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Insurance Against Climate Change and Flooding in the Netherlands: Present, Future, and Comparison with Other Countries

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Climate change is projected to cause severe economic losses, which has the potential to affect the insurance sector and public compensation schemes considerably. This article discusses the role insurance can play in adapting to climate change impacts. The particular focus is on the Dutch insurance sector, in view of the Netherlands being extremely vulnerable to climate change impacts. The usefulness of private insurance as an adaptation instrument to increased flood risks is examined, which is currently unavailable in the Netherlands. It is questioned whether the currently dominant role of the Dutch government in providing damage relief is justified from an economic efficiency perspective. Characteristics of flood insurance arrangements in the Netherlands, the United Kingdom, Germany, and France are compared in order to identify possible future directions for arrangements in the Netherlands. It is argued that social welfare improves when insurance companies take responsibility for part of the risks associated with climate change.

KEY WORDS: Adaptation; catastrophe losses; climate change impacts; flood insurance; insurance sector

1. INTRODUCTION

Catastrophe losses are likely to rise as a result of climate change, since it is projected that global warming will increase the frequency and severity of extreme weather events (IPCC, 2007). Several adaptation measures to climate change are proposed, such as flood protection infrastructure, in order to limit economic impacts and reduce risks (Kabat *et al*., 2005). The potential of "softer" adaptation measures to limit losses and spread risks, such as insurance arrangements against flood damage, is the topic of this article. Climate change and the insurance sector affect each other in two main ways. First, the insurance industry can contribute to climate proofing of societies via efficient risk-sharing mechanisms. Second, the insurance industry itself is likely to be a victim of heightened risk exposures to climate events, which requires adequate incorporation of climate risks in setting premiums and risk management (Mills *et al*., 2005). This article discusses the first issue with a special focus on risk-sharing arrangements for flooding in the Netherlands, given that a large part of the Netherlands is a delta region that is especially vulnerable to flood-related climate extremes.[4]

Climate change projections for the Netherlands also indicate an increased frequency and severity of

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[4] About 70% of properties in the Netherlands lie *below* sea level or below river water level (Kok *et al.*, 2002).

weather extremes (van den Hurk *et al.*, 2006). Therefore, it is expected that economic losses caused by extreme weather events, such as extreme precipitation and flooding, will rise considerably in the Netherlands. Hence, if the number of extreme weather events increases due to climate change, then future insurance claims for weather-related damage are expected to increase as well under *existing* insurance arrangements. This could be problematic for insurance companies, if these premiums are not fully adjusted in response to heightened risks. In addition, requests for public compensation will rise when damage is not covered by insurance arrangements, as is the case for flood damage. Generally, insurance companies in the Netherlands do not cover flood damage because the risks associated with them are regarded as uninsurable by the insurance sector since the catastrophic North Sea flood in 1953 (Heerkens, 2003).

Global economic and insured losses of natural catastrophes have already increased rapidly over the last decade (Munich Re, 2005). This increase is mostly caused by socioeconomic developments, such as urbanization and increases in the economic value that is exposed to natural hazards (Kunreuther & Michel-Kerjan, 2006). There are indications that climate change may have contributed to the rise in losses reported, but skepticism remains about the attribution of climate change to increased losses (Vellinga *et al*., 2001; Changnon, 2003; Mills, 2005; Pielke, 2005; Schiermeier, 2006). Economic losses in the Netherlands caused by weather-related events have also been considerable during the last decade. The high river discharges in 1993 and 1995 and extreme precipitation events in 1998 inflicted considerable damage (Kok & Barendregt, 2004). The absence of private flood insurance resulted in pressure on the government to provide compensation as an insurer of last resort. Although there are legal arrangements for the compensation of disaster losses by the government (de Vries, 1998), the Dutch government has become increasingly reluctant to provide this *ad hoc* compensation and instead stimulates the development of new private insurance arrangements to alleviate budget pressures (Kok, 2005). Because of this, insurability of crop damage and property damage against severe local precipitation increased over the last years.

Apart from public budget considerations, it is questionable whether the absence of private flood insurance is desirable from an economic efficiency perspective. A larger role for private insurance companies in spreading the risks of climate change will provide better incentives to reduce economic losses. It is widely recognized that existing adaptations in the water sector are insufficient to cope with climate change. Therefore, insurances can play an important role in alleviating the negative impacts of climate change by spreading risks among individuals (Bouwer & Vellinga, 2005). It will be argued in this article that economic efficiency will be improved when private insurance coverage against flood damage is extended. However, a continuing role for the government in insurance arrangements is warranted to overcome problems of insurability of weather-related disasters that exist in the private market. In addition, substantial public investments in risk-reducing measures, such as dike infrastructure, are necessary to cope with increasing climate risks.

Recently, several lead authors in the field of catastrophe insurance have proposed forms of public-private partnerships to insure catastrophe risks, in particular for the United States (see, e.g., Kunreuther, 2006a, 2006b; Michel-Kerjan & Marcellis-Warin, 2006; Litan, 2006). The objective of this article is to identify possible future directions for efficient and robust risk-sharing arrangements of flood risks that can cope with climate change, with a particular focus on the Netherlands, which can be regarded as an exemplatory case. For this purpose, possible advantages of a larger role of private insurances are outlined and solutions to overcome difficulties with offering flood insurance are provided. Existing private or public arrangements for compensating flood losses in the Netherlands, the United Kingdom, Germany, and France will be compared in order to identify how possible benefits and problems of private insurances are addressed in each of these countries. Indeed, this will provide relevant insights for giving policy recommendations for a flood insurance program in the Netherlands.

