglitz (1976), private information leads to an *unraveling of market equilibrium*, where insurance companies have an incentive to cream skim lower-risk agents from competitors, again destroying the market. Both phenomena are described in sections A.4.1 and A.4.2 respectively.

A.4.1. Akerlof

This famous principle has been described by Akerlof (1970) using the second-hand car market. In this example, the market of second-hand cars consists of cars of different quality, the ”lemons” being the poorest quality cars, and the ”peaches” being the highest quality cars. Here, the sellers are well aware of the quality of the car they are selling, but the buyers are not. Therefore, the buyers will not be willing to pay more than the average price of all cars. Since the sellers know what their car is worth and will not be selling below that, those with a car worth more than the average price will leave the market. A new market is created, with a new average of what a car is worth. This creates a positive feedback loop, which results in the destruction of the market since all sellers will have leave it eventually.

This principle is easily applied to insurance. Here, individuals which are likely to have high costs (i.e. ”sick” people) are classified as the lemons, and individuals with low costs (”healthy” people) the peaches. The knowledge of whether an individual will have high or low costs is known by the individual self. In case of health insurance, heavy drinkers or smokers know that they will likely receive higher healthcare costs than individuals who eat healthy and exercise regularly. To insurers, all individuals are regarded as having an equal amount of risk. This results in the aforementioned information asymmetry. The insurers will base the premium of the entire pool on the average of all people included, which covers the total health care costs. Assuming that all individuals act rationally, the portion of ”healthier” individuals will not take out an insurance as the cost of the insurance is greater than their healthcare costs and thus their benefit. This again will result in the positive feedback loop mentioned above, resulting in complete failure of the insurance pool.

This does not only apply to health insurance, as was described above, but also to flood insurance. In this case, the information asymmetry is not the case with the question *if* an accident will occur. After all, insurers nor insured know when a flood occurs. However, the insured do have an advantage as they are well aware of the damage that will incur if their house or business is flooded. Where one agent may have canned food and household supplies in their basement, the other may have a high-tech data storage system. While both basements will be flooded, one will have much higher costs than the other. The insurers will charge everyone the same average price of all expected damage that will incur in one year. Therefore, the agent with low expected damage in case of a flood – in this case the one with the canned food – will leave the market. Again, this will lead to the positive feedback loop as described above, where eventually no one will take out an insurance.

A.4.2. Rothschild and Stiglitz

Similar to Akerlof (1970), Rothschild & Stiglitz (1976) have covered the topic of information asymmetry in their work, demonstrating that insurance markets unravel due to competition between insurance firms.

First, an introduction to the model and the space from the work of Rothschild & Stiglitz (1976) is given, see figure A.2. The model represents an economy with two types of insurance takers, low-risk types and high-risk types. A certain fraction f of all individuals are high-risk. The low-risk individuals have a certain chance p_L of incurring an accident in a given year, and the high-risk individuals have a chance $p_H > p_L$ of incurring one. The space consists of a state in which an individual has no accident and one in which it has an accident. The x-axis represents the amount of income without such an accident, denoted by W_{NA}, and the y-axis represents the amount of income with an accident, denoted by W_A. This space is cut in half by the *45°-line*, which represents equal income in both states. Point E is the uninsured state. Here, an individual has the maximum amount of income when it incurs no accident (since it will not pay any premium), and the minimum amount when it does occur an accident, namely its income minus the cost of the accident, denoted by P and C respectively. The line $R - P$ represents the reimbursement the agents receives from the insurance company minus the premium paid. For reference, the area in which an insurance does not exist is shaded in figure A.2. The reader is encouraged to demonstrate that this statement holds for all contracts in the space (W_{NA}, W_A).

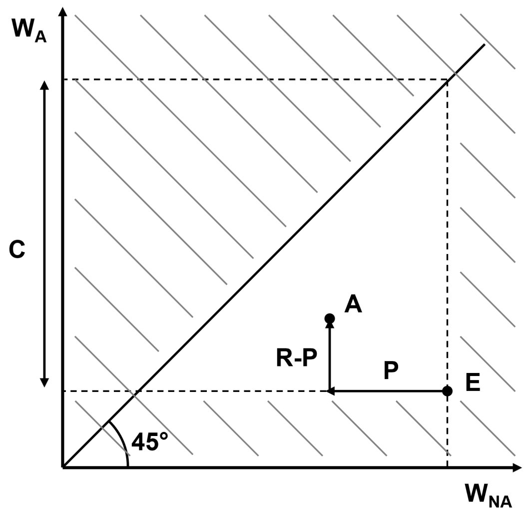


Figure A.2: Available space for insurance packages in the Rothschild and Stiglitz model

