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# When is it beneficial for insurers to engage in climate change adaptation - a cross country comparison

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**Abstract.** Natural hazard insurance is suggested an important mechanism to boost climate change adaptation and especially flood risk prevention at individual level and thus decrease losses caused by weather-related disasters. But there is a gap between the theoretical potential described by academic scholars and the actual engagement of insurers. In this paper, this issue is analyzed from the insurers perspective and it is discussed under which conditions it becomes profitable for them to engage in climate change adaptation. It is shown that for many adaptation measures high market penetration over a longer time-period is crucial to make investments profitable. This condition if often only fulfilled in compulsory monopoly insurance systems. Risk-based pricing to incentivize decentralized single-property measures, is seldom done in practice. Bundling of several risks, high market competition and increased transaction costs, but also the required high upfront payment of policy-holders are considered as hinders.

## 1 Introduction

Economic losses of weather-related hazards are already high and expected to increase in the future (CEA, 2009; Jongman et al., 2014; Paudel et al., 2015; Swiss Re, 2012). Between 2000 and 2016, hydrological events, i.e. flooding, caused 123 billion USD of overall losses, while only 36 billion were insured (Munich Re, 2017). Mainly socio-economic developments, but also climate change can largely be held accountable for rising loss trends, with valuable assets increasingly exposed to flood risks (Alfieri et al., 2016; Botzen et al., 2010; Kundzewicz et al., 2014). The negative impacts of rising flood losses, challenge governments, the public and the private sector to develop sustainable flood risk management mechanisms aimed at reducing those losses (Michel-Kerjan and Kunreuther, 2011; Mills, 2005). Acknowledging the slow progress and limited success of climate change mitigation in reducing greenhouse gases, sustainable adaptation is seen as one necessary management strategy to reduce and manage the risks of climate change (Eisenack et al., 2014; IPCC, 2014). Adaptation is defined as adjustment to actual or future implications of climate change aiming to avoid harm or to exploit benefits (IPCC, 2014). It should be noted that in natural hazard research the terms ‘adaptation’ and ‘mitigation’ are often used synonymously in the sense of reducing impacts or losses (see e.g. Bouwer et al. (2014)). In this paper, I will use the terms ‘adaptation’ and ‘prevention’ when I talk about risk reduction measures. Adaptation measures are in detail discussed in section 2.

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Another indispensable mechanism in disaster risk management is risk transfer i.e. the spreading of losses in time and/or space, shared with third parties in exchange for a premium (Bouwer et al., 2014; Duus-Otterström and Jagers, 2011; Warner et al., 2009). This is often done by insurance schemes. Insurance gives affected people fast access to capital for reconstruction in the aftermath of a disaster, and without insurance many activities would simply be too risky to be undertaken (Ranger et al., 2011). Beyond this core function of insurance, there is growing recognition of the large potential that insurance has in providing incentives for boosting adaptation and damage prevention (Botzen et al., 2010; Bräuninger et al., 2011; Herweijer et al., 2009; Kunreuther, 1996; Surminski and Eldridge, 2015). This aspect also received attention among policy makers: The European Union asks in its Green Paper on insurance of natural and man-made disasters (EC, 2013), how risk transfer mechanisms can better fulfill their prevention role (Surminski, 2014). The re-insurance industry also appeals to combine flood insurance and prevention (Swiss Re, 2012). Rather than being common practice, the link between insurance and prevention, to-date, appears either to be more theoretical in nature, or lagging behind in its infancy stage (Smolka, 2006). Existing examples and potential insurance engagement in climate change adaptation are described in section 5.

Flood insurance schemes in developed countries additionally have many different forms, concerning who provides them, if they are compulsory or on a voluntary basis, which hazards they cover, for whom they are available and how the products are designed (Bouwer et al., 2007; Johannsdottir, 2017; Lamond and Penning-Rowsell, 2014; Porrini and Schwarze, 2014; Suykens et al., 2016). This means there is no 'one solution fits all' approach. Mechanisms to incentivize adaptation will work differently in the various insurance schemes. And equally, similar flood prevention measures will perform differently given the local circumstances. Beside insurers, municipalities are considered as central actors in local climate change adaptation and flood risk reduction. Central governments also play an important role, as they set up legislative frameworks for insurance activities, or in some countries they also act as direct insurers, reinsurers or insurers of the last-resort. The following section will discuss more on this issue.

There is a small but steadily growing body of literature, which looks at the potential of insurance to foster climate change and flood risk adaptation. Present studies have focused on which economic instruments can be used to incentivize adaptation (Bräuninger et al., 2011; Filatova, 2014), how the insurance system should be designed to support more adaptation (Kunreuther, 1996; Lamond and Penning-Rowsell, 2014; Michel-Kerjan and Kunreuther, 2011), how adaptation is or could be considered in the recovery process (Priest et al., 2016; Suykens et al., 2016), the distribution of responsibilities between insurers and the government (Keskitalo et al., 2014), and also recently on how policy and market factors hamper or support insurers engagement in promoting adaptation (Glaas et al., 2016; Surminski et al., 2015), or how in certain regions or countries current insurers contribute to climate change mitigation and adaptation (Johannsdottir et al., 2014; Poussin et al., 2013).

This article takes a slightly different perspective by asking what the potential benefits for insurers would be to become directly engaged in their policyholders or the public's adaptation activities or support adaptation activities. I investigated academic and grey literature, as well as available internet sources to identify examples of insurers engaged in adaptation as well as suggestions about their possible involvement. Taking into account different flood protection measures and various framing conditions such as the flood insurance system, the design of products, or market penetration, I discuss what are the benefits

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for insurers in becoming engaged in these activities, and what are the possible hindrances in doing so. The aim was not to create an exhaustive overview of existing initiatives, but to explore what is done, what could be done, and try to understand why insurance companies are not engaging more in adaptation.

The outline of this article is as follows: in section 2, I explain the flood risk adaptation measures that exist and how they function. Section 3 provides some background information on flood insurance. Section 4 shortly describes the research approach. Findings of current insurance engagement in flood risk adaptation are presented in section 5, as well as suggestions for further activities. The conditions for which engagement is beneficial for insurance providers is also discussed. Section 6 ends with some concluding remarks.

