



ANALYSIS

Willingness of homeowners to mitigate climate risk through insurance

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ABSTRACT

Climate change is projected to increase flood risks in certain regions due to an increase in both precipitation and sea level rise. In addition, socio-economic scenarios project an increase in urbanization in flood prone areas, which results in a higher damage potential. The combined effect of climate and land use change on flood risks requires innovative adaptation policies to cope with rising risks. Increasingly, attention is paid to the role insurance can play in mitigating damage by providing incentives to policyholders to undertake damage reducing measures. The willingness of homeowners in the Netherlands to undertake measures that mitigate flood damage in exchange for benefits on hypothetical flood insurance policies is examined using surveys. The results indicate that many homeowners are willing to make investments in mitigation. In particular, approximately two-thirds are willing to invest in water barriers in exchange for a premium reduction and about a fifth are willing to replace floor types that are vulnerable to flooding with water resistant floor types. Furthermore, about a quarter are willing to move central heating installations to floors safe against flooding in favor of a reduction in the insurance premium. Estimates of the effectiveness of these mitigation measures to limit potential flood damage in the river delta indicate that prevented damage could be substantial, namely in the order of 1 billion euro or larger. Reductions in (absolute) flood risk due to mitigation are especially large under climate change. A probit model indicates that existing arrangements for compensating flood damage, risk awareness and perceptions, and geographical characteristics are important determinants in the decision to undertake mitigation.

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1. Introduction

Climate change is expected to increase the frequency and severity of flooding in certain regions (IPCC, 2007). This is because a warmer climate is likely to result in a more vigorous hydrological cycle, which may cause more extreme precipitation. For the area of the Netherlands, which covers most of the delta of the rivers Rhine and Meuse, it would mean that the consequences and probability of flood risk may rise (e.g., Middelkoop et al., 2001; Aerts et al., 2006; Ward et al., 2008). Moreover, warming may result in melting of ice caps, in particular, of the Greenland and Arctic ice sheets, which will contribute to sea level rise (Alley et al., 2005). The latter may increase flood risks from storm surges in low-lying delta regions that are already vulnerable to flooding, such as the Netherlands. This could have disastrous socio-economic consequences (Bouwer and Vellinga, 2007; Olsthoorn et al., 2008).¹

The decay rate of greenhouse gasses is very slow and hence their presence in the atmosphere² with the accompanying negative consequences will continue in the coming decades (IPCC, 2007; Matthews and Caldeira, 2008). Even if current climate policy would be able to stabilize greenhouse gasses to 2000 levels, then a further warming of about 0.2 °C would occur in the next two decades, while warming is expected to be twice as high than under 2000 levels if emissions increase in accordance with the SRES scenarios of IPCC (2007). This implies a clear need for adaptation policy (Stern, 2007; Pielke et al., 2007). In addition to heightened risk due to climate change, increases in wealth and population contribute to the vulnerability of societies to natural disasters (Bouwer et al., 2007).

In response to increased flood risks caused by climate change, several adaptation measures have been examined and are currently being implemented in the Netherlands (Kabat et al., 2005). These pertain to maintaining current flood probabilities by heightening of primary river dikes and improving of coastal protection. In addition, projects that

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E-mail addresses: wouter.botzen@ivm.vu.nl (W.J.W. Botzen), jeroen.aerts@ivm.vu.nl (J.C.J.H. Aerts), jeroen.bergh@uab.es (J.C.J.M. van den Bergh).¹ About 60% of the landmass of the Netherlands is located below sea level while 70% of GDP is generated here (Kabat et al., 2005).² Montenegro et al. (2007) state that “about 75% of CO₂ emissions have an average perturbation time of 1800 years and the remainder have a lifetime much longer than 5000 years”.

create more space for rivers are undertaken, which also aim at maintaining or lowering the flood probability (e.g., Vis et al., 2003). Another strategy considered is to focus on lowering potential flood damage by developing 'flood proof' houses and structures, which minimizes damage during floods. For example, Aerts et al. (2008a) indicate that elevating a newly built home 5 m above sea level costs approximately in between € 10,000 and € 20,000 per house. This is a substantial investment for a homeowner but has the advantage that it completely eliminates flood risk. Other 'flood proofing' measures that partly reduce flood risks can be considerably less expensive, such as replacing floors vulnerable to flooding with tile floors, especially when replacement is necessary anyway after a flood or because of tear. A combination of measures that both limit damage and reduce the probability of flooding is likely to be the most effective way of preventing the occurrence of extremely large flood damages, as Aerts et al. (2008b) show in a portfolio framework of water management investments.

Insurance arrangements for flood risk may require households to undertake measures that mitigate damage or stimulate households to undertake precautionary measures voluntarily (e.g., Kleindorfer and Kunreuther, 1999; Kunreuther and Pauly, 2006). For example, households who build their house in a way that is more resistant to flooding can be rewarded with premium discounts or higher levels of coverage. These mitigation measures may limit damage during floods and thus be complementary to traditional flood protection. In addition, insurance arrangements serve a useful function in providing financial protection against the residual risk that remains after flood protection infrastructure has reduced risk to optimal levels. Practical experience suggests that individuals rarely undertake mitigation measures voluntarily (Kunreuther, 2006a). It is therefore very relevant to examine whether individuals can be stimulated to take precautionary measures in exchange for benefits, such as discounts, on their insurance policy. Although a number of studies have addressed the issue of how to create incentives for households to control and reduce flood damage through insurance, empirical analysis of the effectiveness of such incentives are rare.

International experiences suggest that mitigation measures may be an effective instrument to limit flood damage. For example, precautionary measures undertaken by (both insured and uninsured) households were very effective in limiting flood damage in Germany during the extreme flood event of the river Elbe in 2002 (Thieken et al., 2005; Kreibich et al., 2005).³ Flood damage could be limited by adapting use of buildings to flooding, which means that cellars and stories susceptible to flooding are not used cost-intensively, and by adapting interior fitting to flooding, which comprises the use of waterproofed building materials and placing of easily movable furniture on low floors. Use of buildings and interior fitting adapted to flooding were especially effective and reduced damage on buildings by 46% and 53%, and damage on contents by 48% and 53%, respectively (Kreibich et al., 2005). Thieken et al. (2006) show that insured households undertook more mitigation during the Elbe flood than uninsured ones. In particular, 28.5% of the insured households undertook at least one of the mitigation measures examined compared with 20.5% of the uninsured.⁴ After the 2002 flood, the city of Dresden was hit again by flooding in March 2005 and April 2006. Increased awareness of flood risk after the 2002 flood resulted in more private precautionary measures being undertaken, which limited flood damage significantly (Kreibich and Thieken, 2007). Another example is the National Flood Insurance Program (NFIP) in the USA, which by

setting (compulsory) mitigation standards contributed to reduce flood losses on new structures by about six times (Pasterick, 1998). Nevertheless, the NFIP program failed to restrain development in flood plains, which may be the case because many premiums are not risk based but partly subsidized (Burby, 2001).⁵ For example, in the last decades considerable development of new structures took place in New Orleans, which augmented damage of hurricane Katrina (Burby, 2006).