The remainder of this article is structured as follows. Section 2 first outlines the projected changes in climate for the Netherlands and discusses the consequences of these projections for flood risks. Section 3 gives an overview of existing risk-sharing arrangements of flood damage in the Netherlands. Subsequently, Section 4 examines the role that private insurance arrangements can play in covering flood damage. Section 5 identifies several problems that exist with offering private flood insurance and suggestions to overcome these problems are given. Section 6 discusses international experiences with private flood insurance arrangements, which allows a comparison with the public compensation scheme in the Netherlands. Finally, Section 7 concludes.

Table I. Projected Climate Change for the Netherlands in 2050

		Scenario			
Global temperature rise		Moderate +1°C	Moderate + +1°C	Warm +2°C	Warm + +2°C
Change in atmospheric circulation		No	Yes	No	Yes
Winter	Mean temperature	+0.9°C	+1.1°C	+1.8°C	+2.3°C
	Yearly coldest day	+1°C	+1.5°C	+2.1°C	+2.9°C
	Mean precipitation	+3.6%	+7.0%	+7.3%	+14.2%
	Wet day frequency	+0.1%	+0.9%	+0.2%	+1.9%
	10-year return level 10-day precipitation sum	+4%	+6%	+8%	+12%
	Yearly maximum daily mean wind speed	0%	+2%	−1%	+4%
Summer	Mean temperature	+0.9°C	+1.4°C	+1.7°C	+2.8°C
	Yearly warmest day	+1.0°C	+1.9°C	+2.1°C	+3.8°C
	Mean precipitation	+2.8%	−9.5%	+5.5%	−19%
	Wet day frequency	−1.6%	−9.6%	−3.3%	−19.3%
	10-year return level 10-day precipitation sum	+13%	+5%	+27%	+10%
	Potential evaporation	+3.4%	+7.6%	+6.8%	+15.2%
Absolute sea level rise		12–25 cm	15–25 cm	20–35 cm	20–35 cm

Source: van den Hurk *et al.* (2006).

2. CLIMATE CHANGE AND THE NETHERLANDS

The Intergovernmental Panel on Climate Change (IPCC) states that it is very likely that anthropogenic factors are responsible for the main part of the observed global warming since the mid 20th century. In particular, it has been acknowledged that greenhouse gases are a significant cause of global warming, even though other factors such as the natural variability of climate play a role as well (IPCC, 2007). Greenhouse gases affect climate because they increase the energy present at the earth's surface. This energy warms the atmosphere of the earth and affects the hydrological cycle, resulting in more precipitation and extreme rainfall, which, for example, increases the probability of flooding.

Here we summarize the projections of climate change that are relevant for flood risks in the Netherlands. These are based on studies of the Royal Dutch Meteorological Institute (KNMI), which build upon the IPCC assessments (van den Hurk *et al.*, 2006). Projected changes in climate for the Netherlands in 2050 relative to a climatological baseline period in 1990 under four scenarios are given in Table I.[5] The four scenarios concern a moderate and a warm scenario in which global temperature rises with 1°C and 2°C, respectively, and a moderate and warm plus scenario. The atmospheric circulation changes as well in these plus scenarios in addition to the aforementioned increases in global temperature. The circulation change in the plus scenarios concerns a stronger westerly circulation in the winter and a more easterly circulation in the summer. This "plus scenario" is included since climate in the Netherlands is susceptible to changes in circulation patterns over Europe.

Table I shows various climate change projections under the four scenarios. Temperatures are expected to increase from 0.9°C up to 2.3°C by 2050. Average precipitation in winter is expected to increase. Average precipitation in summer is expected to increase as well when circulation patterns remain the same, but it decreases considerably when circulation patterns change. Extreme (local) precipitation is projected to increase in the winter and in the summer, while the frequency of wet days decreases during the summer. Projected changes in wind speed are expected to be minor. The rise in sea level at the Dutch coast is expected to be between 15 and 25 cm for 1°C of global warming and between 20 and 35 cm for 2°C of global warming. This sea level rise is exacerbated by subsidence of land.[6] The sea level rise estimates consider

[5] These scenarios date from 2006 and are based on the latest GCM modeling exercises that have been made for the IPCC's (2007) Fourth Assessment Report (van den Hurk *et al.*, 2006).

[6] Land subsidence in the Netherlands is approximately 10 cm per century.

melting of the Greenland and Antarctic ice sheets, but exclude the impact of a very rapid melting of Greenland ice or a collapse of the West-Antarctic Ice Sheet, which have very low probabilities of occurring, but can raise global sea levels considerably (Kerr, 2006). Recent research suggests that these ice sheets may be melting more rapidly than initially anticipated (Dowdeswell, 2006; Overpeck *et al*., 2006). However, considerable uncertainties remain about the melting of these ice sheets. The IPCC (2007) states that the surface mass balance, which is the difference between accumulation and melting of ice, of Greenland ice becomes negative at global average warming in excess of 1.9°C to 4.6°C and that the Antarctic Ice Sheet will remain too cold for widespread surface melting. The Greenland Ice Sheet may melt completely and subsequently contribute to sea level rise by about 7 m if the negative surface mass balance were sustained for millennia. Evidently, this would have disastrous consequences for flood risks in the Netherlands.

The aforementioned projected changes in climate are expected to have a significant impact on Dutch society. Especially in the winter, flood risks of rivers are projected to increase due to increased rainfall and the contribution of melt-water runoff from the Alps. Furthermore, the frequency of extreme precipitation events is projected to increase in a warmer climate (Middelkoop *et al*., 2001). Rising sea levels cause damage by accelerating shoreline erosion and may increase the potential of storm damage (West *et al*., 2001). In particular, sea level rise may increase the probability and intensity of storm surges. Storm surges are the main cause of sea floods in the Netherlands. They occur when water is pushed toward the shore by the force of strong winds. Flood risks are even higher in case climate change also leads to higher wind speeds on the North Sea (Bouwer & Vellinga, 2007).