## 2 What are flood protection measures and how do they work?

Flood adaptation measures are courses of action that either reduce frequency of occurrence or strength of the hazard, the value or number of exposed assets, or the vulnerability of the people at risk. Flood risk management today relies on a mix of structural and non-structural measures (Fuchs et al., 2017; Kreibich et al., 2015; Krysanova et al., 2008; Kubal et al., 2009). Bouwer et al. (2014) categorized adaptation measures in 9 different categories: 1) infrastructure/large-scale structural adaptation measures, 2) hazard modification, 3) decentralized small-scale adaptation measures, 4) prior-to-event communication and education measures including knowledge sharing, 5) monitoring and early warning, 6) emergency response, 7) risk management planning including land-use planning and building codes, 8) risk transfer and 9) financial incentives. For the purpose of our paper I grouped them into the following superior groups:

- structural adaptation and hazard reduction (1-3),
- information, communication, education and knowledge sharing (4-6),
- legislative and regulative adaptation measures (7) and
- financial incentives and risk transfer (8,9).

In the legislative and regulative adaptation measures group, the categories lawsuits on flood damages and agreements between insurers and governments were added. All categories of measures are described in detail in the following section.

### 2.1 Structural adaptation and hazard reduction

**Large-scale structural adaptation infrastructure** such as dams, dikes, embankments, reservoirs and polders (controlled retention basins), or slope stabilization measures decrease the risk of flood occurrence or the magnitude of the event and have proven their effectiveness in flooding events (Thieken et al., 2016). Common to all measures is that safety is only provided when well maintained (i.e. do not fail) and when design levels are not exceeded (Thieken et al., 2016). Two main functionalities of such infrastructure should be distinguished: infrastructure that protects an area from being inundated i.e. keeps the water outside (e.g. dams and dikes), and infrastructure which enables extra room for water storage such as reservoirs and polders. The first type of infrastructure only avoids flooding in a certain area and can have adverse consequences downstream as greater



levels of water flow there. The second type of measures reduces water volume and is thus beneficial for all downstream areas. This difference is important to consider when considering possible downsides to large-scale adaptation infrastructure. Avoidance of flooding leads to a self-reinforcing cycle, of protected areas attracting further economic development (i.e. the number and value of assets increases), which in turn leads to the claim of even stronger flood defense (Filatova, 2014).

Another option for hazard reduction is the **modification of the hazard** itself. Measures include cloud seeding to change precipitation, artificial triggering of snow avalanches by explosion, but also the maintenance or construction of retention areas for floods (Bouwer et al., 2014). Some measures allow modification of single events, such as cloud seeding to trigger precipitation, and are thus relatively inexpensive. Other measures require the modification of larger areas (e.g. extension of floodplains or wetlands) and are more costly. For flooding, a typical hazard modification measure is the use of controlled retention areas also called polders, which allow capping flood peaks and thus reduce damages further downstream (Förster et al., 2005; Thieken et al., 2016). Possible future applications of single-event modifications in the context of floods might include cloud seeding to trigger precipitation when meteorological conditions, which have lead previously to large flooding, coincide with unfavorable hydrological conditions (e.g. moisture saturated or frozen soils).

While large-scale structural adaptation measures aim to reduce the probability of flood occurrence or its strength, **decentralized small-scale adaptation measures** can also reduce the negative consequences of flooding. There are a broad variety of structural and non-structural measures: publicly funded water conservation or protection programs (i.e. conservation of wetlands) that aim to retain water in landscapes, privately funded single-property building measures as elevation or dry- and wet-proofing of houses, or non-structural strategies, such as removing all valuable items from the basement of a property. Several studies demonstrated the effectiveness of these kinds of adaptation measures (Hudson et al., 2014; Kreibich et al., 2005, 2011; Poussin et al., 2015), but also showed that the effectiveness of each measure very much depends on local circumstances, for example, the characteristics of the flood (Hudson et al., 2014; Poussin et al., 2015). It is easy to imagine that mobile water barriers on doors and windows will have no effect once they are surpassed, whereas securing oil tanks against buoyancy will be effective, independent of flood water depth (Kreibich et al., 2011).

### 2.2 Information, communication, education and knowledge sharing

Different forms and various channels of communication are used to raise awareness and increase understanding around issues of climate change, flooding, flood risk, adaptation measures and insurance, and how they are all linked (Bouwer et al., 2014). Several studies underscored the importance of activities related to communication, although it is criticized that the effect of communication or information campaigns are not evaluated (Kousky, 2017).

**Communication and education measures targeting citizens** include mass media campaigns in newspapers, radio, TV and internet, but also compulsory information disclosure for rented or sold properties, as well as education programs. They aim to inform citizens about risk, market insurance policies, but also to promote decentralized small-scale adaptation measures. Partnerships between insurers and governmental actors including municipalities often aim to **share knowledge or data** related to flood risk, i.e. historic flood claims or improved flooding maps.



Besides targeted information with a specific purpose, there are also communication forums, which aim to bring together insurers, researchers, adaptation experts, NGOs and policy-makers to share and discuss their experiences.

**Monitoring and early warning activities** encompass meteorological and hydrological observations, often in combination with forecasting models, which allow predictions of approaching hazards. In addition, successful early warning systems require that citizens receive the warning, understand it and react by taking the appropriate **emergency response measures**. Emergency responses involve removing mobile items of value from the area at risk (such as cars), that temporary small-scale adaptation measures such as floodgates or sandbags are put in place and populations are evacuated. In most developed countries monitoring and early warning activities, as well as emergency response measures are tasks fulfilled by local authorities, although in case of severe events, national governments also provide help. Communication and information sharing does not reduce flood risk as such, except for emergency response measures, although making information available and understanding the risk is an important precondition for the successful implementation of other adaptation measures.

### 2.3 Legislative and regulative adaptation measures

Planning is considered an important factor in flood risk management as well as in climate change adaptation (Botzen and Van Den Bergh, 2008; Hurlimann and March, 2012; Measham et al., 2011; Petrow et al., 2006). As required by the EU floods directive**, flood risk management plans** describe strategies to reduce the impacts, taking into account hazard, exposure and vulnerability throughout the whole risk management cycle, with a focus on prevention, protection and preparedness (Bouwer et al., 2014; EC, 2007).

**Land-use planning** is an integral part of flood risk management, as it allows prevention of future developments that increase flood losses by, for example, avoiding new settlements in flood-prone areas or restricting the use of those areas (Botzen and Van Den Bergh, 2008). Land-use planning takes place at national, regional and local levels, and across levels (Bouwer et al., 2014; Petrow et al., 2006).