The present study examines the willingness of Dutch households to undertake voluntary mitigation measures for insurance benefits. So far, this has not been studied. A survey was undertaken among approximately 500 homeowners in the river delta of the Netherlands. The respondents were asked if they are willing to undertake specific mitigation measures for benefits on a hypothetical flood insurance policy. The effectiveness of these mitigation measures to prevent damage caused by river flooding and reduce flood risk in the river delta under climate change is examined. In addition, we statistically analyze how perceived risks of flooding, knowledge about flooding, experience with flooding, household and geographical characteristics, and responsibilities for covering flood damage influence the willingness to undertake mitigation.

The remainder of this paper is structured as follows. Section 2 briefly discusses Dutch flood risk management and the role of damage mitigation. Section 3 explains the survey. Section 4 examines descriptive statistics of the answers to the mitigation questions. Section 5 provides a range of estimates of the potential of mitigation to limit flood damage. Section 6 discusses estimation results of a statistical analysis of the factors behind the decision of homeowners to invest in water barriers. Section 7 concludes.

2. Flood risk management in the Netherlands

The Netherlands is a densely populated country in which millions of its inhabitants live around or below sea and river water level. Many low-lying parts have been reclaimed from former lakes and are protected by so called 'dike rings' along the main rivers and coastal areas. A dike ring is a geographical unit bounded by a flood protection system, such as dikes (Fig. 1). It is also a separate administrative unit under the Water Embankment Act from 1996. The latter aims to guarantee a certain level of protection against flood risks for each dike ring area. For example, a dike ring with a safety norm of 1/10,000 should be designed and equipped in such a way that it can withstand a water level with a return period of 10,000 years (probability 0.0001). Safety norms have been determined with the use of cost-benefit analysis and vary throughout the country (e.g., van Dantzig, 1956), as shown in Fig. 1.

Most of the investments in flood management in the Netherlands rely strongly on maintaining the safety norms shown in Fig. 1 through dike reinforcements. Meanwhile, however, the potential damage has increased sevenfold over the last 50 years due to continuous developments of new urban concentrations in vulnerable areas (Aerts et al., 2008a). Future projections show a gradual upward trend in house construction: by the year 2040 about 500,000 to 1,500,000 new houses will be constructed, many of which in low-lying areas. This issue has raised the question whether flood risk management should focus on maintaining flood probabilities or on reducing potential damage as well. Even if future flood risk defined as probability times damage will be maintained at a constant level through higher dikes, the potential damage of a flood will rise. Aerts et al. (2008a) show, for example, that additional flood proofing of new urban areas would lower future flood risk by a factor two. Elevating a house to eliminate flood risks costs in between € 10,000 and € 20,000, while other measures that limit risk partially can be undertaken at relatively low costs, such as installing central heating and other utility

³ The Elbe flood in 2002 is regarded as an extreme flood event. The resulting damage was about € 11.6 billion and 21 people were killed (Thieken et al., 2006).

⁴ In general, the potential benefits of insurance in mitigating flood damage are not fully used in Germany. Average market penetration is low, namely 10% for household contents and 4% for residences. Moreover, insurance companies put little effort in stimulating mitigation, even though mitigation measures have proven to be effective during the Elbe flood. Only 14% of insurance companies reward voluntarily undertaken flood protection. The higher number of insured households who undertake mitigation compared with uninsured ones may be due to the former group being more aware of the flood risk faced (Kreibich et al., 2005; Thieken et al., 2006).

⁵ Premiums are risk based for newly build structures in some areas where flood risk maps are accurate.

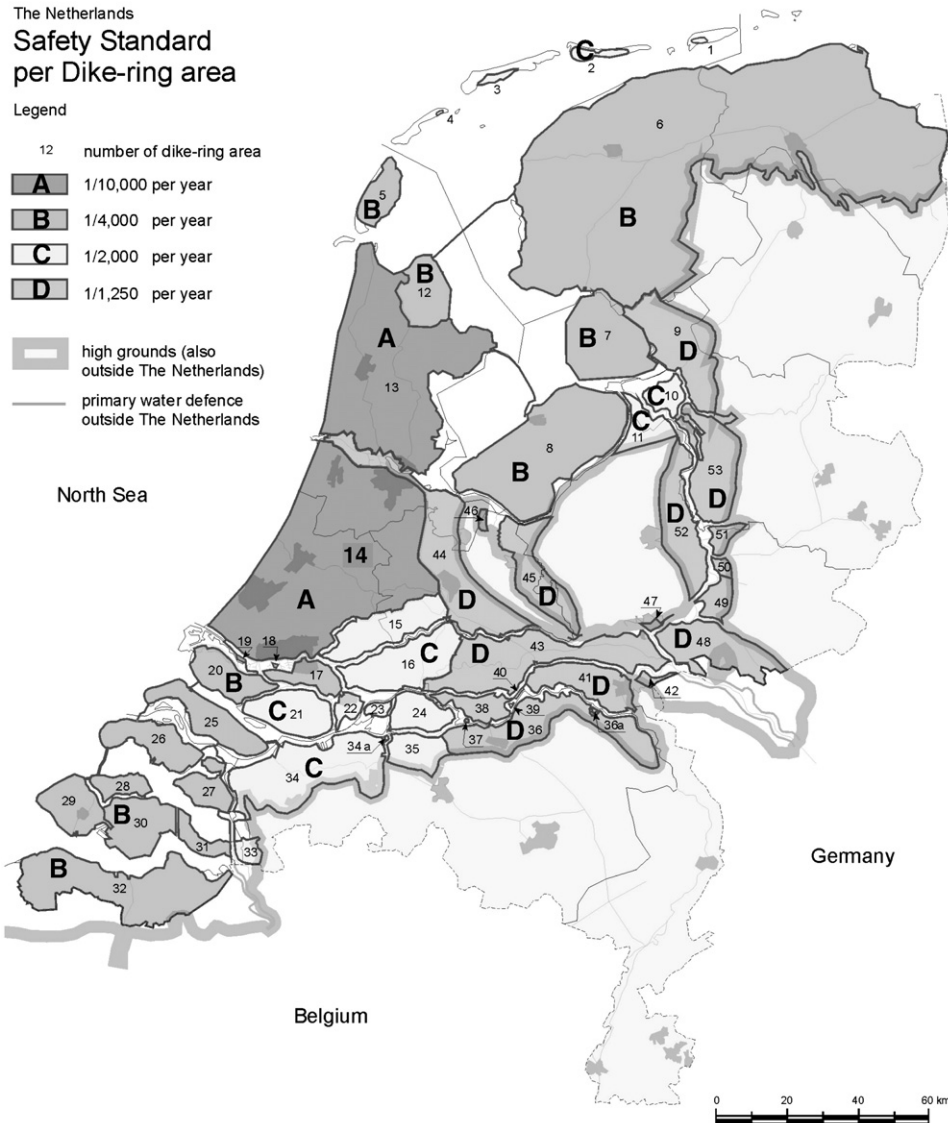


Fig. 1. Safety standards of dike ring areas in the Netherlands.

installations on higher floors. The focus of this study is on such low cost measures.