3. CURRENT RISK-SHARING ARRANGEMENTS OF FLOOD DAMAGE IN THE NETHERLANDS

From 1998 onward, government compensation for disaster losses including flood damage in the Netherlands is arranged with the Calamities and Compensation Act (WTS). This law is partly developed in response to the floods in 1993 and 1995, when the government provided (almost complete) damage relief on an *ad hoc* basis. The total damage of the 1993 and 1995 floods amounted to about 115 million euro and 63.5 million euro, respectively (Kok & Barendregt, 2004). Initially, the Dutch government aimed to extend private insurance coverage to freshwater floods. However, this proposal was rejected by the Dutch insurance sector (de Vries, 1998). The WTS only provides compensation when a flood results in a considerable disruption of public safety and requires a coordinated effort of organization and civil services. Moreover, damage caused by storm surges is excluded from the WTS, because financial costs of such a flood might be considerable and difficult to estimate beforehand. As an illustration, the major North Sea storm surge in 1953 caused 1,853 victims in the Netherlands and direct economic damage of about 0.7 billion euro (Kok *et al*., 2002). Currently, private insurance coverage against flood damage is not generally available.[7] Obviously, the existence of public compensation crowds out private market alternatives. Therefore, most of the risks of flooding are carried by the public sector or by households and businesses in case the former decides not to grant compensation.

A rationale behind compensation by the government instead of private insurance companies might be that the government is regarded as liable for flood damage because of its responsibilities for dike maintenance. After the floods in 1953, 1993, and 1995, a public view existed that the government was partly liable for the incurred damage, due to insufficient investments in coastal protection and dikes (de Vries, 1998). Furthermore, feelings of solidarity can be a reason to provide damage compensation through tax revenues. A disadvantage of the current system with the WTS is that it is not clear in which cases flood damage will be compensated. The decision whether WTS compensation is provided, as well as the determination of the extent of the compensation provided, lies with the government that is in office when the disaster takes place. Therefore, these decisions are influenced by political will and public pressure, which can be regarded as arbitrary and subjective. Decisions concerning compensation are likely to be driven by equity and political motives rather than by rational economic grounds, as research about flood damage compensation by the U.S. federal government indicates (Downton & Pielke, 2001). Uncertainty for individuals concerning the compensation of damage is less when private insurance is available, since insurance provides a contractual right for compensation.

A major drawback of a public compensation scheme is that incentives to limit or reduce

[7] An exception to this is flood damage to cars, which is covered by motor-hull insurance (van Schoubroeck, 1997).

losses for individuals are suboptimal (Kaplow, 1991; Harrington, 2000). These loss-reducing incentives are minimal when individuals expect that the government will provide compensation regardless of individual risk characteristics or prevention measures undertaken. Prevention measures are costly for individuals and benefits are minimal when the government unconditionally compensates potential damage. Although this is partly accounted for by the WTS by compensating damage only partially, loss-reducing incentives are suboptimal due to a lack of transparency and the absence of rewarding *ex ante* damage-reducing behavior via premium discounts. In addition, damage compensation is not adjusted for higher risks taken by individuals who settle into flood-prone areas. In this way, government compensation schemes result in a governmentally subsidized incentive to take on risk. Incentives to limit losses are likely to be better with insurance arrangements, as will be elaborated upon in Section 4. Another disadvantage of the current public compensation scheme is that disaster compensation by the government may hamper economic development broadly if disaster relief is financed through additional taxes or reduced public investments in other areas.

4. SUGGESTIONS TO MANAGE RISKS WITH PRIVATE FLOOD INSURANCE

Several characteristics of insurance can be identified that make it a potentially useful instrument to stimulate adaptation of firms and households to climate change losses. Indeed, well-designed arrangements are able to limit total economic losses and catastrophic impacts for individuals. The ability of insurance arrangements to spread and segregate risks, reduce damage by providing loss-reducing incentives, and monitor and control policyholders can be a rationale for extending private flood insurance coverage with risk-based premiums in the Netherlands.

4.1. Risk Spreading and Segregation

The economic consequences of flooding events or other natural disasters for individual businesses and households can be catastrophic. Damage can be beyond the abilities to pay by affected parties, which could even result in bankruptcy in case compensation is not provided. Insurance spreads the economic costs of such events across many policyholders. In this way, the potential catastrophic consequences for individual households and businesses are shifted to insurance companies. In general, insurance companies are better able to carry these risks because they collect premiums from many individuals in order to pay for damage in case adverse events take place. In this way, insurance arrangements reduce individual loss exposures by spreading risks. Moreover, insurance contracts reduce uncertainty faced by individual parties, which directly increases welfare of risk-averse policyholders and is beneficial for stimulating business activities and economic stability (Botzen & van den Bergh, forthcoming).

Insurance arrangements can be used to segregate risks. Risk segregation means that insurance companies discriminate between different policyholders, using individual risk characteristics, classes of businesses, or groups with different risk exposure (Freeman & Kunreuther, 2003). Segregating risks means that insurance companies set different premiums and policies for different risk categories from a risk pool. For example, insurance companies can charge higher health insurance premiums for older policyholders and set different policies for truck versus recreational automobiles. With regard to flood insurance, insurance providers could set different policies with higher premiums for households and businesses that are settled in flood-prone areas, such as areas that are not protected by primary river dikes. Varying premiums across risk classes can hamper development in flood plains, which may reduce flood risks indirectly (Clark, 1998; Pearce & Smale, 2005). Differentiated flood insurance premiums also provide incentives for individuals to limit their risk exposure, so that they become eligible for lower premiums. Another rationale behind premium differentiation of flood insurance could be to stimulate transparency and consciousness of the costs that settlement in risky areas brings. Furthermore, it might be regarded as unfair that all policyholders pay for larger risks taken by a few.