Another strategy is the enforcement of **building codes**, which can reduce the vulnerability of buildings to flooding and thus also, damages. Flood-adapted building encompasses four strategies: evasion, resisting, drawback and securing (Kreibich et al., 2005). Evasion means to keep the water away from buildings by elevating the house (Aerts and Botzen, 2011; Kousky, 2017) or by using moveable flood barriers. Resisting means that the building was waterproofed and the basement fortified during construction so that despite surrounding the building, water is not able to enter and cause damage to the building's structural integrity. A drawback strategy allows water to enter the buildings however significant damage is averted as the interior is built of flood-resistant materials and sensitive utilities (e.g. energy and water supply installations) are avoided in lower floors. Securing encompasses the safeguarding of hazardous substances, such as oils or chemicals, which could increase damage considerably (Kreibich et al., 2011). There are building codes that are valid for all properties, but in flood-prone areas, building codes are often more strict (Aerts and Botzen, 2011).



Land-use planning and building codes are strategies targeted towards the future: they will only affect built-up areas when complete reconstruction of buildings is necessary or in the case of relocation. Both strategies must be enforced by the government to ensure they are an effective tool against future flood losses.

Even though not directly considered a flood adaptation measure, I added the category **lawsuits on flood damages**. Lawsuits are most common either by private persons or insurance companies, against the government. All levels of government can be sued, from national to local governments, and even municipalities (Kusler, 2011). The argumentation chain is often that the government omitted the implementation of structural adaptation measures, insufficiently designing or maintaining them, or that land-use planning did not consider the flood risk to a sufficient extent. If governments are increasingly declared liable for flood damages via lawsuits, a strong signal is sent on the importance of flood risk prevention.

**Agreements between insurers and governments** can be considered another tool to foster flood adaptation. The content of these agreements can be of variable nature; ranging from informal agreements on the roles of insurers and governments in flood risk management to very detailed agreements, specifying for example, cooperation activities.

### 2.4 Financial incentives and risk transfer

**Risk transfer**, or the spreading of losses between people and/or in space and over time can occur via insurance schemes, but also via the use of relief funds (Bouwer et al., 2014). While insurance schemes are based on a contract between the insurer and the policy-holder and can thus be considered more reliable, relief funds are often only paid in the case major events with significant losses (e.g. the EU solidarity fund), or on an ad hoc basis, for example after severe flooding in Germany (DKKV (ed.), 2015; EC, 2014). Insurance schemes for natural disasters, including flood, differ considerably between countries (Lamond and Penning-Rowsell, 2014; Priest et al., 2016). In section 3 it is discussed in detail how flood insurance functions.

Insurance schemes can comprise **financial incentives** aimed at reducing losses by stimulating adaptation and risk-reducing behavior. Premiums, deductibles and to a certain extent, coverage specification can be considered as different types of financial incentives insurers can give. Deductibles were introduced in insurance contracts to avoid moral hazards (Wang et al., 2008), but to also fulfill a function as ‘co-insurance’, i.e. the policy-holder also carries a part of the risk (Smolka, 2006). The rationale behind financial incentives is that flood-proof design of new buildings or installation of adaptation measures on existing buildings is rewarded with lower premiums, lower deductibles and increased coverage (Kunreuther, 1996). But the opposite approach is also possible: lacking engagement in adaptation can be penalized with higher premiums and deductibles, reduced coverage and the exclusion of certain assets or events, up to complete refusal to provide insurance. Insurance withdrawals are possible for single properties, high risk areas, but also for complete markets, as for example flood insurance in the US in 1929, which led to the creation of the National Flood Insurance Program (NFIP) (Thomas and Leichenko, 2011) or in 1953 in the Netherlands where insurance companies declared flood risk uninsurable (Suykens et al., 2016).



Governments can also establish financial incentives to facilitate adaptation. They can provide grants or cheap loans to private persons or municipalities for investing in adaptation measures. And even on a supranational scale, financial incentives are provided: the European Investment Bank financially supported flood risk reduction in EU member states (Bouwer et al., 2014). Cooperation with third parties from the financing sector is also possible. For example, the government or a bank could provide a loan to the policy-holder to implement adaptation measures. The policy-holder in return can pay lower premiums. This arrangement benefits all parties: the policy-holder benefits from increased protection and lower premiums, the insurance company from decreased losses, the bank from selling a loan, and if they provide the mortgage on the property, from increased protection too, in addition to the government, from increased protection and decreased losses.

To lead to significant loss reductions on a larger scale (e.g. national), financial incentives must be offered and subsequent measures implemented by a large enough number of people. Financial incentives by insurers only function when market penetration is high enough, preferably in markets where coverage is mandatory (Smolka, 2006).

## 3 How does flood insurance work?

Insurance is based on the principle of solidarity, i.e. individual persons get together to form a risk-bearing community in the case of losses, to cover the loss of its individual members. This function is today organized and coordinated by insurance companies, which offer insurance to individuals in exchange for a premium. The collected premiums are then used to compensate individual losses.

In principle risks are considered insurable when the following conditions are fulfilled: there is a **large enough number of exposed people** that perceive they might suffer a **considerable loss** that they cannot cope with alone. Subsequently, if they wish to share this risk with a third party there is a demand for insurance. The loss itself must **happen randomly** and must **be evident**, i.e. it must be possible to demarcate it i.e. it happens at a certain time interval, at a defined place, and from a known cause. In order to offer insurance, insurers must be able to **calculate expected losses** by knowing their probability of occurrence as well as the costs attached to recovery. Historic data is often used to assess this. Many risks occur with different frequencies and intensities and therefore insurance companies must be sure that there is **only limited risk that catastrophically large losses will occur**. Furthermore, insurers must be able to offer a product at an **affordable premium** so that demand can be met. At the same time, **economic feasibility** must be known, i.e. the sum of premiums should at least be high enough to cover the expenses of the insurer (loss compensation plus administrative costs) or in case of private insurance companies, to also generate a profit.

These criteria must not be seen as absolute: catastrophically large losses are at least partly transferrable to reinsurance companies and financial markets, and sometimes governments take the role as insurer of the last resort as for example the Consorcio de Compensación de Seguros in Spain. Demand can be sufficiently created by bundling one type of risk with another (e.g. fire insurance is bundled with flood insurance in Belgium) or by making insurance compulsory for everyone. Affordability



for low-income groups can be accomplished by state subsidies; for example in the US, low-income households can receive premium discounts, although this practice has now been phased out (Kousky and Kunreuther, 2013).