In some areas in the Netherlands maximum inundation depths of a flood are several meters. At such water levels, simple mitigation measures such as the installation of sandbags are expected to fail (ICPR, 2002). However, a recently developed flood risk map (<http://www.risicokaart.nl/>) shows that despite the low lying position of dike ring areas below sea level, inundation depths are not uniformly distributed. Many areas that lie several meters below sea level have an expected maximum inundation depth of only 1 m. This provides scope for further exploration of the effectiveness of mitigation measures. Moreover, several mitigation measures could be undertaken that limit flood damage even though water levels are high. Examples are moving installations or furniture to higher floors that are safe from flooding.

Until recently little attention was paid by policymakers to the role insurance arrangements can play in damage mitigation in the Netherlands. Private insurance coverage against flooding is not available at this moment. The government may partly compensate damage via the Calamities and Compensation Act (WTS), but it is uncertain whether compensation will be granted since a right to compensation does not exist (de Vries, 1998; Botzen and van den Bergh, 2008a). At this moment the Dutch government considers

concrete plans to introduce flood insurance in a “Task force” consisting of several ministries and representatives from the insurance sector. The current scheme of government compensation of flood damage, which is unconditional on the risk taken by households who settle in flood planes, can be regarded as undesirable, since incentives to limit damage are minimal (e.g., Priest, 1996). Therefore, it is worthwhile to examine how insurance arrangements could stimulate mitigation of flood damage.

Botzen and van den Bergh (2008a) discuss the advantages and difficulties of introducing flood insurance in the Netherlands. They propose a multilayered insurance program in the form of a public–private partnership for insuring flood damage, as has been proposed for insuring weather risk in the USA (Kunreuther, 2006b). In such a program, a first layer of small losses is paid by households, private insurance companies deal with a second layer of larger losses using risk based premiums, and the government covers a third layer of very large losses to prevent problems with insurability of highly correlated risks. Availability of insurance is likely to improve welfare of risk averse individuals by reducing uncertainty of compensation (Botzen and van den Bergh, forthcoming). Moreover, this insurance scheme may give adequate incentives to limit flood damage.

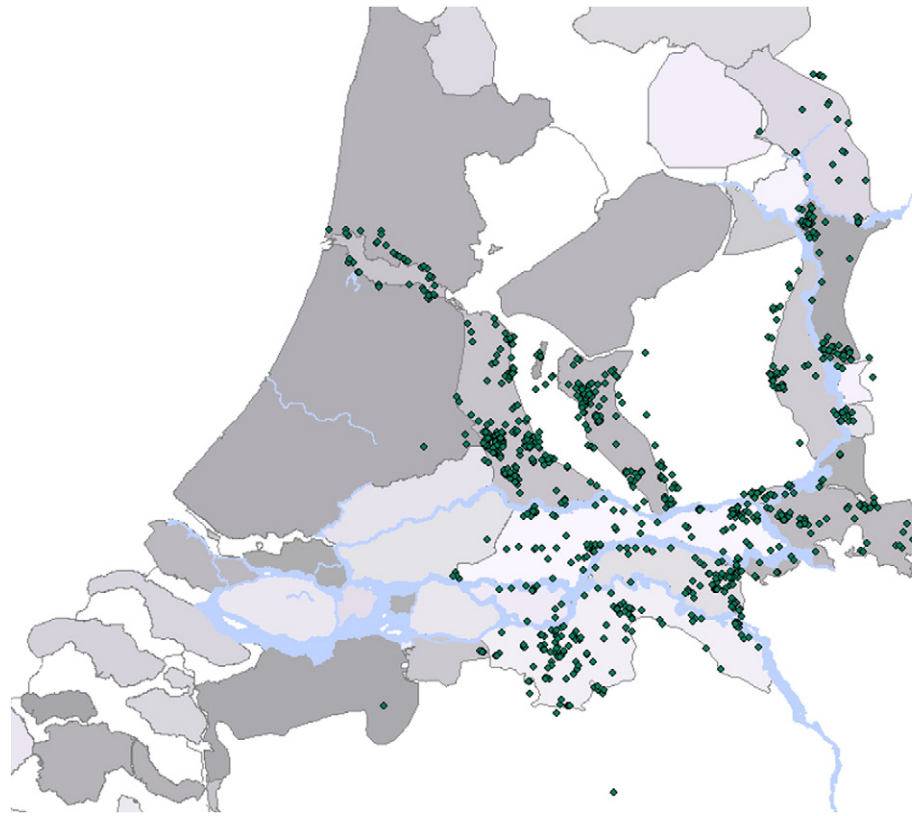


Fig. 2. Location of the respondents to the survey in the dike ring areas.

An important principle in actuarial practice and economics is that society's welfare is maximized by undertaking prevention as long as the costs of it are lower than the avoided expected harm of the hazard defined as *probability*damage* (see the so called "Learned Hand" formula in e.g., Grossman et al., 2006). However, individuals often lack information about the expected harm before a disaster occurs, making it difficult for them to trade-off the expected benefits of investing in mitigation measures and its costs, which may result in a sub-optimal level of mitigation investments. Insurance companies with a specialized knowledge of the probability and expected damage of hazards could give a market signal via premiums about the expected harm that individuals face. In case premiums are risk based and insurance markets are competitive, insurance could stimulate the undertaking of damage mitigation measures by offering premium reductions to individuals who invest in mitigation. Individuals can be expected to undertake such investments if the premium reductions outweigh the costs of mitigation. The possible benefits of introducing flood insurance in the Netherlands through stimulating homeowners to invest in mitigation are examined in the subsequent sections.

3. Explanation of the survey

The willingness of households to undertake mitigation measures for certain benefits on hypothetical insurance policies is examined using a survey. The four mitigation measures considered are the purchase of sandbags for a premium discount, the purchase of a water resistant floor type if damage from floors vulnerable to flooding is not covered, removal of certain machines (laundry and dryer machines), and central heating boiler to higher floors for a premium discount. These particular measures are examined for the following reasons. The experience during the 2002 Elbe flood and the International Commission for the Protection of the Rhine (ICPR) (2002) indicate that these measures could be very effective in limiting damage of river

floods, as will be explained in more detail in Section 4. It is further of interest to examine if homeowners have different attitudes to measures that prevent damage by keeping water out of the building (with sandbags) or prevent damage once water has entered the building (e.g., replacing machines). Moreover, the incentives provided to encourage homeowners to undertake these measures differ, namely exclusion of coverage in the measure that concerns replacing floors and premium discounts for the other measures. In this way both the effectiveness of the "carrot and stick" incentives that can be provided by insurance are examined.

The respondents were selected using area codes that corresponded to dike ring areas near the main river system with safety norms of 1 in 1250 in the Netherlands (areas indicated with letter D in Fig. 1). The geographical distribution of the respondents is depicted in Fig. 2 which shows the part of the dike ring areas of Fig. 1 that comprise the river delta. A description of the survey and an overview of the questions are given in Botzen et al. (2008).