4.2. Limiting Catastrophe Damage by Loss-Reducing Incentives and Monitoring

Insurance companies adopt techniques to modify behavior of potentially insured parties in order to create uniform risk categories (Freeman & Kunreuther, 2003). Insurance arrangements can provide loss-reducing incentives with the use of deductibles, premium discounts, and policy regulations. By rewarding behavior that reduces risks and potential damages, insurance arrangements are able to reduce total costs and moderate economic impacts of adverse events (Board on Natural Disasters, 1999). In

this way, extending private coverage to flood insurance has the potential to limit total flood damage. For example, vehicle insurance is less expensive for drivers with good driving records, which provides incentives to drive carefully. This valuable characteristic of insurance arrangements has reduced risks and their associated costs for society throughout history. Often, insurance companies have been the driving force behind safety procedures and new protective measures (Brainbridge, 1952). For example, the U.S. National Flood Insurance Programme (NFIP), which is a public-private partnership, contributed significantly to reduced vulnerability of new buildings to flood impacts. Nevertheless, there still seems to be considerable scope to increase the efficiency of the NFIP program by limiting development in high-risk areas, abolishing subsidies on insurance premiums, improving risk mapping, limiting exposure to flood losses on older buildings, enforcing building codes, and increasing market penetration and coverage (Burby, 2001). However, such measures need to be balanced with equity considerations. For example, subsidized premiums may increase the low uptake of insurance in certain areas, but also cause a shortfall between premium revenue and the payout of claims.

The ability of insurance companies to provide incentives to mitigate damages is very relevant in the context of adaptation to climate change. Effectively designed insurance arrangements can limit societal costs of future disaster losses by providing incentives to implement damage-reducing adaptation measures. Market discipline is likely to be more efficient in reducing damage than public insurance or compensation arrangements (Priest, 1996). Insurance arrangements can limit damage by rewarding well-designed buildings with lower premiums, lower deductibles, and higher coverage limits on insurance policies (Kunreuther, 1996). Flood damage can also be limited when flood insurance arrangements stimulate strict building codes in flood-prone areas. Financial institutions could help enforce these regulations by requiring guarantees that structures meet building code standards before mortgages are granted. In addition, the undertaking of cost-effective loss-reducing measures could be encouraged by bank loans that are tied to structures. In practice, investments in loss-reducing measures are often limited in the absence of these bank loans because (yearly) premium reductions are relatively small compared to the (often one-time) costs of mitigation measures. Bank loans can overcome investment problems for individuals with short time horizons, budget constraints, or for individuals who plan to move to a new place in the near future (Kleindorfer & Kunreuther, 1999).

Flood insurance can also provide incentives for individuals to limit losses by, for example, excluding coverage for damage from carpet or wooden floors, which stimulates the use of tile floors or water-resistant timber floors. Another strategy to reduce flood losses and claims for insurance companies is to inform policyholders about flood-adapted building use and materials, as well as damage-reducing measures that individuals can undertake once a flood occurs (Thieken *et al*., 2006). With the use of deductibles policyholders are motivated to be creative in limiting potential losses *ex ante, ex post*, as well as during floods. For example, survey analysis indicates that insured individuals spent more time on flood mitigation measures than uninsured individuals in the advent of the 2002 flood in Germany (Thieken *et al*., 2006).

Another valuable characteristic of insurance is that insurance companies generally monitor activities of their policyholders. This monitoring is performed to determine whether policyholders operate in a manner consistent with underwriting standards. For example, if insurance arrangements provide premium discounts when loss-reducing measures are undertaken then insurance companies will monitor policyholders to verify whether specified standards have been met. Therefore, monitoring insured parties *ex ante* ensures that loss-reducing measures are actually implemented and adhered to. It should be recognized that over time increased losses that might result from climate change will at least be partly shifted to policyholders, by increased premiums and altered policy regulations. In this way, increased risks will partly be carried by the insured (Tol, 1998).

5. PROBLEMS ASSOCIATED WITH PRIVATE FLOOD INSURANCE ARRANGEMENTS AND SUGGESTIONS FOR POSSIBLE SOLUTIONS

Although it might be desirable to extend private insurance coverage to flooding, several problems exist that make it difficult to establish a pure private market. Two conditions must be met before a risk is regarded as insurable (Freeman & Kunreuther, 2003; Kunreuther & Michel-Kerjan, 2006). First, it must be possible to estimate the probability of occurrence of the event, as well as the extent of losses that the insurance company will incur under different levels of coverage. This may be difficult for flood insurance because floods occur with a very low frequency and

potential damages are difficult to estimate, due to the absence of extensive loss data sets. Therefore, it might be required to share some of the risks faced by insurance companies with individuals and maybe the government (Pearce & Smale, 2005). This problem of ambiguity of risk is exacerbated by climate change (Tol, 1998). Uncertainty associated with climate scenarios is significant and the influence that climate change will have on the frequency of flooding is uncertain as well. Second, insurance companies must be able to set premiums for each customer or class of customers. This can be problematic due to ambiguity of risk, adverse selection, moral hazard, and correlated risks, as will be explained below. However, these problems are alleviated by the flexible nature of the insurance sector since premiums and policies can be adjusted on an annual basis, which limits risks for insurance companies (Bouwer & Vellinga, 2005).