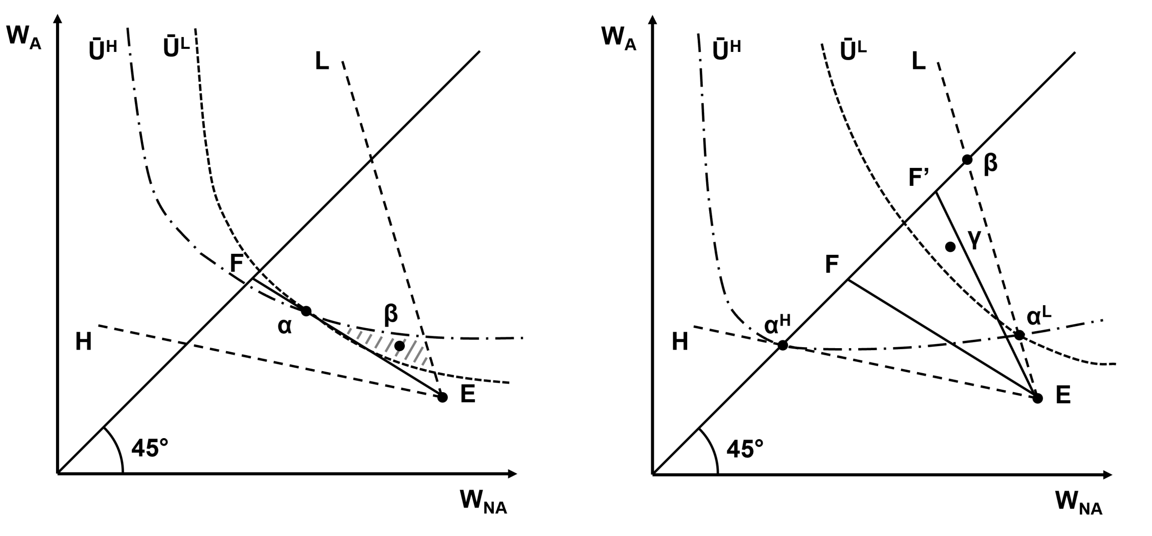
With the space of the model explained, three critical assumptions are introduced (Chetty, 2012):

1. **Static model**: individuals either occur an accident or not and do not anticipate on this in the future, meaning no *dynamic adverse selection* [1].
2. **No moral hazard**: agents choose an insurance contract but make no choices after signing a contract.
3. The insurance market is **perfectly competitive**, meaning firms earn zero profits in equilibrium.

[1] In dynamic adverse selection, individuals are able to anticipate on future outcomes. For example, when an insurance company covers an anticipated expense like child birth, an individual will want to switch to a different contract if it plans to become pregnant (Chetty, 2012).

An equilibrium occurs in this market when the following statements are true. First, all individuals pursuit optimisation, meaning that both the low-risk and high-risk types cannot find a better contract than the ones they have chosen. Second, firms pursuit optimisation, leading to all firms in the market to earn zero profits. This leads to two types of equilibrium:

1. **Pooling equilibrium**: both low-risk and high-risk individuals are offered the same contract α.
2. **Separating equilibrium**: low-risk and high-risk individuals are offered the contracts α^L and α^H respectively.



(a) Pooling equilibrium

(b) Separating equilibrium

Figure A.3: Unraveling of pooling and separating equilibrium in the Rothschild and Stiglitz model (recreated from Rothschild & Stiglitz (1976))

Pooling equilibrium

First, the non-existence of the pooling equilibrium will be explained, see figure A.3a. The same space (W_{NA}, WA) from figure A.2 is taken. The lines EL and EH represent the *actuarially fair lines* of low-risk and high-risk individuals respectively. The actuarially fair line represents all contracts on which the insurer earns zero profit, meaning the expected premium is equal to the expected reimbursement. The line EF represent the pooling line, which visualises the pool of low- and high-risk types. The direction the pooling line is leaning to represents the majority type in the pool. For reference, about two-thirds of individuals in the pool are of the high-risk type in figure A.3a. A random contract α is offered on the pooling line. This contract is offered by all existing firms in the market. The location of the contract on the pooling line represents the relative amount of reimbursement an individual receives in case of an accident. Remembering that the *45°-line* represents full insurance and point E represents zero insurance, gives that point α in figure A.3a represents a contract in which around 75% of damage is covered by the insurer and 25% by the individual in case of an accident. The lines $\bar{U}^L$ and $\bar{U}^H$ represent the indifference curves of low-risk and high-risk individuals. The indifference curve represents a set amount of utility an individual has in the space (W_{NA}, WA), meaning that for every contract along the curve the individual has the same amount of appetite. All contracts above the indifference curve are desired in favour of a contract on the indifference curve, and all contract below it are disliked. The difference in steepness of the curves relates to the character of the individuals. If the perpendicular line above the curve is the most desirable direction, it is clear that low-risk types favour less premium over higher reimbursement, and high-risk types favour the opposite. This is logical if one thinks about the motive of the individual.

Now a new firm with enters the market offering a contract β, see figure A.3a. This contract is located above the indifference curve for low-risk types $\bar{U}^L$, attracting all low-risk individuals, beneath the indifference curve for high-risk types $\bar{U}^H$, deterring the high-risk individuals, and left of the actuarially fair line of lor-risk types, meaning that the insurance company makes a nonnegative amount of money on the contract from low-risk types. This is called a *cream-skimming package*, where only the low-risk types – and thus the profitable customers from an insurers perspective – are attracted to a contract. This would result in a situation in which only the high-risk types are left in contract α. The premium from the high-risk types that are left in the contract would not be enough to reimburse all costs inflicted by the high-risk types, resulting in a higher premium. This unravels the equilibrium in a similar fashion that has been seen with Akerlof (1970). Since point α was randomly taken in the space, this also disproves the existence of a pooling equilibrium.