The structure of the survey is as follows. The questionnaire started with questions on the experience of the respondent with flooding, flood damage and evacuation due to flood threats. An open-ended question about the causes of flooding was included to test the respondent's knowledge and stimulate the respondent to think about the nature of flood risks. In addition, several questions addressed the perception of flood risks and the expected effects of climate change. In particular, respondents were asked to rate their flood risks in comparison with an average Dutch resident (e.g., Viscusi and Zeckhauser, 2006). Moreover, respondents were asked to give quantitative estimates of the return period of a flood at their home, using a logarithmic probability scale as a visual aid.⁶ These questions familiarize the respondents with the topic

⁶ Following Schneider and Zweifel (2004) the return period was elicited using a logarithmic scale ranging from 1 to 100,000 years as a visual aid. The legal norm of flooding of 1 in 1250 years was indicated on top of the scale to facilitate answering the question.

and the answers may serve as explanatory variables in modeling the responses of the mitigation questions.

Next, the current regulation of compensation of flood damage was explained. This explanation differs between two versions of the questionnaire. In one version, it was explained that the government may provide partly compensation of damage suffered by households according to the current legislation and that private insurance coverage is available as well. In contrast, in the other version it was explained that such government compensation would no longer be provided and that only private insurance coverage is available instead. This allows for assessing the independent effect of the current compensation scheme on the willingness of homeowners to undertake mitigation measures. Moreover, an explanation was included in both versions about probabilities of flooding and safety standards in the Netherlands to help respondents to comprehend the risk they face.

The mitigation questions were part of an extensive survey that also included questions about demand for flood insurance (Botzen and van den Bergh, 2008b). Questions about willingness to pay for flood insurance, which are not discussed in this paper, follow the risk perception questions. Subsequently, the mitigation questions were asked (shown in Appendix A), which are the main questions of interest for this study. Each mitigation question and descriptive statistics of the answers will be discussed in detail in the next section. The questionnaire concluded with the usual socio-demographic questions.

During the design of the survey, experienced stated choice practitioners, other economists, natural scientists, water management experts, and psychologists reviewed versions of the questionnaire. After incorporating their comments three pretests of the questionnaire were conducted between August and October 2007 using face-to-face interviews. Four trained and carefully supervised interviewers (50% male and female) interviewed 88 households. These pretests turned out to be useful in checking the understanding of the survey by the respondents and resulted in several adjustments in the formulation of explanations and questions. A fourth and final pretest was conducted to test the online questionnaire, which resulted in minor adjustments in layout.

The survey was administered over the Internet using Sawtooth CBC software.⁷ This computer-based method has the advantage that follow-up questions can be automated, interviewer effects can be avoided, and a large geographically spread sample can be obtained at relatively low costs. Respondents were selected from the consumer panel of Multiscope and contacted by e-mail.⁸ This e-mail did not specify the topic of the survey to prevent selection bias. The sample consists of random draws of panel members who live in dike ring areas in the Netherlands with a safety standard of once in 1250 years. The sample was set up to be representative for the Dutch population until an age of 60 years. Fewer older individuals are represented in the Internet sample, because seniors are generally less active on the Internet than younger people. The survey starts with a selection question and only respondents who own a house are allowed to fill out the remainder of the questionnaire. It is more relevant to target mitigation measures to homeowners than renters because most flood damage will be caused on buildings, while home contents may be moved to higher floors during floods. Therefore, homeowners are more likely to invest in measures that mitigate flood damage since they fully benefit from the reduced damage of mitigation. Respondents who live in apartments higher than the first floor and respondents who live outside the sample area have been removed from the data. The survey was removed from the Internet once the desired number of respondents was reached.⁹ The resulting total number of completed questionnaires is 509.

4. Descriptive statistics of the willingness to undertake mitigation

4.1. Mitigation measure 1: buy sandbags to create a water barrier

Sandbags can act as a water barrier that protects the house from flood damage if they are placed in front of doors or low windows during a flood (ICPR, 2002). This measure is only effective if water levels are low, but there is uncertainty about the exact maximum water level at which water barriers are still effective. The maximum height of waterproofing is approximately 1 m above the ground according to Kelman and Spence (2003). In contrast, the International Commission for the Protection of the Rhine (ICPR) (2002) states that water barriers are effective during low depth floods with water levels smaller than 2 m. A maximum water level of 1 m may be a safe indicator for determining the effectiveness of sandbags.

According to the ICPR (2002) water barriers can reduce damage by about 60% up to 80% in case the flood does not overflow the barrier. A good example to assess the effectiveness of mitigation is the extreme flood of the Elbe in Germany in 2002. During the Elbe flood most water barriers were overtopped. Nevertheless, damage was reduced by 29% for buildings with water barriers, which is substantial (Kreibich et al., 2005). This indicates the relevance of examining the willingness to install water barriers in the Netherlands since the benefits in terms of reduced damage could be large.

The first mitigation question asks whether respondents are willing to purchase twenty sandbags, which has a one-time cost of € 20 in total, for a € 5 discount on their flood insurance premium per year. The survey indicates that mean willingness to pay (WTP) for flood insurance by respondents who are willing to purchase insurance is about € 10 per month or € 120 per year based on the contingent valuation method. As an illustration, the discount of € 5 yearly is about 4% of WTP for the insurance, which indicates that the discount is relatively small as are the investment costs. Suppose that respondents view the undertaking of this measure as a standard intertemporal utility maximization problem. This means that the investment is undertaken if the future benefits discounted over time exceed the cost. The ratio of discounted benefits over cost of the investments will be larger than one after six years using a discount rate of 10%. This indicates that a risk neutral individual would undertake this investment as long as the individual expects to benefit from the premium reduction for at least six years. Individuals with a larger discount rate, i.e. a very short time horizon, as well as very risk seeking individuals would be less likely to buy the sandbags.

The results of the survey indicate that about 62% of the respondents are willing to make the investment to buy the sandbags, while the remainder is not willing to buy the sandbags for the discount on the insurance premium. Only 7% of the German households had water barriers available during the Elbe flood, which may be due to the little experience with flooding and knowledge of living in a flood prone area or lack of trust in the effectiveness of private precautionary measures (Kreibich et al., 2005).¹⁰ This percentage of respondents willing to buy the sandbags is large compared with the experience in Germany. The findings of our survey suggest that providing benefits on the insurance policy may be useful to stimulate respondents to undertake this mitigation measure.

4.2. Mitigation measure 2: water resistant floor

The second mitigation question examines the willingness of respondents to replace a floor type that is vulnerable to flooding by a

⁷ See www.sawtoothsoftware.com.

⁸ For more information see www.multiscope.nl.

⁹ The use of the consumer panel of multiscope does not allow us to calculate the exact response rate to our survey since the survey was removed from the Internet once a pre-specified quota of completed questionnaires was reached. On average, response rates of the consumer panel are well above 20% (www.multiscope.nl).