5.1. Risk and Uncertainty

The difficulty in assessing flood probabilities and estimating potential damages impedes setting adequate premiums and risk management by insurance companies. Empirical evidence indicates that the greater the uncertainty of the probability of an event and the magnitude of losses, the greater will be the insurance premium charged (Kunreuther *et al.*, 1995). Premiums are higher to account for the risks taken by insurance companies caused by uncertainty about the frequency and magnitude of future claims. This implies that insurance premiums for flooding will be higher than, for example, fire insurance premiums even if expected losses will be the same, due to greater uncertainty associated with the frequency and severity of floods. Uncertainty associated with floods is more significant, since there are less historical data and scientific information about the nature of floods compared to fires because floods are low-probability events. Insurance companies can use catastrophe models to gain insight into loss exposures to catastrophe events, such as flooding, but this is unlikely to completely resolve uncertainty (Grossi & Kunreuther, 2005).

5.2. Information Asymmetries: Adverse Selection and Moral Hazard

The fear of problems relating to adverse selection was one of the main reasons why Dutch insurers resisted government pressures to extend flood insurance coverage in the period shortly before the drafting of the WTS (de Vries, 1998). Adverse selection occurs when high-risk individuals are more likely to demand insurance coverage than low-risk individuals. As a consequence, insurance companies will suffer losses when premiums are based on the average probability of a loss. Adverse selection is caused by information asymmetries between insurance companies and policyholders. This problem can arise when individuals are able to determine their individual risk characteristics and insurance companies have difficulties in distinguishing good- from bad-risk individuals. In case information asymmetries would not exist, insurance companies could simply charge higher premiums to high-risk individuals. Adverse selection can result in very high premiums in case insurers are risk averse, which can explain a missing market.

Adverse selection may arise when flood insurance is available because individuals living in flood-prone areas are more likely to demand insurance coverage against flooding. Screening low- from high-risk individuals and charging the latter higher premiums can overcome this problem. Therefore, the allowance of price discrimination can mitigate the adverse selection problem. In practice, flood risks can be audited with the use of geographical information systems, allowing insurers to adjust premiums accordingly (Pearce & Smale, 2005). The relation between the degree of risk exposure and geographical characteristics is very high. Therefore, the adverse selection problem can be overcome for flood insurance since insurance companies are able to distinguish good- from bad-risk individuals. It further seems unlikely that individuals have superior knowledge about flood risks than insurers given the expertise required in assessing climate-related risks, which would limit the adverse selection problem (Henriet & Michel-Kerjan, 2006). However, premium differentiation might be socially and politically infeasible when the difference in premiums of individuals living in low-lying areas compared to high-lying areas becomes too great. Another solution is to bundle flood insurance with other kinds of disasters, such as earthquakes (Kok, 2005). Alternatively, flood insurance can be bundled with property or home contents insurance. This bundling could be made compulsory as is, for example, government policy in France.

Information asymmetries between insurance companies and policyholders can also result in moral hazard. Insured individuals may behave less carefully

when they have insurance coverage, while this is unobservable by the insurer. This information asymmetry results in an inefficient level of risk prevention (Gollier, 2005). For example, persons with vehicle insurance are likely to drive less carefully than persons without insurance, *ceteris paribus*. The probability of losses increases after the individual has bought insurance coverage due to the behavior of the policyholder, which is defined as moral hazard (Freeman & Kunreuther, 2003). Moral hazard can arise when individuals are covered for flooding. However, problems with moral hazard can be minor in practice, due to adequate design of insurance contracts (Thieken *et al*., 2006). In addition, the moral hazard of insureds is argued to be a minor problem for flood insurance because insureds agents do not have control over the catastrophe event, that is, the probability that damage occurs, although insureds have control over the extent of damage during and after a flood (Jaffee & Russel, 1997).

Monitoring the insured is an option to change asymmetric to symmetric information according to their risk characteristics. However, in practice, monitoring is a costly activity, making perfect monitoring an unattractive option. Incentives to limit losses can be suboptimal when insurance contracts are improperly designed. Other solutions to moral hazard are introducing deductibles, co-insurance, and upper limits on coverage. Sufficiently large deductibles are an incentive for individuals to undertake loss-reducing measures, since individuals have to pay for part of the damage. This also applies to placing upper limits on insurance coverage. Another advantage of deductibles is that they lower transaction costs, since only insured individuals with damages larger than the deductible will submit a claim (Gollier, 2005). This is particularly relevant for insurances against natural disasters because transaction costs can be relatively large for these insurances. This is the case because catastrophes, such as flooding, result in many claims at the same time. Under co-insurance, a certain percentage of the losses are borne by the insurers and a certain percentage of the losses are carried by the insured. Therefore, individuals have an incentive to limit damage and the undertaking of precautionary measures is encouraged with this risk-sharing arrangement. Another measure to protect the insurance company from moral hazard is raising insurance premiums in order to reflect the larger risks. A disadvantage of raising premiums is that this decreases the demand for insurance coverage and might be resisted by regulators.

5.3. Correlated Risks

Insurer insolvency is possible when many losses occur simultaneously due to a single event (Vellinga *et al*., 2001). This situation can arise when risks are highly correlated. Moreover, natural disasters such as flooding can have devastating consequences. A major flood damages many homes and companies in a concentrated area at the same time. Therefore, insurance companies are suddenly faced with significant losses, which may not be met by premium revenues when risks are not well diversified geographically. Major flood losses can be beyond the carrying capacity of insurance companies, due to a lack of capital. Spreading of insurance over many different river basins, coastal areas, and polders is necessary to achieve a sufficient degree of independence of flooding events (Kok *et al*., 2002). Insurance companies will charge higher premiums when risks are highly correlated in order to compensate for the possibility of insolvency due to catastrophic losses and to cover the cost of holding large amounts of capital. A related problem is the high variability in the annual pattern of losses for catastrophe insurances, which is due to the low-probability/high-impact nature of these events. This creates the difficulty to smooth catastrophe losses over time and have sufficient liquid capital available on a continuous basis.