Separating equilibrium

Second, the existence of a separating equilibrium is explored. In a separating equilibrium, the contracts of the low- and high-risk types are separated in stead of pooled. A contract for high-risk individuals in offered on the intersection of line EH and the 45°-line, which represents a contract which fully insures the high-risk types and makes a zero-profit for the insurers. Now, the indifference curve for high-risk types $\bar{U}^H$ is drawn which is relatively flat (due to reasons explained above). The best possible contract for low-risk types to offer is at the intersection of lines EL and $\bar{U}^H$. This contract provides the most insurance for the low-risk types, without attracting the high-risk types (by offering contract β for example), which would lead to a pooled equilibrium as described above. This again demonstrates the problem of asymmetric information, where insurance companies can not now if they offer a contract to a low-risk or high-risk individual. Therefore, all individuals who demand a contract β are sold one.

To determine whether this equilibrium is stable, a pooling line F' is drawn. This pooling line intersects the 45°-line between the intersections of lines $\bar{U}^H$ and L. In this situation, a new firm is able to offer a new contract, here denoted by point γ, which will attract both low- and high-risk types, and make a nonnegative profit for the insurance company as it is located to the left of the pooling line. This proves that the current separating equilibrium is disrupted and therefore it is not stable.

Now, a second pooling line F is drawn, intersecting the 45°-line between the intersections of lines H $\bar{U}^H$ this time. In this situation, it is clear that there is no contract in the space (W_{NA}, WA) which attracts both low- and high-risk individuals and makes a nonnegative profit for the insurance company. Therefore, it is proven that in case the pooling line F intersects the 45°-line between the intersections of lines H and $\bar{U}^H$, there exists a separating equilibrium. Simply said, if there are sufficiently many high-risk people such that EF represents the market, there exists an equilibrium since γ will not make a nonnegative profit (Rothschild & Stiglitz, 1976).

B
Substantiation model assumptions

B.1. Linear versus logarithmic relation Impact Curve

To evaluate the assumption from Section 4.1.3 which sets the relationship between points on the impact curve to be linear, both linear and logarithmic models are examined in this section. This will demonstrate the difference between methods, provide insight into why the assumption was made, and give the quantitative difference between both approaches.

First, to understand the significance of the relationship type for impact points, a housing shape is randomly selected and its impact points are plotted in four different configurations, alternating between linear and logarithmic x-axis and relationships, which is presented in Figure B.1. It becomes evident that a linear relationship on a logarithmic x-axis appears counter-intuitive, whereas a logarithmic relationship yields a more coherent curve that aligns closely with the plotted points. It is important to remember that the area under the impact curve equates to the Yearly Expected Damage (YED).

To calculate the area underneath a curve with a logarithmic relationship between each point, 4 logarithmic functions for every housing shape need to be defined, resulting in over 50,000 logarithmic functions. Subsequently, for each of these functions, definitive integration needs to be applied to calculate the area underneath the function, which represents the YED. This process is computationally very intensive.

However, to calculate the area underneath a curve with a linear relation, a simple Trapezoidal Rule can be applied, which can be easily replicated across all points. Therefore, given the need for simplicity and computational efficiency, a linear assumption is considered justifiable.

To further illustrate the discrepancy between linear and logarithmic approaches, the areas under the curve for five randomly selected housing shapes are computed using both relationships. The process starts with extracting impact points from the model, plotting them on an appropriate probability scale, and then calculating the area under the curve for both linear and logarithmic relations. These calculations are detailed in Table B.1.

From Table B.1, it is seen that the linear relation yields a YED which is approximately 41% higher than the logarithmic relation. This difference is deemed considerable, and thus, it is advised that in future research a logarithmic approach is applied.