Insuring against floods is a challenging issue (Swiss Re, 2012). First, it is technically difficult to assess exposure, probability of occurrence and potential losses. Climate change complicates this further as it is still largely unknown how climate change will impact flood risk in detail (Kundzewicz et al., 2014). Second, the risk-bearing community is often too small: only people who perceive to be at risk from flooding, demand insurance. This is linked to another problem, called **adverse selection**; those living in highly exposed areas seek more coverage than those with low or no exposure (Swiss Re, 2012). To build up financial resources enough to cover potential damages would require high premiums, which in turn counteract the affordability criterion. It is not surprising that from a mathematical point of view certain areas or properties are considered uninsurable. This is often where the government steps in – nevertheless this intervention can have very different forms. The degree to government intervention ranges from taxpayer financed flood loss compensation in the Netherlands, monopoly insurance systems as in Switzerland [1] and Spain, compulsory all-natural-hazard or bundled insurances (e.g. France), to single-hazard mixed government-private sector systems (US) and private insurance markets with only limited or ad-hoc compensation by the government (e.g. Germany, UK). Flood insurance can also be quasi-compulsory, meaning that the insurance itself is voluntary, but for example, needed for taking up a property mortgage (Smolka, 2006). To explore this, several scholars have carried out comparative reviews of insurance systems in different countries (Bräuninger et al., 2011; Keskitalo et al., 2014; Lamond and Penning-Rowsell, 2014; Paudel, 2012; Porrini and Schwarze, 2014; Suykens et al., 2016).

Government interventions can have advantages and disadvantages. When losses are compensated by the tax-payer or by ad-hoc post disaster government assistance (as in Germany after severe flood events in 2002 and 2013) (Thieken et al., 2016) this can lead to a problem called **moral hazard**: people at risk do not see the necessity to purchase insurance or undertake prevention measures as they presume their losses are already covered. Unfortunately, moral hazard can also occur when large structural prevention measures are implemented. Living behind a dike is often perceived as safe. Similarly will premiums that do not fully reflect the risk, such as subsidized premiums or flat-rate premiums (as well as bundled insurance where the premium reflects several risks), mask the severity of the risk and thus the urgency to adopt prevention measures (Lamond and Penning-Rowsell, 2014). Moral hazard can also occur at the government level,, where high insurance market penetration or the availability of emergency funds (as from the European Solidarity Fund) might lower the urgency for the government to implement prevention measures (Surminski, 2014; Surminski et al., 2015).

Differences also exist in the design of flood insurance products. Coverage exists for damages to buildings, their contents, and cars, as well as to cover business interruption, the loss of agricultural harvest or damages to infrastructure. A distinction is often made between different types of flood, which is necessary to demarcate the event. Examples include riverine flood,

[1] For Switzerland it should be noted that most articles characterize the Swiss system as a monopoly insurance system (see e.g. (Bräuninger et al., 2011; Porrini and Schwarze, 2014). In fact this is only true for 19 of the 26 cantons. In the remaining cantons, where natural hazard insurance is not provided by Cantonal Insurance Monopolies, private companies compete in a free-market system (Paudel, 2012).



coastal flood/storm surge, flash flood, torrential rainfall, dam burst, ice jam, mudflow, lahar, groundwater flooding or tsunami (Swiss Re, 2012). There is insurance that covers only one type of flood, several, or that bundle the flood risk together with other natural hazards, such as the French all-hazards insurance (Bräuninger et al., 2011). The insurance contract specifies the length of the contract, premium and deductibles, coverage and exclusions (e.g. of certain types of events or certain assets) as well as special conditions (Surminski and Eldridge, 2015). These special conditions can include the implementation of preventive measures. In combination with the premium, deductibles and coverage are considered the lever to trigger more preventive behavior (Kunreuther, 1996). Theoretically, special conditions could be formulated for every individual policy-holder. The disadvantage is that this would require the insurer to follow up that the conditions are fulfilled, which raises their **transaction costs** (Botzen and Van Den Bergh, 2008). Nowadays one-year insurance contracts are most common (Bräuninger et al., 2011). This is often seen as a barrier for risk prevention, as most measures only pay off in the long run – both for insurance companies as well as policy holders (Michel-Kerjan and Kunreuther, 2011).

## 4 Research approach

This research can be described as a desk-study of explorative character. I examined scientific literature in research databases (Google Scholar, Web of Science, Oria) for key words and combinations, such as “flood”, “natural hazard”, “climate change”, “insurance”, “prevention”, “adaptation” and “mitigation”. And I used the references cited in these articles to search further. To find examples of insurance activities I searched Google for websites containing information on “insurance” and flood adaptation measures described previously. The search was performed mainly in English and German and concentrated on developed countries. As stated, my aim was not to perform an exhaustive search, but one more explorative in nature and thus will not give a complete overview of all insurance activities in relation to climate change and flood adaptation.

## 5 Results and discussion

### 5.1 Activities related to investment in, or incentives for structural adaptation and hazard reduction

#### 5.1.1 Large-scale structural adaptation measures

Usually it is the government who invests in structural adaptation measures. To my knowledge there are no insurers to-date directly financing prevention measures on their own. From a purely economic point of view, investments in structural adaptation measures are rentable, when the amount of avoided losses exceeds the investment. A precondition for making such kinds of investment profitable for insurance companies is that the policy-holders protected by the measures stay with the same insurer over a long period, i.e. at least until the investment is paid-off. Due to the dominance of one-year contracts, this precondition is today only fulfilled in countries where insurance is compulsory, such as Switzerland, Spain or France or quasi-compulsory, as in flood-zones in the US.



In Switzerland, where a dual system of public and private natural hazard insurance exists, the public monopoly insurers invest on average 15% of their premium incomes in prevention (Ungern-Sternberg, 2004). But also private insurance companies co-found structural adaptation measures in municipalities[2]. Nevertheless, public investments in risk reduction are much higher in districts with a district insurance monopoly (Paudel, 2012). Hungary is also mentioned as a country where insurers play an indirect role in risk reduction investments (Surminski et al., 2015).

In the US, the NFIP offers incentives for communities to implement large scale adaptation measures. Communities who joined the NFIP can voluntarily participate in the community rating system (CRS), which offers premium reductions for the implementation of a list of flood protection measures. This list also contains dams and levees as structural adaptation measures (Sadiq and Noonan, 2015). But the overall success of this approach seems to be low: by 2014 only 5% of all NFIP communities participated in the CRS (Kousky, 2017) and by 2013 none of them were credited for the measures levees or dams (Sadiq and Noonan, 2015).