A solution to excessive concentration of risks for insurance companies is to buy reinsurance and diversify in different insurance branches and geographical regions. The latter option is limited due to efficiency gains in specialization and regulatory as well as practical limits on firm size, explaining the observed demand for reinsurance coverage. In general, two kinds of reinsurance contracts can be identified: proportional reinsurance and excess-of-loss reinsurance. Under a proportional reinsurance contract the reinsurer assumes a share of the risks in exchange for a share of the premiums. The primary insurer retains risks up to a specified amount and the reinsurer above that amount with an excess-of-loss reinsurance contract. The problem with reinsuring catastrophe risks is that the reinsurance market lacks sufficient insurance capacity, especially after the occurrence of a disaster event (Weiss & Chung, 2004). Reinsurance is often not available at premiums close to actuarially fair levels because reinsurance markets are not adequately developed yet. Reinsurers face capital shortages due to capital market imperfections and suffer from adverse selection. Moreover, the main reinsurance companies exhibit market power (Jaffee & Russel, 1997;

Cutler & Zeckhauser, 1997; Froot, 2001). In addition, reinsurers (as well as primary insurers) suffer from "timing risk" when they insure events that have the potential to cause very large claims. Timing risk refers to the possibility that reinsurers that cover catastrophe risks have to pay large claims before they are able to collect sufficient premiums (Litan, 2006). This is especially relevant when new arrangements are introduced. Nevertheless, a promising trend of increased reinsurance industry capital has been observed recently (Kunreuther, 2006a). Despite this increase in capital, reinsurance premiums increased significantly over the last years due to large natural disasters, such as storms in France and floods in Central Europe, increased concentration of economic values, and bad investment results of reinsurance companies (Verbond van Verzekeraars, 2005).

Insurance companies can also hedge their risks in the capital market directly, instead of relying on reinsurance. Financial instruments that hedge catastrophe risk can provide liquidity to insurance companies to pay for catastrophe claims. They can further be attractive for investors because their returns are argued to be almost unrelated to general economic activity. Bond instruments can provide capital to insurance companies in advance of a catastrophe. These (catastrophe) bonds are designed such that the obligation to make interest and principal payments (at least partially) ends once a specific catastrophe event occurs or when specified industry-wide or insurer-specific losses are suffered. In this way, catastrophe bonds can enhance the degree of intertemporal diversification. Other financial instruments available to hedge against catastrophe risks are catastrophe options and futures. These financial instruments are designed such that they pay out a specified sum of money once catastrophe losses have been suffered. However, practical difficulties with pricing these instruments and ensuring contract performance limit their use (Jaffee & Russel, 1997). Pricing catastrophe options is complicated by the low-probability/high-impact nature of catastrophes. Traditional measures to guarantee contract performance, such as marking to market, are inadequate for catastrophe options since large price changes only take place once a catastrophe occurs, with little warning in advance. Problems with catastrophe bonds are that their trading frequency is low, they are not treated as equivalent to reinsurance by regulators, and correlation of their return with stock markets is higher than initially anticipated (Litan, 2006). Overall, catastrophe bonds have not yet been a major capital source to finance catastrophe losses (Kunreuther, 2006a).

The practical problems associated with reinsurance and financial instruments suggest that a government role exists to overcome liquidity shortages of insurance companies that offer flood insurance for large catastrophe losses. Experience in storm-prone areas, such as Florida in the United States, has shown that private insurers may want to withdraw from the market entirely after catastrophe losses have been suffered repeatedly (Kunreuther & Roth, 1998). In such a case, a form of public insurance may be a good way to guarantee insurance availability for households. Instead of providing complete public insurance cover the government can stimulate reinsurance or provide public reinsurance to overcome problems with correlated risks. An arrangement where insurance companies are liable up to a certain maximum amount and the government thereafter may be desirable, especially since governments generally have quick access to cheap debt. A major strength of the government as a reinsurer is that governments are able to diversify risks over the entire population as well as over future generations (Michel-Kerjan & Marcellis-Warin, 2006). Lewis and Murdock (1996) proposed that governments offer catastrophe reinsurance by auctioning excess-of-loss contracts, which would pay off to their holders when aggregate or industry-wide catastrophe losses from a specified event or over a certain time period exceed an attachment point. These contracts could complement private market reinsurance for large magnitude losses. Alternatively, setting up a public or private fund to cover catastrophe losses could ensure capital availability. Furthermore, the government could stimulate capital accumulation by insurance companies by providing tax incentives and stimulate the use of financial instruments to hedge flood risks.

The above suggestions are similar to a multilayered insurance program, as has been proposed by Litan (2006) and Kunreuther (2006a, 2006b) for insuring catastrophe losses in the United States. Such a program should be administered by private insurance companies, meaning that they sell insurance, collect premiums, estimate damage, and pay claims. It is likely that private insurance companies are more efficient in the day-to-day management of an insurance program than government agencies (Michel-Kerjan & Marcellis-Warin, 2006). The first layer of (small) flood losses is borne by the victims themselves, in order to provide loss-reducing incentives and prevent

moral hazard. Private insurance companies cover the second layer of flood losses with risk-based premiums and coverage depending on the surplus of the insurer, its current portfolio, and its ability to diversify across risks. The third layer of losses is covered by reinsurance and catastrophe bonds, which are to be acquired by the primary insurers. A prefunded government reinsurance program covers the fourth layer, consisting of extreme losses. Alternatively, this fourth layer could in due time be covered by a national fund, which can be publicly or privately financed.