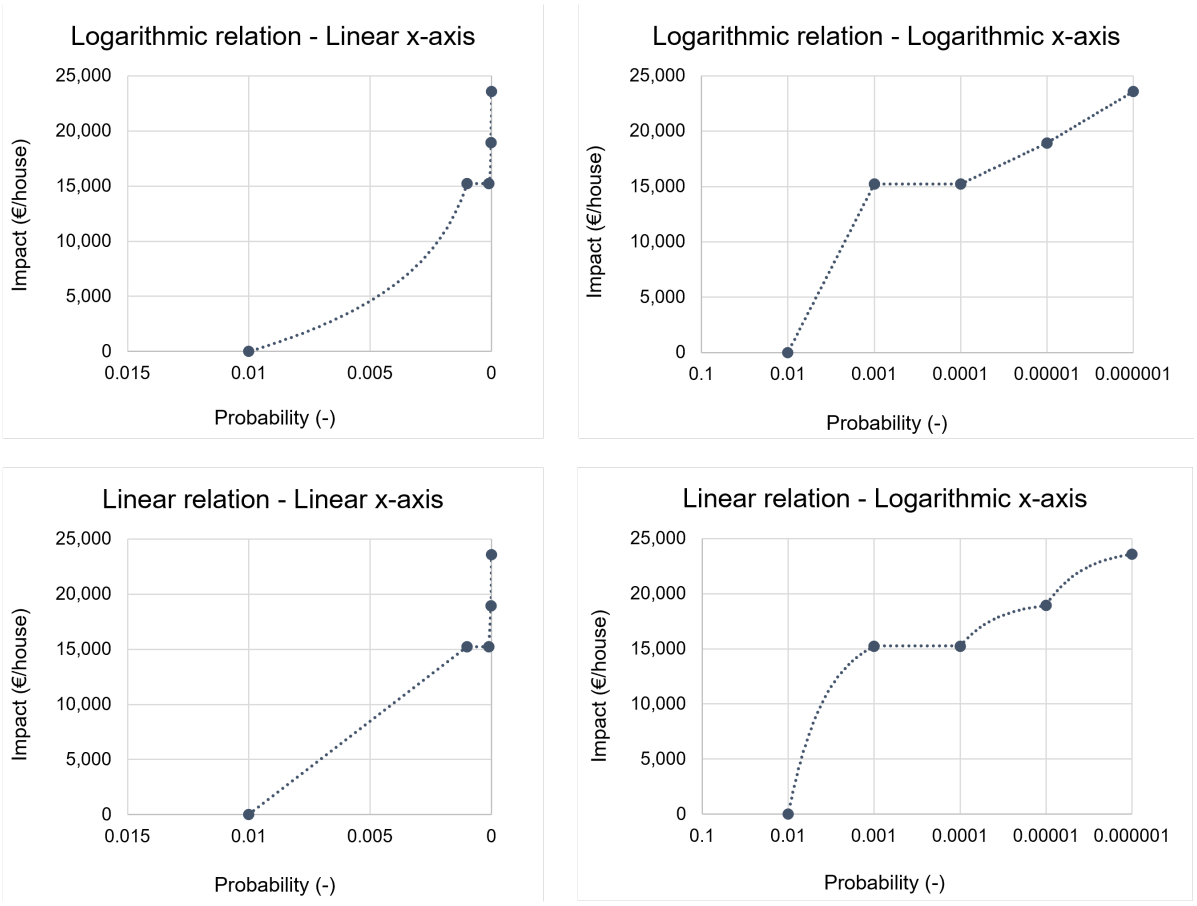


Figure B.1: Impact point relation and x-axis configuration

Table B.1: Difference in area (YED) between logarithmic and linear relationship between impact points

Return period (x-axis)	$1.0{\cdot}10^2$	$1.0{\cdot}10^3$	$1.0{\cdot}10^4$	$1.0{\cdot}10^5$	$1.0{\cdot}10^6$
Impact (y-axis)					
Shape 1	0.0	15,215	15,215	18,929	23,575
Shape 2	0.0	0.0	0.0	203,632	216,047
Shape 3	0.0	0.0	19,845	19,845	19,845
Shape 4	0.0	0.0	106,686	112,663	124,120
Shape 5	0.0	0.0	0.0	65,090	72,915
YED	Shape 1	Shape 2	Shape 3	Shape 4	Shape 5
Linear relation (€/h/y)	83.89	11.05	10.90	58.95	3.55
Logarithmic relation (€/h/y)	63.48	7.79	7.74	41.85	2.50
Difference (%)	**40.7%**	**41.8%**	**40.8%**	**40.8%**	**41.9%**

C

Expert Judgment Analysis

C.1. Weighted and unweighted data

Table C.1: Standard deviation round 1

Stdev R1	Unweighted						Weighted					
	US	UK	BE	SP	NL	Avg	US	UK	BE	SP	NL	Avg
Risk predictability	27.50	20.79	23.90	21.42	37.27	26.17	28.60	20.00	20.22	23.57	38.32	26.14
Cumulative risk	32.87	21.87	22.91	17.40	7.50	20.51	36.31	24.49	24.73	18.63	7.00	22.23
Correlated risk	29.92	26.64	28.33	19.52	35.71	28.02	31.21	19.29	27.92	22.44	33.99	26.97
Risk perception	28.87	20.79	31.72	26.73	33.17	28.25	29.93	20.00	33.74	26.68	34.74	29.02
Adverse selection	29.97	22.02	15.81	15.81	39.28	24.58	27.49	24.29	15.00	17.68	39.24	24.74
Moral hazard	41.87	22.36	12.50	11.79	23.57	22.42	39.69	23.11	11.46	11.79	20.00	21.21
Charity hazard	31.13	26.68	27.39	36.98	20.79	28.59	35.56	24.65	19.98	36.98	21.58	27.75
Average	31.73	23.02	23.22	21.38	28.18	25.51	32.69	22.26	21.86	22.54	27.84	25.44

Table C.2: Standard deviation round 2

Stdev R2	Unweighted						Weighted					
	US	UK	BE	SP	NL	Avg	US	UK	BE	SP	NL	Avg
Risk predictability	26.35	15.71	16.67	24.80	30.10	22.73	27.78	14.34	17.62	23.57	30.59	22.78
Cumulative risk	28.87	21.87	19.64	12.50	7.50	18.08	31.72	24.49	19.64	12.50	7.00	19.07
Correlated risk	29.92	26.35	23.57	12.10	33.91	25.17	29.93	18.71	20.83	12.50	32.06	22.81
Risk perception	25.76	16.67	27.24	17.40	30.52	23.52	27.24	14.34	27.72	12.50	31.83	22.73
Adverse selection	23.57	27.78	9.32	12.37	37.42	22.09	23.75	25.82	7.50	12.50	37.01	21.31
Moral hazard	24.74	18.71	12.50	30.62	23.57	22.03	22.26	20.41	11.46	30.62	20.00	20.95
Charity hazard	25.75	26.68	10.00	43.59	11.79	23.56	26.79	24.65	9.32	43.59	12.18	23.30
Average	26.42	21.97	16.99	21.91	24.97	22.45	27.07	20.39	16.30	21.11	24.38	21.85