A completely private insurance market has existed in the UK since 1960, when insurers and the government agreed that insurance should be provided to all households and small businesses, but that the government must invest in flood defense. This can be also interpreted as an incentive to preventative measures. The agreement has been revised several times over the years, and although the new 'Flood Re' insurance Scheme still contains this requirement , there is no mechanism to monitor compliance defined (Surminski and Eldridge, 2015). As it currently exists, the agreement has been heavily criticized: there is sparse evidence that insurers were reducing their premiums, despite implementation of large-scale structural adaptation measures by the government i.e. the expected benefit in the form of avoided losses was not transferred to society or policy-holders, but resulted in additional profit for insurance companies (Penning-Rowsell, 2015). Evidence on this issue is difficult to provide as flood insurance is offered bundled, with other hazards, making it difficult to disentangle the flood proportion of the premium. To overcome this situation, Penning-Rowsell (2015) suggests that insurance companies must be forced to reduce premiums in the case that significant risk reductions are expected (2015).

Largely, the main hindrance for increased insurer engagement in large-scale structural adaptation measures is probably that insurers currently do not see it as their role to directly provide or invest in risk reduction measures (Surminski et al., 2015; Swiss Re, 2013).

#### 5.1.2 Risk reduction by hazard modification

Similar to structural adaptation measures, investments in hazard modification are cost-efficient when large losses can be avoided or reduced. Financing measures that modify single hazard events (e.g. a hailstorm or a snow avalanche) can be rentable for private, as well as state insurers, even when only short, one-year contracts are issued. For measures that are not targeted towards single events and are expected to have long-lasting effects, such as flood retention areas, the investment is unlikely to pay off in the short-term, but after several years. As a result, long-lasting contracts are required and insurance penetration must

[2] https://www.mobiliar.ch/die-mobiliar/engagement/uebersichtskarte-engagements#?topic=34



be high enough, which is again, usually only the case in compulsory state systems. An example of event-based hazard modification is the Alberta Hail Suppression Project. In 1996, several private insurance companies joined forces and funded the Alberta Severe Weather Management Society, which coordinates cloud seeding to avoid or reduce the power of hail storms each year between 1. June and 15. September[3] in the large agricultural area south of Calgary, called the Canadian "Hailstorm Alley". Similar projects exist in the US for triggering precipitation[4]. To my knowledge there are currently no single flood modification measures applied by insurers.

#### 5.1.3 Loss-reduction by decentralized private small-scale adaptation measures

There is a steadily growing body of literature which proves the effectiveness of single-property adaptation measures to reduce risk (Bubeck et al., 2012; Hudson et al., 2014; Kreibich et al., 2005, 2011; Poussin et al., 2015). However, the engagement of insurers in positively acknowledging single-property flood risk reduction measures in the pricing of insurance-policies or in their recovery policies is very limited (Thieken et al., 2006). There are likely two reasons for this. First, even though there is general evidence that building protection measures reduce losses, their efficiency varies depending on the type of measures taken, as well as local flooding conditions. To consider those measures when calculating risk-based premiums would thus require detailed knowledge of the local conditions, which is not always available (Kousky, 2017). Second, insurers would have to follow-up to check if the measure was adopted by the single policy-holder, which is especially difficult for temporary protection measures such as water barriers or non-structural measures, such as the removal of valuable items from basements. Both would require an increased effort in handling single policies and thus rise the transaction costs for insurers considerably, which makes this less or unrentable at present (Botzen and Van Den Bergh, 2008). This does not have to be the case in the future. In the past, the reason for similar premiums was often the absence of accurate, location specific information (Penning-Rowsell, 2015). As more data becomes available, the effectiveness of measures can be calculated taking into account flood event characteristics (see Hudson et al (2014) for a scientific example), thus results will be more generalizable.

A barrier for policy-holders to implement flood adaptation measures is certainly the large upfront-investment required (Aerts and Botzen, 2011; Bräuninger et al., 2011; Kunreuther, 1996). Such an investment must be done all at once, while benefits in the form of lowered premiums or deductibles will accrue over a long period of time. Bräuninger et al. (2011) illustrated this with a clear example: estimating a high premium of 400 EUR to insure an average-sized private building against flooding, even a large discount of 25% would only yield 100 EUR in savings, which is far from being enough to install any prevention measures. The authors argue that only high deductibles, which are lowered after implementation of measures, could motivate policyholders to invest in preventive measures. Because only when the expenses for the deductible are in the same range as the costs for implementing adaptation measures, the rentability of the adaptation measure becomes obvious for the policy holder.

[3] https://www.awinins.ca/blog/what-is-the-hail-suppression-program-and-how-does-it-work
[4] http://www.weathermodification.org/projectlocations.php



A suggestion to overcome this dilemma is that insurers or cooperating banks provide inexpensive loans to invest in adaptation measures (Botzen and Van Den Bergh, 2008; Kunreuther, 2006), which require the precondition of long-term contracts between insurers and policy-holders, or regular re-purchase of insurance (Kunreuther and Michel-Kerjan, 2009; Savitt, 2017). When the monthly repayments for the loan are less than the difference between the insurance premium with and without adaptation measures, there would be a clear financial gain for the policy-holder (Bräuninger et al., 2011).

In practice, only the NFIP in the US offers grants to policy-holders to implement adaptation measures on existing buildings, or to upgrade them to comply with current building codes in the case of severe damages (Kousky, 2017). In case of severe repetitive damages, the policy-holder has to implement adaptation measures to avoid an increase in premiums of 150% (Aerts and Botzen, 2011). Unfortunately, currently the list of adaptation measures that are eligible for grants is very short and includes only elevation of houses, flood-proofing and relocation (Aerts and Botzen, 2011; Kousky, 2017).

In private systems, approaches to strengthen private adaptation seem to be in their infancy. A German insurer mentioned that in single cases they allow for flood-proof reconstruction when this does not cause higher costs than a standard reconstruction following the applicable building codes. The same rule applies in Germany for relocation, i.e. insurers refund costs for recovery at the same place, additional costs due to relocation are not covered (DKKV (ed.), 2015). In the UK in 2017 an initiative was launched where certified surveyors will provide information on building protection measures to property owners, as well as collect data about the effectiveness of these measures after an event and enter it into a database shared by several insurance companies[5]. Such a database in the future could deliver the information needed for single-property risk-based pricing.