6. INTERNATIONAL EXPERIENCE OF FLOOD INSURANCE ARRANGEMENTS

This section compares existing arrangements concerning compensation of flood damage in three European countries, namely, the United Kingdom, Germany, and France. This will allow us to identify desirable and undesirable characteristics of these arrangements, which serves as a basis to suggest possible new directions for policy in the Netherlands.

6.1. The United Kingdom

Private insurance companies cover flood risks for households and companies in the United Kingdom. The government does not provide compensation in case flood damage occurs. Allowing insurers to accumulate tax-exempted reserves stimulates capital accumulation by the insurance industry. Coverage against flood damage is usually included in building or home contents insurance, implying that it is bundled with other risks. Homeowners are forced to have this insurance, since mortgage is only provided in the case of full insurance coverage, including flood risks (Hubert, 2004). Insurance companies differentiate premiums based on geographical risk characteristics, which reward settlement in low-risk areas. Companies can insure themselves against damage that results from business interruption due to floods as well. In general, flood risks in the United Kingdom are significantly lower and more predictable than in the Netherlands. Furthermore, potential damages from river floods are expected to be lower (Kok & Barendregt, 2004).

A drawback of the British system is that public investments in flood protection are considered to be too low (Baan, 2004; Crichton, 2005). Moral hazard on the part of the government seems to be present because incentives for the government to invest in protection measures are lower when it is not the government that provides flood compensation but the private insurance sector instead. Underinvestment in flood defenses is especially problematic in case flood risks rise because of climate change. Coordination of investments in flood protection between the government and insurance sector is insufficient. In 2002, an agreement between the government and the insurance sector that insurance companies will offer coverage against flood damage for a reasonable price ended (Hubert, 2004). Lately, it is more difficult to obtain insurance in risk-prone areas because insurance companies are dissatisfied with the current safety standards in those areas (Crichton, 2005). An exception to this is Scotland, where risks for insurance companies have not increased due to stricter building codes (Baan, 2004). Another drawback of the arrangements in the United Kingdom is that insurance coverage is not mandatory, which leads to the ethical problem that insurance coverage is low (30%) for poor households, compared to a total market penetration of approximately 95% (Crichton, 2005).

6.2. France

In France, flood insurance arrangements are based on a public-private partnership. Insurance coverage against flooding and other natural hazards is mandatorily included in building and home contents insurance (van Schoubroeck, 1997). This reduces problems with adverse selection and ensures that insurance penetration is practically 100% (Swiss Re, 1998). Coverage is also available for the commercial sector. Private insurance companies collect the insurance premiums and handle claims and payouts in case damage occurs. The government provides a state guarantee in case flood damage exceeds abilities to pay off insurance companies and sets insurance coverage by law. Low-priced reinsurance for flooding with unlimited coverage is obtainable via a publicly owned reinsurer the "Caisse Centrale de Réassurance," which again benefits from an unlimited state guarantee. The government sets the "natural catastrophe" surcharge and premium differentiation is not allowed, which implies that incentives to reduce losses are suboptimal. For this reason, additional measures are undertaken to stimulate building in safe areas (Kok & Barendregt, 2004). Moreover, insurance arrangements include deductibles to stimulate loss-reducing measures.

In the French system, flood damage is compensated when the government officially recognizes the flood as a disaster and the area where the damage occurred as a disaster area. The French insurance arrangement lacks transparency because the definition

Table II. Characteristics of Arrangements Against Flood Damage

Kind of Arrangement	The Netherlands	The United Kingdom	France	Germany
Private coverage available	No	Yes	Yes	Yes
Premium differentiation	NA[a]	Yes	No	Yes
Public reinsurance	NA[a]	No	Yes	No
Public compensation scheme[b]	Yes	No	No[c]	Yes

[a]Not applicable because private coverage is not generally available.
[b]Does not involve a right to compensation.
[c]Evidently, the public reinsurance scheme is (partly) financed through taxes.

of what constitutes a disaster is unclear. It is also possible to obtain private insurance coverage against flooding separately from the public-private partnership. With such an insurance policy, compensation does not depend on governmental recognition of a disaster, as the public reinsurance system does not come into effect. Overall, the French system has proved to be quite efficient and in general insurers and insured are quite satisfied with the working of the system in practice (Kok & Barendregt, 2004).

6.3. Germany

In Germany, flood damage is privately insurable as a package with other natural disasters as supplements to home contents or building insurance. Damage resulting from storm surges is excluded. Although building insurance has a large market penetration of about 90%, market penetration of flood insurance is only about 10% for home contents and 4% for residential buildings in most parts of Germany (Thieken *et al*., 2006). Market penetration for industrial risks is also smaller than 10%. Adverse selection is argued to pose a major problem, despite the bundling of flood insurance with earthquake coverage. Buildings that are situated in hazard-prone areas are often excluded from flood insurance, or they can only be insured by very high premiums. Flood insurance arrangements include deductibles to stimulate loss-reducing measures by individuals. Apart from these deductibles, stimulation of damage-reducing measures by insurance companies is minimal (Thieken *et al*., 2006).