Table C.3: Standard deviation difference

Difference	Unweighted						Weighted					
	US	UK	BE	SP	NL	Avg	US	UK	BE	SP	NL	Avg
Risk predictability	-1.15	-5.07	-7.23	3.38	-7.16	-3.45	-0.82	-5.66	-2.60	0.00	-7.73	-3.36
Cumulative risk	-4.00	0.00	-3.26	-4.90	0.00	-2.43	-4.59	0.00	-5.09	-6.13	0.00	-3.16
Correlated risk	0.00	-0.29	-4.76	-7.41	-1.80	-2.85	-1.28	-0.58	-7.08	-9.94	-1.93	-4.16
Risk perception	-3.11	-4.12	-4.47	-9.33	-2.65	-4.74	-2.69	-5.66	-6.02	-14.18	-2.91	-6.29
Adverse selection	-6.40	5.76	-6.49	-3.44	-1.87	-2.49	-3.74	1.53	-7.50	-5.18	-2.24	-3.43
Moral hazard	-17.13	-3.65	0.00	18.83	0.00	-0.39	-17.43	-2.69	0.00	18.83	0.00	-0.26
Charity hazard	-5.38	0.00	-17.39	6.61	-9.00	-5.03	-8.78	0.00	-10.67	6.61	-9.40	-4.45
Average	-5.31	-1.05	-6.23	0.54	-3.21	-3.05	-5.62	-1.87	-5.56	-1.43	-3.46	-3.59

Table C.4: Average impact round 1

Avg R1	Unweighted						Weighted					
	US	UK	BE	SP	NL	Avg	US	UK	BE	SP	NL	Avg
Risk predictability	72.22	61.11	63.89	40.63	58.33	59.24	76.56	60.00	72.22	41.67	54.84	61.06
Cumulative risk	69.44	72.22	69.44	40.63	97.50	69.85	71.88	80.00	68.06	41.67	97.86	71.89
Correlated risk	77.78	63.89	55.56	46.88	65.00	61.82	76.56	68.33	63.89	45.83	68.57	64.64
Risk perception	75.00	63.89	53.13	25.00	45.00	52.40	73.44	65.00	62.50	20.83	45.00	53.35
Adverse selection	43.75	32.14	25.00	25.00	38.89	32.96	48.21	41.07	30.00	25.00	42.74	37.41
Moral hazard	54.17	50.00	62.50	66.67	33.33	53.33	67.31	43.75	57.50	66.67	40.00	55.04
Charity hazard	46.43	45.83	50.00	56.25	86.11	56.92	55.77	54.17	54.17	56.25	83.87	60.84
Average	62.68	55.58	54.22	43.01	60.60	55.22	67.10	58.90	58.33	42.56	61.84	57.75

Table C.5: Average impact round 2

Avg R2	Unweighted						Weighted					
	US	UK	BE	SP	NL	Avg	US	UK	BE	SP	NL	Avg
Risk predictability	75.00	55.56	75.00	34.38	62.50	60.49	78.13	56.67	76.39	41.67	60.00	62.57
Cumulative risk	75.00	72.22	69.44	37.50	97.50	70.33	78.13	80.00	69.44	37.50	97.86	72.59
Correlated risk	77.78	66.67	58.33	40.63	65.00	61.68	73.44	70.00	62.50	37.50	67.14	62.12
Risk perception	69.44	66.67	56.25	15.63	47.50	51.10	68.75	68.33	66.07	12.50	47.86	52.70
Adverse selection	41.67	34.38	20.83	14.29	40.00	30.23	45.31	48.21	22.50	12.50	43.57	34.42
Moral hazard	71.43	55.00	62.50	50.00	33.33	54.45	69.23	50.00	57.50	50.00	40.00	53.35
Charity hazard	42.86	45.83	55.00	35.00	91.67	54.07	48.08	54.17	54.17	35.00	90.32	56.35
Average	64.74	56.62	56.77	32.49	62.50	54.62	65.87	61.05	58.37	32.38	63.82	56.30

Table C.6: Average impact difference

Difference	Unweighted						Weighted					
	US	UK	BE	SP	NL	Avg	US	UK	BE	SP	NL	Avg
Risk predictability	2.78	-5.56	11.11	-6.25	4.17	1.25	1.56	-3.33	4.17	0.00	5.16	1.51
Cumulative risk	5.56	0.00	0.00	-3.13	0.00	0.49	6.25	0.00	1.39	-4.17	0.00	0.69
Correlated risk	0.00	2.78	2.78	-6.25	0.00	-0.14	-3.13	1.67	-1.39	-8.33	-1.43	-2.52
Risk perception	-5.56	2.78	3.13	-9.38	2.50	-1.31	-4.69	3.33	3.57	-8.33	2.86	-0.65
Adverse selection	-2.08	2.23	-4.17	-10.71	1.11	-2.72	-2.90	7.14	-7.50	-12.50	0.83	-2.99
Moral hazard	17.26	5.00	0.00	-16.67	0.00	1.12	1.92	6.25	0.00	-16.67	0.00	-1.70
Charity hazard	-3.57	0.00	5.00	-21.25	5.56	-2.85	-7.69	0.00	0.00	-21.25	6.45	-4.50
Average	2.05	1.03	2.55	-10.52	1.90	-0.60	-1.24	2.15	0.03	-10.18	1.98	-1.45

C.2. Questionnaire

The questionnaire is included on the following page.