### 5.2 Activities related to information, communication and the creation of a knowledge base on adaptation

#### 5.2.1 Information and knowledge sharing with governmental actors, especially municipalities

In a workshop on how to improve the linkages between insurance and disaster risk reduction, lack of access to detailed information was mentioned as a barrier (Surminski et al., 2015). Indeed, information sharing between insurers and governmental actors, in particular, municipalities were suggested in several studies (NOU 2015:16, 2015). Apparent benefits for both governmental actors, as well as insurers, are that they can improve their knowledge base on flood risk by integrating new data sets. For example, in Germany, the insurance industry integrated improved public data into their flood zoning system (ZÜRS), which resulted in a more accurate risk classification, and that more households were considered insurable against flooding. In Switzerland, a large private insurance company combined public natural hazard maps with national economic data and their insurance data, and made the data publicly accessible[6]. In the US, flood insurance-rate maps developed under the NFIP are regarded as an important risk communication tool (Kousky, 2017). In fact, the whole organization of the insurance

[5] https://www.bre.co.uk/news/BRE-Global-to-launch-a-new-certification-scheme-for-property-flood-resilience-surveyors-1217.html

[6] https://www.mobiliar.ch/die-mobiliar/engagement/praevention/mobigis



system is based on these maps, as the flood zones determine who is required to purchase flood insurance. These maps are evaluated regularly and local governments can get engaged in the mapping process and contribute with better data (Kousky, 2017). On the other hand, municipalities can also learn more about their exposure by looking at historic insurance claim data, as they did in a pilot project in Norway. Information transfer from insurers to municipalities might be more problematic compared to the other way around. Claim data is spatially explicit, i.e. data protection issues must be considered. And in private insurance systems, historic claim data has a competitive value and therefore insurers are often reluctant in sharing it (Botzen et al., 2010).

Another example for successful information sharing and public-private cooperation with insurance involvement is the HORA online-platform[7] developed in Austria, which provides risk zoning for natural hazards, including floods, and aims to inform citizens (Stiefelmeyer and Hlatky, 2008). In France, where flood insurance is compulsory and provided by private companies backed up with a state guarantee (Porrini and Schwarze, 2014), a part of the insurance revenues from natural hazard insurance are transferred to the Major Natural Risk Prevention Fund, also known as the Barnier Fund8. This fund finances actions that decrease the exposure of insurers (Poussin et al., 2013; Suykens et al., 2016). In the context of communication, it finances the studies necessary to prepare natural disaster prevention plans, which are obligatory for all municipalities.

There also exists communication fora initiated by insurers or reinsurers to discuss climate change adaptation, including floods. Examples are the Munich Climate insurance initiative (MCII)[9] in Germany, ClimateWise in the UK[10] or international fora like the Extreme Events and Climate Risk forum hosted by the Geneva Association[11] or the UNEP Finance initiative[12].

#### 5.2.2 Awareness campaigns and education of citizens

Insurers have a vital interest in raising public awareness about flood risks, as they need to assure a high enough market penetration to avoid negative selection. In Germany, information campaigns for natural hazard insurance were run by several the federal states with support from the German Insurers Association (GDV). They were quite successful in raising the insurance penetration to on average 40% and managed to double the number of policies within the last 15 years[13]. In France, awareness-raising campaigns are eligible for funding from the Barnier-Fund, which is financed by insurance premiums[14]. In Switzerland, private insurers use the public hazard maps to combine them with information on how to protect private property

[7] http://www.hora.gv.at/
[8] https://www.ccr.fr/en/fonds-publics
[9] http://www.climate-insurance.org/home/
[10] http://www.cisl.cam.ac.uk/business-action/sustainable-finance/climatewise
[11] https://www.genevaassociation.org/research/topics/climate-risk/
[12] http://www.unepfi.org/
[13] http://www.gdv.de/2017/04/mehr-hausbesitzer-versichern-sich-gegen-ueberschwemmungen/
[14] http://www.gdv.de/2016/07/58-000-hausbesitzer-koennen-sich-jetzt-einfacher-gegen-hochwasser-versichern/



from natural hazards[15]. Outreach and marketing campaigns are also run by the NFIP in the US (Kousky, 2017). A survey among private insurance companies in the US showed that nearly half of all interviewed property and casualty insurers mailed leaflets or provided information on their website on how to reduce losses from weather related disasters (Leurig and Dlugolecki, 2013). In Norway, in a cooperation of academia and Finance Norway, an umbrella organization for the financial industry including insurers, an education tool for schools[16] was developed to introduce knowledge about climate change, extreme weather events and prevention (Finans Norge, 2012). In the US, information-based activities rank highest for implementation by municipalities beyond the measures, which are awarded by credit points in the NFIP community ranking system (Sadiq and Noonan, 2015).

#### 5.2.3 Monitoring, early warning and emergency response

Even though monitoring, early warning and emergency response right after or during a flood are governmental tasks, some insurance companies provide a warning-service for policy-holders. For example, a Swiss insurance company offers a mobile phone application that warns the user from approaching natural hazards and at the same time provides safety information on how to reduce losses[17]. The benefit for insurers is that their policy-holders then have the possibility to safeguard movable items (e.g. cars, furniture) and thus reduce losses. The cost of such a service can be considered low, when the insurance company makes use of existing governmental prediction systems and only contributes by disseminating the warning. In addition, this might have positive effects for the insurer-policy-holder relationship.

To my knowledge there are no insurers that are currently engaged in emergency response activities. But insurers try to become active as soon as possible after the damage has occured. During damage appraisal, their employers can often give valuable advice on how to avoid a further increase in damages by properly starting the recovery process.

### 5.3 Activities related to legislative and regulative adaptation measures

#### 5.3.1 Exert influence on land-use planning and building codes

The decree and enforcement of building codes as well as land-use planning procedures are governmental tasks. Due to their importance for flood loss reduction it is not surprising that in countries where the state provides flood insurance, insurers exert influence on land-use planning and building codes. In the US, the NFIP i.e. the insurer itself, sets minimum requirements for participating municipalities concerning their flood zoning and their buildings codes. They require elevation of all new buildings or when heavily damaged buildings are reconstructed, to build above water levels of the 100-year flood line (Aerts and Botzen, 2011; Kousky, 2017, p.17; Petrow et al., 2006). Communities can voluntarily legislate stricter building codes than required by

[15] https://www.zurich.ch/de/services/naturgefahren/start
[16] https://www.miljolare.no/en/aktiviteter/klima/ekstremver/
[17] https://wetteralarm.ch



the NFIP. In New York additional requirements for elevation, and wet and dry flood-proofing of buildings exist, which are distinguished according to whether a building lies in a coastal or an inland risk zone (Aerts and Botzen, 2011). While NFIP was evaluated positively for limiting the vulnerability of new buildings, it was evaluated negatively for its land-use management, giving incentives to settle in hazard areas, instead of limiting new developments in flood zones (Aerts and Botzen, 2011; Johnston, 2012; Pompe and Rinehart, 2008).