¹⁰ The survey among the residents near the Elbe River indicates that about 25% and 27% of the households had collected information before or during the flood about flood protection. More information campaigns could be issued to increase knowledge about the effectiveness of precautionary measures and encourage households to invest in damage mitigation (Kreibich et al., 2005).

tile floor, which will not be damaged during a flood. Practical experience shows that this flood-adapted interior fitting measure may reduce households' flood losses considerably (Yeo, 2002). In particular, the ICPR (2002) states that about 27% of flood damage on buildings consists of damage on floors and floor coverings only, which indicates the relevance to examine the willingness to undertake this measure. Damage on parquet, wood, laminate, or carpet floors arises during floods with both very high and low water levels. Therefore, replacing these floor types with tile floors has the potential to reduce damage during most types of flooding events. A further advantage of this measure is that it can be implemented at relatively low costs, although, some respondents may object it for aesthetic reasons.

This question consists of two parts. First, it is asked if respondents have a vulnerable floor type on their ground floor. The vast majority of the respondents have such a floor type (72%) and they are asked to answer a follow-up question whether they are willing to buy a tile floor if their current floor needs replacement in the future when the flood insurance does not cover damage on their current floor type. Approximately 20% of the individuals who have a floor type that is vulnerable to flooding indicate that they will buy a tile floor in case flood insurance does not cover damage on their current floor. This result suggests that restrictions of coverage in insurance policies can be useful to encourage mitigation.

4.3. Mitigation measure 3: move laundry and dryer machines to a higher floor

This measure concerns to move the laundry or dryer machines to a floor higher than the first floor in case homeowners have installed those machines on the ground floor. In general, moving goods such as furniture is a very effective measure to limit flood damage. As an illustration, the flood of the Dutch Meuse in 1995 resulted in 80% less damage on furniture compared with the 1993 flood of the Meuse due to appropriate removal of goods, even though flood depth and warning times were comparable for both floods (ICPR, 2002). Damage was less during the second Meuse flood because households were more experienced and better prepared (Wind et al., 1999). A problem is that laundry and dryer machines are relatively heavy and are probably only moved to safer floors if flood warnings are timely issued. Smaller and less heavy furniture is likely to be removed first. For this reason, it is of interest to examine if households are willing to remove these machines ex-ante the flood threat.

This question first asks whether respondents have a laundry or dryer on a floor that is vulnerable to flooding, which is the case for 43% of the respondents. Subsequently, a follow-up question asks if respondents are willing to move their laundry and dryer machines to a floor higher than the first floor for a yearly discount of € 5 on their flood insurance premium. Only 6.8% cannot place the laundry machine or dryer on a higher floor, because their house consists of only one level. The vast majority (85%) has a first floor or higher, but does not want to remove their laundry machine and dryer. A small fraction of 8% indicated that they are willing to move their laundry machine and dryer to a higher floor for the premium discount. This suggests that reasons such as convenience or available space may play a larger role in the decision to move heavy household equipment than monetary incentives via flood insurance arrangements.

4.4. Mitigation measure 4: move central heating boiler to a higher floor

The final measure concerns moving the boiler of a central heating system to a higher floor, in case it is currently installed on a floor level vulnerable to flooding. Evidently, this measure can also mitigate flood damage in case of high water levels (FEMA, 1999). Kreibich et al. (2005) show that the installation of heating and other (electrical) utilities on higher floors could reduce mean absolute damage by € 24,000 per house based on experience with the 2002 Elbe flood in

Table 1

Responses to the mitigation questions.

| Mitigation measure | % for whom the measure is relevant (A) | % of (A) who are willing to undertake the measure (B) | % of total sample willing to undertake the measure (A*B) |
|--|--|---|--|
| 1) Buy sandbags that can be used as water barrier | 100 | 68 | 68 |
| 2) Replace current floor with a tile floor | 72 | 20 | 14 |
| 3) Move laundry and dryer machines to a higher floor | 43 | 8 | 3 |
| 4) Install central heating boiler on a higher floor | 19 | 24 | 5 |

Germany. Moreover, they estimate that flood damage was about 36% lower for households who had their utility installation placed on a floor safe to flooding. The average damage on the heating installation in particular was € 7836.¹¹

This mitigation question consists again of two parts. First, it is asked whether respondents currently have a central heating boiler installed in their cellar or ground floor. In total, 19% answered that this is the case. These respondents then are asked to answer the follow-up question whether they will place their boiler on the first floor or higher when it needs replacement in the future for a yearly premium discount of € 10 on their flood insurance. A minority of the respondents does not have a higher floor (11%) and are, therefore, unable to undertake the mitigation measure. Approximately, 65% have a higher floor but do not want to move their boiler and almost a quarter is willing to place their boiler on a higher floor for the premium discount.

4.5. Summary of the willingness to undertake mitigation measures

Table 1 shows the percentage of respondents for whom the mitigation measures are relevant (column A) and the percentage of those respondents who are actually willing to undertake the measure (column B) and the product of the two, which represents the percentage of total respondents who will undertake the measure. We note that the measure to move machines to higher floors and replace the central heating boiler to higher floors is only relevant to homeowners who currently have these machines and boiler installed on their ground floor level. Also the measure to replace vulnerable floor types with tile floors is only relevant to respondents who do not already have a tile floor on the ground floor level.

From the table it is apparent that the water barrier may be a promising mitigation strategy since this measure is relevant for all respondents and a large percentage of homeowners are willing to buy the sandbags. The measure that replaces a vulnerable floor type with a tile floor has the largest percentage of respondents to whom this measure is applicable compared with the other three measures since 72% do not have a tile floor at the time of the survey. About a fifth of these respondents indicate that they would replace their floor type by a tile floor in case damage on their current floor is not covered by insurance. The measure to move laundry and dryer machines to a higher floor is applicable to almost half of the respondents (they placed those machines on the ground floor level), but only a very small proportion is willing to undertake it. Therefore, this measure seems least promising. A smaller proportion has a central heating boiler on a lower floor so that the mitigation measure is relevant for them, but about a quarter of these homeowners is willing to move it to a floor that is safe to flooding.

¹¹ Personal communication of Dr. Heidi Kreibich.

5. Estimating the potential contribution of mitigation in limiting flood damage

It is useful to examine how much damage may be prevented by undertaking the four mitigation measures included in the survey. This in turn allows for identifying what measure is likely to be most effective in limiting damage. The last column of Table 1 indicates the proportion of homeowners who will undertake a specific mitigation measure. This information is used to estimate damage prevented by mitigation, using two approaches. First, damage prevented by the four mitigation measures is examined if a major river flood would occur in a representative dike ring area. Second, the reduction in flood risk, defined as probability times prevented damage, resulting from the mitigation measures is estimated for all of the dike ring areas with a 1 in 1250 norm, under different scenarios of climate change. This is of special interest since little is known about the effectiveness of mitigation measures in the Netherlands. We will use estimates of damage prevented for each individual mitigation measure based on the 2002 Elbe floods and estimates by the ICPR (2002), because of a lack of empirical evidence of prevented damage by mitigation in the Netherlands.