In 2002 a considerable flood occurred in Germany. The resulting damage was mainly compensated by the government and through donations. Total direct flood damage amounted to 9.1 billion euro, which was almost completely compensated. Insurance companies compensated approximately 1.8 billion euro (Baan, 2004). Public pressure on the government to provide damage relief was considerable because of the low insurance penetration and the poor economic conditions in the affected areas. However, this public compensation crowds out the private insurance market and reduces individual incentives to limit damage. Although private insurance coverage is available in Germany, the larger portion of the flood risks is still carried by the government, as well as by households and businesses in case the government decides not to grant (complete) damage relief.

6.4. Summary of Risk-Sharing Arrangements

The characteristics of the (public or private) arrangements for flood damage in the Netherlands, the United Kingdom, France, and Germany are summarized in Table II. The heterogeneity in risk-sharing arrangements suggests the relevance of identifying desirable and undesirable characteristics, which in turns aid the design of a more efficient risk-sharing arrangement for the Netherlands. The Netherlands is the only country of these four in which private flood insurance is currently not available. The flood insurance market in the United Kingdom is closest to a pure private market because premiums are risk based, the government is not involved as a reinsurer, and a public compensation scheme is absent. According to the discussion in Section 4, this type of arrangement is likely to be most efficient due to optimal loss-reducing incentives. However, the absence of public reinsurance makes insurance premiums relatively expensive, which, in combination with the voluntary nature of the market, may explain the low coverage among poor households.

The French system is characterized by a high degree of solidarity, since premium differentiation is not allowed and the insurance scheme is kept affordable with public reinsurance. The public reinsurance solves problems associated with high correlated risks. A drawback of the absence of premium differentiation is that this impairs efficiency by failing to reward

development in low-risk areas and loss-mitigating investments. Although private insurance coverage is available in Germany, insurance penetration remains low. This might be explained by the voluntary nature of the insurance and beliefs in public compensation of flood damage. In addition, coverage might be regarded as being too expensive, which is possibly the result of public reinsurance being absent. The negligible insurance penetration in Germany implies that the merits that insurance coverage can bring as an adaptation instrument are not fully utilized.

7. CONCLUSIONS

The frequency and severity of extreme weather events are projected to increase due to climate change. As a result, economic and insured losses caused by natural disasters are expected to increase as well. Especially relevant for the Netherlands is the increased exposure to risks resulting from extreme precipitation and flooding. Currently, private insurance coverage against extreme precipitation damage is generally available for households. This implies that risks of increased precipitation in the future are partly shifted to the insurance sector. In contrast, flood risks are not insurable in the Netherlands. Government compensation of fresh water floods is possible via the WTS, although the decision to provide compensation as well as the extent of damage relief provided depends on political will. It seems likely that the government will aim to stimulate private insurance coverage in the future when flood risks and flood damage increase due to climate change. Moreover, the current situation can be regarded as undesirable from an economic efficiency perspective because incentives to take *ex ante* and *ex post* loss-reducing measures and limit losses during floods are minimal under current arrangements.

Private insurance arrangements can be a useful adaptation instrument to climate change losses. The ability of private insurance companies to spread risks, segregate risks, encourage loss-reducing incentives, and monitor and control policyholders can be a rationale for extending insurance coverage to flooding in the Netherlands. Individual uncertainty associated with flood losses can be reduced when private insurance is available, which improves social welfare. Most importantly, private insurance arrangements are able to limit total economic losses when they provide incentives to undertake loss-reducing measures. In addition, premium differentiation can decrease the desirability to settle in risk-prone areas. However, several problems exist with offering private catastrophe insurance, such as ambiguity of risks, adverse selection, moral hazard, and correlated risks.

These problems require an active role of the government, as experience with insuring flood damage in other European countries indicates. The existence of private insurance schemes in the United Kingdom, France, and Germany suggests that a partly private market can be viable despite the aforementioned problems. Adverse selection can be limited by allowing for premium differentiation or by making coverage of flood insurance compulsory on, for example, home contents or building insurance, as is government policy in France. Extensive insurance penetration can also be established by requiring building insurance with flood coverage in applying for mortgages. Moral hazard on behalf of the insured can be limited by monitoring and adequate design of insurance contracts.

Capital problems due to correlated risks can be overcome by stimulating reinsurance or capital accumulation by insurance companies, as is government policy in the United Kingdom. Alternatively, the state can act as reinsurer and provide a state guarantee, as is practiced in France. Another option is to set up a private or public fund to cover flood losses and provide tax exemptions for capital reserves against catastrophes. In addition, it might be desirable to stimulate the use of financial instruments that hedge against flood risks, such as catastrophe bonds and options. An advantage of keeping the government partly liable for flood losses is that moral hazard on the part of the government, as is experienced in the United Kingdom, can be limited. Adequate investments in flood protection measures are especially desirable in a changing climate, for example, due to increased coastal erosion. International experience further indicates that it may be difficult to ensure adequate insurance penetration in a pure private market. Insurance coverage for poor households is low in the United Kingdom and overall penetration is very low in Germany. There might be a role for governments to ensure insurance affordability by, for example, providing public reinsurance. Alternatively, coverage against flood can be made compulsory, as is the case in France.

This study indicates that several future directions for risk-sharing mechanisms of flood damage are possible. The multilayered insurance program seems to be a promising public-private partnership that can provide adequate incentives to limit flood losses and overcome capital shortages in insuring large catastrophe losses. Increased flood risks and catastrophe losses in the future are likely to heat up the debate

about the appropriate compensation arrangement. Economic rationale suggest that extending private coverage against flood risks in the Netherlands can be a fruitful strategy to cope with climate change risks, although an active role of the government in overcoming capital shortages, investing in risk prevention, setting up strict regulations on building codes and land use, and stimulating adequate coverage and market penetration remains desirable.

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