In Switzerland, insurers are involved in the process of enforcing building codes. In areas with a determined risk they will for example, check the building plans and requirements for adapted building construction (Camenzind and Loat, 2014). Swiss insurers can also significantly influence land-use planning processes: denying coverage will lead to an adjustment of land-use plans (Petrow et al., 2006).

In private insurance systems, I found no evidence for insurers exerting influence on land-use planning or building plans. A possible reason is that land-use planning and the enforcement of building codes occur mostly at the local level. The transaction costs, i.e. the time and resources it would require from insurers to familiarize themselves with local conditions, are too high in comparison to potential loss reductions.

#### 5.3.2 Lawsuits on flood damages

Legislation on the liability of government in the case of flooding varies from country to country. In the US, governments are not obliged to protect their citizens from flooding or build drainage systems, but if new constructions worsen existing flood conditions they may be liable (Gerrard, 2011). There have been lawsuits in the US where landowners sued governments for giving building permissions which increased flooding on their property (Kusler, 2009). In the US, not only the number of flood-related lawsuits has increased, but also the damages which are disputed, and expected to further increase as flood risk increases (Kusler, 2011). To my knowledge, there are no studies that exist comparing the number and reasons for lawsuits related to flood damages.

#### 5.3.3 Agreements with state actors

There is one example of a very prominent agreement between the government and insurers for flood risk management in the UK. In the 'Gentleman´s Agreement' from 1961 and its subsequent amendments, the insurance industry (represented by the Association of the British Insurers) and the government agreed that private insurers will provide insurance coverage to all dwellings which have a minimum standard of flood protection of 1/75 (i.e. are protected against floods with a recurrence interval of 75 years) (Penning-Rowsell et al., 2014). This threshold can be interpreted as an incentive for the government to establish flood adaptation measures to reduce flood risk below 1/75, and thus enable more households to obtain insurance (Surminski and Eldridge, 2015). It is disputed whether this agreement functions adequately. Insurers are criticized for being the main winners of an increase in risk reduction by means of structural protection measures financed by the government, i.e. the taxpayers (Penning-Rowsell and Pardoe, 2014). In 2013 the agreement was replaced by Flood RE a public-private partnership solution for flood insurance in the UK (Mysiak and Perez-Blanco, 2016).

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### 5.4 Activities related to risk transfer and financial incentives

#### 5.4.1 Risk-reflecting premiums and deductibles as steering tools

In academic literature, the most frequently mentioned mechanisms to stimulate policy-holders to adopt risk-adaptive behavior are premiums and deductibles, which reflect the actual risk a policy-holder is exposed to (Botzen and Van Den Bergh, 2008; Kunreuther, 1996). In a perfect market, with well-informed and rational-acting market participants, insurers would earn enough premiums to cover all losses and policy-holders would implement adaptation measures when it is economically reasonable for them. Reality however, looks a bit different. Firstly, premiums calculations often do not only follow actuarial principles, but are restricted by legislation (Kousky and Shabman, 2014) with the aim to avoid excluding certain policy-holders or to avoid rapid price hikes. In France, where the solidarity principle is very important, all citizens pay the same fixed rate determined by the government, independent from the risk they are exposed to (Suykens et al., 2016). Secondly, flood risk is bundled with other risks so the premium does not reflect a single risk. Bundling flood with other natural hazards (France, Portugal, Switzerland and Iceland), fire (Belgium, Denmark) or building/household insurance (US, Spain) is very common (Lamond and Penning-Rowsell, 2014; Maccaferri et al., 2012). Thirdly, premiums are cross-subsidized, either within a peril, between low and high risks, or between perils. For example, in the US, policy-holders in low risk areas are charged a higher premium than the one which would be adequate for their risk, and thus subsidize high-risk areas where the risk-reflective premium is considered to be too high to be affordable by policyholders (Kousky, 2017; Kousky and Shabman, 2014). Fourthly, market competition in private markets is so high that insurers keep the premiums artificially low to attract more customers; this is for example the case in the UK (Priest et al., 2016). And fifthly, policy-holders or potential policy-holders do not always behave rationally; people tend to underestimate low-probability risks and their need for insurance (Botzen et al., 2013; Kunreuther, 1996). Their decision to purchase insurance relies on their risk perception, previous experience, previous provision of governmental loss compensation, and other factors (Seifert et al., 2013). There is a large body of literature studying behavioral determinants of insurance purchase (see e.g. Botzen and van den Bergh (2012), Bubeck et al. (2013), Kahneman and Tversky (1979), Kunreuther and Pauly (2004), Slovic (1987)), however it would go beyond the scope of this manuscript to discuss this in detail.

In fact, despite being addressed so often in academic literature, risk-reflecting premiums seem to be more the exception than the rule. In Germany, where flood insurance is an optional add-on to building insurance and provided by private companies, risk-based pricing based on flood zoning is applied. Individual risk-pricing on the single property level is uncommon (Thieken et al., 2006). In the UK for example, the new 'Flood Re' scheme hopes to initiate a smooth transition towards risk-based pricing (Surminski and Eldridge, 2015), although at current, risk decrease due to large-scale adaptation measures on the municipal level is not considered in premium prices (Penning-Rowsell, 2015). The NFIP in the US determines its full-risk premiums (i.e. unsubsidized premiums) by considering risk-zones as well as the type of property, and certain property characteristics such as number of floors, existence of a basement or elevation, and several premium adjustment factors in



addition (Kousky, 2017). Such a system could lead to risk-reflecting premiums, but currently the pricing structure is still too coarse, risk-reflection is disturbed by cross-subsidies, and the risk-zoning maps were criticized to be inaccurate; all factors which inhibit reflection of the real risk (Kousky et al., 2016). Indicating a potential risk increase in the near future, are the negative price signals the NFIP can use when communities do not fulfill their criteria for flood management even after notification. In this case, communities are put on probation and can be suspended from the program in the worst case scenario. In the suspension phase a surcharge is added to each new or renewed policy, aiming to make the policy-holders aware of the shortfalls of the community[18] or to exert pressure on the municipal government to fulfill the NFIP criteria.