Flood insurance in the Netherlands:
Expert Judgment Analysis

Dear participant,

As part of my graduation thesis, which explores possible solutions for a flood insurance system in the Netherlands covering damage incurred by flooding of primary flood defences (along the coast, big lakes and big rivers), I will perform an expert judgment analysis. Expert judgment analysis is a research methodology used to gather expert opinions on a specific topic. Valuable insights into topics which lack hard data are gained by gathering the opinions of experts in this field.

This expert judgment analysis is performed according to the Delphi method, a widely used approach within expert judgment analysis. It is a structured process that involves several rounds of anonymous questionnaires and feedback, with the goal of reaching a consensus among experts on a particular issue.

As a panel of experts in the field of (flood) insurance, your participation in this Delphi method study is crucial in quantifying the impact of several failure mechanisms on flood insurance systems / reimbursement schemes and additionally providing valuable insights and rationales. Both the failure mechanisms and the insurance systems are introduced hereafter, after which you are asked to provide your expert judgment on the topic.

It is important to note that the Delphi method is a scientific method and therefore it is crucial to maintain objectivity and impartiality throughout the process. The anonymity of the process stimulates unbiased and uninfluenced opinions among participants.

I would like to thank you in advance for your participation and contributions to this study. Your expertise and insights in the (flood) insurance sector will be invaluable in helping this research obtain a better understanding of the pros and cons of different insurance systems reimbursement schemes that are being used.

With kind regards,

Olivier Platzer,

Under supervision of Prof. dr. ir. Matthijs Kok (TU Delft)

Introductory information

In order to create a more level playing field among different experts, a summary of both the failure mechanisms and the insurance systems is provided here. Participants are asked to read through the information before filling in the expert judgment form. Comments on the content of the information can be made in the designated field.

Failure mechanisms of flood insurance

Risk predictability

Risk predictability refers to the ability to accurately predict the likelihood and potential impact of a flood event. This is important for insurers as they need to be able to assess the risk in order to set premiums that both cover potential pay-outs and attract customers to purchase insurance contracts. However, due to the low occurrence of floods and the dependency between flood events, it is difficult for insurers to predict flood risk, making them more difficult to insure than other types of risks such as fires. This is known as low-probability high-impact events. If a flood in an area becomes a medium-probability, medium-impact event, the impact of risk predictability is mitigated.

Cumulative risk

Cumulative risk refers to the accumulation of potential damage in one year from multiple events or policies. In the context of insurance, it refers to the potential damage that an insurance company may incur from a large-scale catastrophe where multiple policies incur damage at the same time. This can cause financial strain on the insurer, potentially resulting in bankruptcy. Cumulative risk is mainly mitigated by spreading the risk portfolio over a large area. This way, a single flood can only impact a small part of the portfolio.

Correlated risk

Somewhat similar to cumulative risk, correlated risk refers to the risk that when one event occurs, it is likely that other related events will also occur. For instance, there is a large possibility that a flood occurs during a storm. This means that in the event of a storm, both contracts against storm damage and flood damage pay-out, leaving the insurance company at great risk. Again, this is correlated by spreading the risk portfolio.

Risk perception

Risk perception refers to how individuals evaluate and perceive potential hazards and risks. It is an important factor in flood insurance, as people's perceptions of risk often differ from expert assessments, and their actual risk often exceeds their perception. The theory of subjective expected utility, states that individuals form a subjective probability of uncertain outcomes, upon which they decide if and how to take action to mitigate the effects. This means that with a low perception of the risk of flooding, individuals are less likely to take out insurance, making it difficult for a market for flood insurance to emerge.

Adverse selection

Adverse selection refers to a market failure that occurs due to information asymmetry between buyers and sellers, meaning one party has more information about the good being sold than the other. This information asymmetry can disrupt the market equilibrium. In the context of insurance, Adverse selection occurs when insurance companies don't have enough information about the risks of the policyholders, while policyholders know their own risks. This results in low-risk individuals not taking out insurance, since they would be worse off. This can lead to the unravelling of the market. In the case of flood insurance, two forms of adverse selection can arise; one from people living in flood-prone areas being more likely to demand insurance and second from a discrepancy in information regarding the damage the insured would incur. Solutions to this problem can be screening low-risk from high-risk individuals and making insurance compulsory in the contents insurance.