5.1. Case study of dike ring area 36

Dike ring area 36 is located in the South of the Netherlands (Fig. 1) and is part of the 1 in 1250 safety norm dike ring areas sampled in our survey. The river The Meuse bounds this dike ring in the North and the East where dikes protect an area of 740 km² from flooding. Approximately 161,099 houses are located in this dike ring area (DWW, 2005), of which about 55% or 88,600 are privately owned (Statistics Netherlands, 2008). Wouters (2005) estimates that potential flood damage on houses and their contents due to an extreme flood in this dike ring amounts to a maximum of € 11 billion. Dividing this by the total number of houses and adjusting to end of the year 2007 price levels gives an average expected damage per house of € 79,000, caused by an extreme flood. More detailed analyses of potential flood damage in dike ring area 36 have been made by the “Floris” study (Rijkswaterstaat, 2005a). According to the Floris study, the maximum total flood damage is lower and amounts to € 7.5 billion, of which about € 4 billion can be attributed to property damage (Rijkswaterstaat, 2005b). Using the maximum estimate by Wouters (2005) and the lower estimate by the Floris study results in a lower and upper damage estimate per house of € 79,000 and € 29,000. These estimates of average flood damage per house will be used in the computations of prevented damage by mitigation.

Table 2 shows the number of homeowners who will undertake the mitigation measures as derived from the survey and an estimate of damage prevented by each measure if a river flood takes place. Multiplying the total number of homeowners in the area (88,600) with the proportion of who will undertake the measure (last column Table 1) gives the total number of homeowners who will undertake the measure. The underlying assumption is that the proportions in Table 1, which represent a sample of the homeowners in all 1 in 1250 norm dike ring areas, apply also to dike ring area 36 (that is part of the 1 in 1250 norm areas). Nevertheless, our estimates provide a useful indication of the contribution mitigation can make in preventing damages and relative effectiveness of the four measures examined here.

Total flood damage prevented by water barriers is computed by multiplying the number of homeowners who undertake the measure by estimates of damage prevented per house. It is uncertain how much damage water barriers can prevent and, therefore, different scenarios of effectiveness and expected damage will be applied. In particular, an optimistic and a pessimistic scenario of effectiveness of water barriers to mitigate damage will be used in these calculations. The optimistic scenario is based on the ICPR (2002), which states that water barriers can prevent up to 60–80% of total flood damage per house in case the flood does not overflow the barrier. We will use the lower estimate

Table 2

Estimates of prevented damage by mitigation in dike ring area 36.

| Mitigation measure | Homeowners who undertake the measure | Total prevented flood damage (Mln €) |
|--|--------------------------------------|--------------------------------------|
| 1) Buy sandbags that can be used as water barrier | | |
| – Pessimistic effectiveness and low expected damage | 60,248 | 506.7 |
| – Pessimistic effectiveness and high expected damage | 60,248 | 1427.9 |
| – Optimistic effectiveness and low expected damage | 60,248 | 1048.3 |
| – Optimistic effectiveness and high expected damage | 60,248 | 2855.8 |
| 2) Replace current floor with a tile floor | | |
| – Low expected damage | 12,758 | 99.9 |
| – High expected damage | 12,758 | 272.1 |
| 3) Move laundry and dryer machines to a higher floor | 3048 | 2.1 |
| 4) Install central heating boiler on a higher floor | 4040 | 31.7 |

(60%) of this range in our optimistic scenario. The pessimistic scenario is based on the effectiveness of water barriers during the 2002 extreme Elbe flood when many water barriers were overflowed and on average 29% of total damage per house was prevented by installing water barriers (Kreibich et al., 2005). We note that above 1.5 to 2 m water depth most mitigation measures are ineffective as described in Keijzer (2008) and the assumption here is that on average, the maximum water depth in dike ring area 36 is below 1.5 to 2 m. This is, however, an important variable that should be quantified in more detail in further research, especially because considerable uncertainty exists about the relation between water depth and flood damage (Merz et al., 2004).

The proportions of damage prevented in the optimistic and pessimistic scenarios are multiplied with the potential flood damage per house in dike ring 36, which is estimated as € 79,000 or € 29,000 based on Wouters (2005) and the “Floris” study, respectively. Total damage prevented with this measure is considerable and is in between € 0.5 and € 2.8 billion, as Table 2 shows. It should be noted that this damage prevented by water barriers is computed as if it is implemented without undertaking the other mitigation measures. Evidently, prevented damage by water barriers will be lower if floors vulnerable to flooding are replaced also.

The estimate of total damage prevented by changing vulnerable floor types to tile floors is derived in a similar way using the ICPR (2002) estimate of damage on floors of 27% of total damage per house. It is assumed that this damage is not suffered if tile floors are used instead of floor types that are vulnerable to flooding. Because of uncertainty of damage prevented by changing floor types it is computed using the low (€ 29,000) and high (€ 79,000) estimates of average damage per house. Total damage prevented is in between € 100 million and € 270 million, which is substantial but lower than the water barriers measure because fewer homeowners will replace their current floor.

The mitigation measure that involves replacing certain machines (laundry and dryer machines) to a higher floor is not very effective, because total prevented damage is only about € 2 million. Prevented damage is computed by multiplying the number of homeowners who undertake the measure by the average damage prevented, which is estimated to be € 675.¹² Replacing the central heating boiler to a higher floor is more effective, because more homeowners are expected to undertake the measure and prevented damage per

¹² The average price to buy a new laundry and dryer machine is about € 1300 in total (www.milieucentraal.nl). It is assumed that the average value of existing machines is about half, which results in an average damage prevented of € 675 per house.

Table 3

Expected value (EV) of prevented loss (in 1000 €) by mitigation under climate change for all 1 in 1250 norm dike ring areas.

| Mitigation measure | EV prevented loss current climate | EV prevented loss temperature +1 °C | EV prevented loss temperature +2 °C |
|--|-----------------------------------|-------------------------------------|-------------------------------------|
| | $p = 1/1250$ | $p = 1/750$ | $p = 1/550$ |
| 1) Buy sandbags that can be used as water barrier | | | |
| – Pessimistic effectiveness and low expected damage | 2445 | 4075 | 5557 |
| – Pessimistic effectiveness and high expected damage | 6610 | 11,017 | 15,024 |
| – Optimistic effectiveness and low expected damage | 5059 | 8431 | 11,497 |
| – Optimistic effectiveness and high expected damage | 13,677 | 22,795 | 31,084 |
| 2) Replace current floor with a tile floor | | | |
| – Low expected damage | 469 | 781 | 1065 |
| – High expected damage | 1267 | 2112 | 2880 |
| 3) Move laundry and dryer machines to a higher floor | 9 | 15 | 21 |
| 4) Install central heating boiler on a higher floor | 180 | 300 | 409 |

house is larger. Flood damage prevented is based on the experience during the Elbe flood when average damage on heating installations on low floors was € 7836,¹³ which is multiplied by 4040 homeowners who will undertake the measure, resulting in almost € 32 million. Table 2 summarizes the results, and shows that considerable gains are possible through the first two and fourth mitigation measures.