When it comes to the difference between premiums and deductibles, Bräuninger et al. (2011) argue that risk-reflecting deductibles might be far more effective in promoting risk-adapted behavior than premiums, as they are in a similar order of magnitude as adaptation measures and thus the rentability of an investment becomes more obvious to the policy-holder (see also section 5.1.3). Smolka (2006) argues that policy-holders have to carry a substantial portion of the loss to make deductibles an effective tool to incentivize risk adaptation. He suggests deductibles should be at least 5% of the insured sum or 10% of every loss. A counter argument is that deductibles are uncertain future costs for policy-holders and that they will not notice the cost-effectiveness of adaptation measures in comparison to deductibles before a flood hits them (Priest et al., 2016).

A similar mechanism to exert pressure on local governments via the citizens is used in France, where deductibles increase considerably in the case of repeated losses and when the municipality does not develop risk prevention plans. The aim there is that affected citizens should also lobby the government to implement large-scale adaptation measures. This mechanism does not really appear to be successful (Poussin et al., 2013; Suykens et al., 2016).

From an insurers perspective, risk-adapted pricing is only rentable when market penetration is high enough. This is usually the case in markets with compulsory or quasi-compulsory flood insurance. In free, unregulated markets it is difficult to find a balance between risk-reflecting prices and acceptability and affordability by customers (Smolka, 2006).

There is however, only very limited evidence to-date on the effectiveness of risk-based premiums and deductibles as tools to incentivize risk adaptation.

#### 5.4.2 Special contract conditions, coverage adjustments and withdrawal

Other steering tools insurers use to trigger risk adaptation include special policy conditions in insurance contracts, coverage adjustments or withdrawal of insurance. In Denmark and Iceland, after a flood event insurance policies can require implementation of adaptation measures or coverage will be reduced or insurance completely refused (Priest et al., 2016). In the Netherlands restrictions and exceptions for coverage of losses caused by extreme precipitation exists and are defined in the insurance contracts (Botzen et al., 2010). The NFIP in the US requires that new or reconstructed buildings within the one-

[18] NFIP: Lack of enforcement memo: http://www.msema.org/wp-content/uploads/2012/07/NFIP-lack-of-enforcement-memo.pdf



hundred year flood zone are elevated above the water depth expected for a one-hundred year flood (Aerts and Botzen, 2011; Kousky, 2017, p.17; Petrow et al., 2006). Only with an 'elevation certificate' are property owners eligible for premium reductions (Aerts and Botzen, 2011).

Withdrawal of insurance should be considered as a last resort solution, even though it is a legitimate measure. For large areas, this option is neither in the interest of the public, which have to cover potential losses and thus decrease the financial security of households (Botzen et al., 2010), nor an adequate solution for insurers as they must consider this as foregone business (Smolka, 2006). In history, flood insurance withdrawal often led to the creation of national flood loss compensation systems, such as in the US (Thomas and Leichenko, 2011) or in the Netherlands (Suykens et al., 2016). But both examples showed that withdrawal is often not a permanent solution: in both countries private flood insurance is available once again – even though it is difficult for private insurers to enter the market again.

For smaller areas or single properties at high-risk, withdrawal must be considered as a reasonable solution to avoid high or repetitive losses. The threat of insurance withdrawal is for example used in the NFIP in the US, where policy-holders in the one-hundred year flood zone are only eligible for insurance when they and their municipality fulfill certain adaptation obligations[19].

Unfortunately, there are currently no studies that investigate how often, in which countries, and under which insurance systems insurers made use of the possibility to formulate special policy conditions, adjusted coverage according to risk, or when withdrawal was practiced (Priest et al., 2016).

#### 5.4.3 Other financial incentives by insurers

As discussed in section 5.1.3, the large up-front investment is considered a barrier for policy-holders to implement adaptation measures. It is known from the NFIP in the US that policy-holders can obtain grants to implement adaptation measures (Kousky, 2017), but it is unknown if this is also practiced in other countries. Michel-Kerjan and Kunreuther (2011) argue that, instead of subsidizing the insurance premiums of low income households living in poorly constructed houses in the one-hundred year flood zone, money should be used to provide them with grants or low-interest loans to implement adaptation measures, or to even relocate their homes to safer areas. The reduction in insurance premiums could then offset the annual costs of the loan. The NFIP also provides financial incentives for states and local governments to undertake mitigation activities. Grants are available to support demolition and relocation of buildings or infrastructure, for structural and non-structural retrofitting and elevation of buildings, flood control and prevention projects, as well as for better planning of flood prevention (Aerts and Botzen, 2011). In France, the Barnier-Fund also provides financing for municipalities to conduct studies, which are necessary to develop required risk prevention plans.

[19] NFIP: Lack of enforcement memo: http://www.msema.org/wp-content/uploads/2012/07/NFIP-lack-of-enforcement-memo.pdf

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**6 Conclusions**

Exploring scientific and grey literature, as well as investigating relevant webpages has revealed that there is some insurance engagement in relation to flood risk adaptation, but that there is significant potential for increased activities. The most common activities appear easy to implement (and relatively inexpensive), such as the education of policy-holders on how to reduce losses. If larger investments are required, such as structural adaptation measures, these measures are beneficial when insurers can establish a long-relationship with their policy-holders and have high market penetration. This is often only the case in monopoly insurance systems, but not in private insurance markets. Aside from the NFIP in the US, there appear to be no fixed procedures on how to integrate flood risk prevention into the daily insurance business and there are only a very limited number of adaptation options considered.

Despite the suggestion by many scholars, the use of risk-based premiums and deductibles to incentivize decentralized single-property preventive actions is in practice difficult to implement. It requires detailed quantitative information about the risk and the damage-reducing effect of the various adaptation measures, in addition to increased transaction costs, which might be difficult to transfer to policy-holders, especially in highly competitive private insurance systems.

If insurers should become more engaged in adaptation activities, the role of insurance and the public in flood risk reduction must firstly be renegotiated. Changes in the insurance industry will remain insignificant as long as there is the perception that proactive adaptation is not their responsibility. Layered public-private partnerships could be a solution for sharing the risk between policy-holders, insurers and the government.

Quantitative studies on current insurance activities in adaptation, including withdrawal practices, would be of interest for future research. Qualitative studies are needed for better understanding of the barriers and triggers for insurance companies to engage in adaptation activities. In addition, more studies are needed that provide evidence on the effectiveness of risk-based premiums and deductibles as tools to incentivize risk adaptation on the policy-holder level. Furthermore, improved data is needed, which allows assessment of the effectiveness of adaptation measures.

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