Moral hazard

Moral hazard refers to an increase in risk-taking behaviour by an insured individual because of the presence of insurance. It arises from information asymmetry between the insured and the insurer, where the insured has more information about the actions they take. The concept is also known as the principal-agent theory, in which the agent (insured) has a conflict of interest with the principal (insurer) due to information asymmetry. In flood insurance, although limited, the possibility of moral hazard exists. While agents cannot influence the possibility of a flood, they can influence the amount of damage incurred by a flood. Therefore, an agent with coverage against flooding has a reduced incentive to prevent damage from a flood. Due to the fact that agents cannot influence the possibility of a flood, but only the amount of damage, only the mitigation measures which influence the value of damage are relevant.

Charity hazard

Charity hazard refers to the reduction in willingness to pay for insurance by individuals due to the expectation of free compensation from the government or other higher institutions in the event of a large-scale catastrophe such as a hurricane, terrorist attack or flood. This can lead to underinsurance or lack of insurance against damage from such events, and can result in high costs for society. The existence of government aid may remove the incentive for individuals to protect and mitigate risks, and it may be difficult to mitigate charity hazard as politicians may use the compensation of damage to gain political support among citizens. However, in countries with low occurrence of floods, the charity hazard may be reduced among the population due to a low acquaintance with government-provided financial aid.

Flood insurance systems

United States

The National Flood Insurance Program (NFIP) is a program established by the American government in 1965 to provide access to flood insurance and mitigate and reduce the comprehensive flood risk by implementing floodplain management standards. It is managed by the Federal Emergency Management Agency (FEMA) and covers over USD 1.3tn in assets spread across 5 million flood insurance policies. Communities can volunteer to participate in the program and in return must adopt the program’s minimum standards to reduce and mitigate flood risk. The FEMA produces the Flood Insurance Rate Maps, which dictate risk and premiums for the communities. Individuals in communities participating in the program can buy coverage against various forms of flood risk. Currently, the program is USD 20.5bn in debt to the US Treasury after it had to borrow heavily to pay claims after major natural disasters and it pays interest at a rate of over USD 1m per day.

United Kingdom

Flood reinsurance in the UK is handled by Flood Re Limited (Flood Re), which oversees the Flood Reinsurance Scheme. The scheme's goal is to promote available and affordable home insurance for homes at risk of flooding in the UK. It is intended to be a transitional solution to a home insurance market which can cover risks by itself, which is aimed to be achieved by 2039.The scheme is intended for individuals living in an area at risk of flooding, unable to obtain affordable buildings and contents insurance. It is not mandatory for homeowners to join Flood Re but taking out flood insurance is often a condition of getting a mortgage on a property. All flood claims are handled through the insurers and paid out through the Flood Re scheme, protecting the insurers of high costs by spreading the risk across the industry. The scheme is a joint initiative between the UK Government and the insurance industry and was established in 2014. The scheme provides reinsurance coverage for individuals at a subsidised rate and is financed by a levy on all UK household insurers. To incentivize building in non-flood-prone areas, all buildings built after 2009 are excluded from the scheme.

Belgium

The Belgian system has gone through an evolution in recent years. At first, a model of national solidarity was applied with the National Disaster Fund. People affected by disasters (i.e., flooding) could apply for compensation. Since 2005, the role of the fund has been reduced. Currently, coverage for flood-induced damage is mandatorily included in fire insurance policies offered by private insurance companies. However, while most individuals (95% of Belgian homeowners) do have fire insurance, it is not mandatory. The premium is assessed by the insurer and the insurer may adjust additional premiums or reward a deductible on a risk-based basis. In practice, most insurers offer flat premiums for the additional flood risk in the fire insurance bundle.

Spain

In Spain, flood insurance is managed by the Consorcio de Compensación de Seguros (CCS), which is a state-owned public business organization that is attached to the Ministry of Economic Affairs and Digital Transformation. The CCS acts as a supplementary service to Spain's insurance industry, and its main task is to provide coverage for extraordinary risks that are not specifically covered by insurance policies taken out by insurers, one of which is flooding. The CCS does not issue any policies but only compensates claims in the case of extraordinary risks, which are determined as such by the Spanish government. Flooding has historically accounted for the majority of claims, consisting of 69% of total claims from 1987-2018. The income of the CCS is derived from premiums, surcharges, and yields on investments, and it must set aside enough capital to meet its solvency requirements.

The Netherlands

In the Netherlands, compensation of flood-related damage is split by in insured damage and uninsured damage. Insured damage mainly includes damage by local rainfall events and flooding of so-called regional flood defences. Currently uninsured is damaged caused by flooding of *primary flood defences*. The primary flood defenses in the Netherlands are a combination of dikes, dams, and storm surge barriers which protect the low-lying area of the country from flooding from the sea, lakes and major rivers. All primary flood defences are designated as such by Rijkswaterstaat. Defences not included are considered *regional flood defences*. Compensation of damage caused by flooding of primary flood defences is arranged through the "Wet tegemoetkoming schade bij rampen" (Wts). Under the Wts, individuals and businesses can claim compensation for damages to their property, possessions, and loss of income due to natural disasters like flooding. To be eligible for compensation, the damages must be caused by a natural disaster that has been officially declared as such by the government, and to which there is no option to insure against. Damage is never fully compensated through this arrangement, but only intended to cover the most severe costs. In addition, the Wts is not applicable in case of flooding from the sea (flooding of salt water).