5.2. Mitigating flood risk in the 1 in 1250 norm dike ring areas under climate change

The previous analysis estimated the potential of the mitigation measures to prevent flood damage in a representative dike ring area. Subsequently, it is examined how the mitigation measures can contribute to reduce flood risk in all dike ring areas with a 1 in 1250 safety norm on which our sample of the survey is based (indicated by “D” in Fig. 1), which allows for assessing the potential benefits of mitigation in a large part of the river delta. It is, nevertheless, very unlikely that all 1 in 1250 norm dike ring areas will be flooded at the same time. Therefore, an estimate of total prevented damage by mitigation in all these areas is not a very relevant indicator of the benefits of mitigation. The reduction in the *expected value* (probability times prevented damage) or flood risk will be estimated instead, which is an important indicator in cost–benefit analysis of water management policy. Moreover, the effects of climate change on the effectiveness of mitigation to limit flood risk are examined.

The approach to estimate prevented damage per mitigation measure for all 1 in 1250 norm dike ring areas, which is an input for the probability times prevented damage calculations, is similar to the approach underlying the computations for dike ring area 36 above. The only differences are that the total number of homeowners and expected damage per house for the 1 in 1250 norm areas are used as an input for the analysis instead of the values for dike ring area 36. The total number of houses in these areas is 1,043,758 (DWW, 2005) of which approximately 55% or 574,000 are privately owned (Netherlands Statistics, 2008).

The average flood damage per house is estimated by adding the total expected damage on houses and home contents caused by a major flood in all of the 1 in 1250 norm areas, as has been estimated by Wouters (2005), and dividing this by the total number of houses in these areas. Adjusting this for the end of the year 2007 price level results in an average flood damage per house of € 73,000. Unfortunately, more detailed analyses of expected flood damage as has been made in the “Floris” study are only available for dike ring area 36 and not for the other 1 in 1250 norm dike ring areas. The flood damage per house based on the “Floris” study was about 37% of the estimate based on Wouters (2005). As an approximation we assume that the same difference applies to the other 1 in 1250 norm dike ring areas and use € 27,000 as a scenario of low average flood damage per

house. The expected value of prevented damage is then computed by multiplying prevented damage of a mitigation measure by the flood probability.¹⁴

The expected values of prevented losses are estimated for three scenarios of flood probabilities, namely the current safety norm of 1 in 1250 and two scenarios where flood risk increase to 1 in 750 and 1 in 550 due to climate change by 2050. These increased flood probabilities are consistent with a 1 °C and 2 °C rise in global temperature with consequently higher peak discharges on the rivers Meuse and Rhine (see Aerts et al., 2008a) and have been derived by Botzen and van den Bergh (forthcoming) based on RIZA (2003) and used in an application of Aerts et al. (2008b). Evidently, flood risk will be lower if the government invests in heightening of primary river dikes. Note that changes in probability due to climate change differ across each 1/1250 dike ring as shown in Aerts et al. (2008a) depending on varying influences of sea level rise or changes in extreme discharges of rivers. Here we assume, however, that the changes in probability are on average the same.

Table 3 shows the expected value (EV) of prevented damage of the four mitigation measures under different scenarios of flood probabilities. The estimates show that especially water barriers and replacing floor types considerably reduce flood risks. In contrast, the gains of offering premium discounts to move machines to higher floors is small, while stimulating homeowners to replace their central heating installation is moderately effective. A very relevant insight of the computations in this subsection is that the yearly reduction of flood risk due to mitigation in the entire river delta can be non-negligible even if climate change does not increase flood probabilities. The (absolute) expected values of prevented damage under the two climate change scenarios indicate that the benefits of mitigation increase considerably if climate change increases flood risk. This suggests that stimulating mitigation with insurance arrangements is an attractive adaptation strategy.

6. A statistical model of the decision to mitigate: buy sandbags as a water barrier

The benefits received by the policyholder to undertake mitigation measures, for example premium discounts, are likely to be the main determinant in the decision whether to undertake the measure. However, other factors may influence decisions to undertake mitigation measures as well, like household and geographical characteristics. Insight into these factors is of interest for two main reasons. First, it is relevant from a social welfare perspective to know what types of households are willing to undertake mitigation measures. In particular, whether these households are at low or high risk is important information. Second, it is of interest for insurers to know what type of households they can target or stimulate to undertake

¹³ Personal communication of Dr. Heidi Kreibich.

¹⁴ Computed as prevented damage*flood probability.

such measures. Moreover, the influence of risk perception and availability of compensation of damage by the government in decisions regarding the undertaking of mitigation is studied. A statistical model is estimated to examine the factors that influence the decision to undertake mitigation for the first mitigation measure, i.e. the willingness to buy sandbags for a premium discount. The previous section has indicated that this measure may be the most effective because it is applicable to all respondents, a large proportion of respondents (68%) are willing to undertake it, and prevented damage may be large.

6.1. Estimation results of the probit model

Appendix B explains the probit model used to analyze the mitigation decision and gives an overview of the explanatory variables and their descriptive statistics. The estimation results are shown in Table 4 and will be discussed in this section. Table 4 shows the mean marginal effect (ME) of a change in the explanatory variables, the corresponding standard error and the *t*-statistic of the hypothesis that the marginal effect equals zero. This means that the marginal effects of dummy variables give the change in probability of the respondent undertaking the mitigation measure if the variable has value one. The overall fit of the model is reasonable given that the premium discount is likely to be the main motivation for undertaking the mitigation measure, but cannot be included in the model since it is fixed. The pseudo R^2 of the model is 11%, which is not the same as the R^2 statistic in an ordinary least squares regression, since a probit model is non-linear. The pseudo- R^2 value of the estimated model corresponds to an R^2 statistic of about 0.3 (Domencich and McFadden, 1975).

Two variables are included to capture actual or perceptions of responsibilities for compensating flood damage. The first variable represents the version of the questionnaire explaining the current regulation according to which the government may partly compensate

flood damage compared with the version explaining that such compensation is not available. The variable is significant at the 5% level and the marginal effect indicates that the probability of a homeowner buying sandbags to mitigate flood damage is about 0.09 smaller if the government provides partly compensation of flood damage. This suggests that the availability of damage relief reduces incentives to undertake private mitigation efforts, as has been argued in several studies (e.g., Kaplow, 1991). Further, a variable “Government is perceived as responsible” has been included that represents respondents who object against buying flood insurance as they feel that the government is responsible for providing damage relief or guaranteeing adequate protection against flooding.¹⁵ It can be expected that these respondents are also less inclined to undertake mitigation measures themselves, which is confirmed by the estimation results since the effect is significant at the 5% level and the size of the marginal effect is large. In particular, the probability of such respondents buying sandbags to mitigate flood damage is about 0.31 lower than other respondents.¹⁶

Several variables are included that measure perceptions of the respondent's flood risk and expectations about effects of climate change. These variables are statistically significant while the coefficient signs indicate that the larger the respondents expects the effects of climate change to be and the larger the flood risk is perceived, the larger is the probability of the respondent buying sandbags. In particular, the probability to undertake mitigation is larger if the negative effects of climate change for the Netherlands are perceived as large (ME = 0.0676) and if it is expected that climate change will increase flood risk (ME = 0.1514). It is less likely that homeowners will undertake mitigation if they perceive their flood risk as being lower than an average resident (ME = −0.0938).