Comments

This section provides an opportunity to comment on the content described above. Commenting is not required and only recommended if deemed useful for the second round of the analysis.

Comments on content of failure mechanisms

Comments on content of insurance systems

Expert judgment analysis

You are asked to provide you expert judgment in this form. Please rate the impact of failure mechanisms 1 – 7 on the flood insurance/reimbursement systems A – E. **++** indicates that the failure mechanism has a *very high* impact on the system, meaning a serious threat to the viability of the system. **– –** indicates a *very low* impact on the system, meaning hardly any / no threat to the system. If a failure mechanism cannot take place in a certain system, please respond with *not applicable* (*).

In addition to quantifying the impact of the failure mechanisms, you are kindly asked to provide a short rationale for your decision. This rationale and the rationale of other participants will be assessed, summarized, and subsequently returned to all participants before the second round. This will enable all participants to assess the views of other experts before entering the second round in which the same questionnaire will be handed out. This way, according to the Delphi-method, a form of consensus can be reached among the experts.

An example could be country X, which is a sparsely populated country with frequent occurrence of floods. One could argue that the failure mechanisms *risk predictability* has a *low* or *very low* impact on the viability of the system, since the impact of the flood would be low (sparsely populated) and anticipation is high (regular flooding).

Contact details

Please provide your contact details below. The contact details will only be known to the issuers of this form and will under no circumstances be shared with any other participants/third parties.

Name: *	
Company / institution:	
Job title / function:	
Email: *	
Phone:	
My name may / may not be mentioned in the thesis report*	

** Fields marked with an asterisk (*) indicate mandatory fields*

Familiarity with insurance systems

Please indicate your familiarity with the five insurance / reimbursement systems covered in this analysis.

	US	UK	Belgium	Spain	Netherlands
Familiarity					

++ = most familiar – *"I am a true expert on this subject"*

\+ = very familiar – *"I know quite a lot about this subject"*

+/- = familiar – *"I am knowledgeable about this subject"*

– = not so familiar – *"I have heard about this subject"*

– – = not familiar at all – *"My knowledge of this subject is purely from the information provided"*

Risk predictability

	A	B	C	D	E
*	US	UK	Belgium	Spain	Netherlands
1 Risk predictability					

++	= very high impact	+	= high impact	+/-	= moderate impact
–	= low impact	– –	= very low impact	*	= not applicable

** All fields in this table are mandatory fields*

Please provide your rationale for your choice at A1 – E1

A1	
B1	
C1	
D1	
E1	

Cumulative risk

	A	B	C	D	E
*	US	UK	Belgium	Spain	Netherlands
2 Cumulative risk					

++	= very high impact	+	= high impact	+/-	= moderate impact
–	= low impact	– –	= very low impact	*	= not applicable

** All fields in this table are mandatory fields*

Please provide your rationale for your choice at A2 – E2

A2

B2

C2

D2

E2

Correlated risk

	A	B	C	D	E
*	US	UK	Belgium	Spain	Netherlands
3 Correlated risk					

++ = very high impact + = high impact +/- = moderate impact
– = low impact – – = very low impact * = not applicable

** All fields in this table are mandatory fields*

Please provide your rationale for your choice at A3 – E3

A3	
B3	
C3	
D3	
E3	

Risk perception

		A	B	C	D	E
	*	US	UK	Belgium	Spain	Netherlands
4	Risk perception					

++	= very high impact	+	= high impact	+/-	= moderate impact
–	= low impact	– –	= very low impact	*	= not applicable

** All fields in this table are mandatory fields*

Please provide your rationale for your choice at A4 – E4

A4	
B4	
C4	
D4	
E4	

Adverse selection

		A	B	C	D	E
	*	US	UK	Belgium	Spain	Netherlands
5	Adverse selection					

++	= very high impact	+	= high impact	+/-	= moderate impact
–	= low impact	– –	= very low impact	*	= not applicable

** All fields in this table are mandatory fields*

Please provide your rationale for your choice at A5 – E5

A5

B5

C5

D5

E5

Moral hazard

		A	B	C	D	E
	*	US	UK	Belgium	Spain	Netherlands
6	Moral hazard					

++	= very high impact	+	= high impact	+/-	= moderate impact
–	= low impact	– –	= very low impact	*	= not applicable

** All fields in this table are mandatory fields*

Please provide your rationale for your choice at A6 – E6

A6

B6

C6

D6

E6

Charity hazard

		A	B	C	D	E
	*	US	UK	Belgium	Spain	Netherlands
7	Charity hazard					

++	= very high impact	+	= high impact	+/-	= moderate impact
–	= low impact	– –	= very low impact	*	= not applicable

** All fields in this table are mandatory fields*

Please provide your rationale for your choice at A7 – E7

A7

B7

C7

D7

E7

Overview

	*	A US	B UK	C Belgium	D Spain	E Netherlands
1	Risk predictability					
2	Cumulative risk					
3	Correlated risk					
4	Risk perception					
5	Adverse selection					
6	Moral hazard					
7	Charity hazard					

** All fields in this table are mandatory fields*

++ = very high impact
+ = high impact
+/- = moderate impact
– = low impact
– – = very low impact
* = not applicable