The expected return period of a flood is included through two variables; a dummy variable captures the respondents who answered a zero expected return period and a continuous variable represents the expected return period of respondents with positive answers. The expected flood probability is the inverse of the return period of flooding. The marginal effects are −0.2 and −0.0004 of the zero and positive expected return variables, respectively, which indicates that the larger the respondent perceives the probability of a flood in his or her living area the larger is the probability that the respondent will undertake the mitigation measure.

We have included a variable of ‘experience with evacuation’ in the model.¹⁷ This variable is not statistically significant. Therefore, respondents who have experienced a serious threat of flooding in the sense that they needed to be evacuated are not more or less likely to undertake mitigation. The most recent flood event in 1995 may have been too long ago to affect mitigation decisions. Several studies show that the willingness to undertake precautionary measures first increases after a disaster but then rapidly decreases in subsequent years (e.g., Kunreuther et al., 1985). A variable about the knowledge of

Table 4
Estimation results of a probit model of the willingness to buy sandbags.

| Variable | Marginal effect | Standard error | <i>t</i> -statistic |
|---|-----------------|----------------|---------------------|
| <i>Role government</i> | | | |
| Government compensation is available | −0.0899** | [0.0465] | −1.94 |
| Government is perceived as responsible | −0.3094** | [0.1452] | −2.00 |
| <i>Risk perception</i> | | | |
| Negative effects of climate change | 0.0676** | [0.0314] | 2.15 |
| Climate change causes higher flood risk | 0.1514*** | [0.0619] | 2.46 |
| Lower flood risk than average resident | −0.0938** | [0.0490] | −1.91 |
| Zero expected return period flood | −0.2038** | [0.1499] | −2.25 |
| Expected return period flood | −0.0004* | [0.0002] | −1.74 |
| <i>Experience and knowledge</i> | | | |
| Experience with evacuation | −0.1289 | [0.0907] | −1.45 |
| Knowledge about floods | −0.1398** | [0.0565] | −2.30 |
| <i>Geographical characteristics</i> | | | |
| Elevation house and barrier is lower than water level | −0.1179** | [0.0496] | −2.38 |
| House is close to main river | 0.0857* | [0.0496] | 1.71 |
| Rural area | 0.3339*** | [0.0467] | 3.53 |
| <i>Socio economic characteristics</i> | | | |
| Female | −0.0158 | [0.0493] | −0.32 |
| Age | −0.0013 | [0.0021] | −0.63 |
| Income | 0.000004 | [0.00002] | 0.15 |
| Education | 0.0490* | [0.0269] | 1.82 |
| Number of observations | 494 | | |
| Pseudo R^2 | 0.11 | | |
| Log likelihood | −290 | | |

Notes. One, two and three asterisks (*) indicate respectively significance at the 10%, 5%, and 1% level. Estimations are performed with the statistical software package Stata.

¹⁵ The questionnaire asked whether respondents are willing to pay for flood insurance. An open-ended question asks for reasons if respondents do not want insurance. This dummy variable takes on the value 1 if respondents indicate that the government is responsible for providing damage relief or guaranteeing adequate protection against flooding as reasons not to buy flood insurance, and 0 otherwise.

¹⁶ We estimate whether the willingness to undertake mitigation is related to the willingness to purchase flood insurance. The results (not shown in the table) indicate that this relation is not statistically significant, which suggests that the scenario for the mitigation questions proposing respondents to imagine they possess flood insurance coverage is accepted.

¹⁷ The questionnaire also asks whether respondents have experienced a river flood in their living area. About 20% of the respondents answered that they did experience a flood. However, only 3 respondents indicated that they actually suffered flood damage. We regard experience with evacuation as a more relevant measure of experience with flooding than the variable representing experience with flooding in general since practically all individuals in the latter group did not suffer any flood damage. Therefore, we did not include the experience with flooding in general.

respondents about the causes of flooding is statistically significant. The estimation results indicate that individuals who are able to state at least one cause of flooding have a smaller probability of undertaking mitigation, compared with individuals who are not able to state any cause of flooding ($ME = -0.1398$). This suggests that homeowners who have little knowledge about the flood threat are more likely to buy protection, i.e. sandbags, against the risk.

Three variables in the model reflect objective measures of the flood risk faced by the respondent based on geographical characteristics. Geographical Information Systems (GIS) maps, such as a digital elevation map, have been linked to the respondent's exact geographical location using postal codes.¹⁸ A variable indicates whether the elevation of the postcode area of the respondent plus the height of a one-meter water barrier, for example sandbags, is located below the expected water level of a flood.¹⁹ The other two variables indicate if the house is located close to a main river and if the respondent lives in a rural area. These variables are of special interest for the following reasons. The effectiveness of a water barrier depends on the elevation of the area of the house relative to the potential water level of a flood. Therefore, it is of interest to examine whether respondents who live in a too low area for additional water barriers, like sandbags, to be effective are more or less likely to buy the sandbags. In this analysis, it is assumed that sandbags are no longer effective for homeowners whose elevation of their house plus 1 m is located below the expected water level of a flood. Furthermore, respondents who live closer to a main river may be at higher risk and, therefore, also more aware of the threat posed by flooding as shown by Botzen et al. (2009), making them more willing to undertake mitigation. Finally, inhabitants of rural areas with lower population densities and concentrations of economic values may have different attitudes towards undertaking flood risk mitigation than inhabitants of cities.

The results in Table 4 indicate that homeowners who live in an area that is too low for effective mitigation with water barriers are less likely to undertake the mitigation measure ($ME = -0.1179$). Even though the large majority of respondents will not know exactly the elevation of their house compared with potential water levels, discussions with respondents during the pre-tests of the questionnaire indicated that many households do relate their exposure to flooding with elevation. The results of this analysis indicate that homeowners with very low-lying houses are less likely to undertake mitigation with water barriers.

Respondents with a home close to a main river are more likely to undertake the mitigation measure, but this effect is only marginally significant (p -value = 0.09). Respondents close to a main river are more likely to suffer flood damage. Therefore, it is sensible that they are more likely to invest in mitigation. The probability that homeowners in rural areas are willing to undertake mitigation is almost one third larger than respondents in urban areas and this is significant at the 1% level. This indicates that inhabitants of rural areas have more positive attitudes towards mitigation than inhabitants in cities, which may be because they are more aware of the flood risk (Botzen et al., 2009).

The socioeconomic characteristics sex, age and income have no statistically significant effect on the decision to undertake mitigation. The education level has a positive and significant effect (p -value = 0.07). In all, the role of the government, risk perceptions, and geographical characteristics are more important determinants in the decision to undertake mitigation than the socioeconomic characteristics of the

respondent. We note that the main incentive for homeowners to choose for investing in water barriers is likely to be the premium discount on the flood insurance policy provided to them in the survey, although the other factors examined in this section play a role as well.

7. Conclusions

Climate change is projected to increase flood risk in the Netherlands because of more extreme precipitation, increased river runoff and sea level rise. This requires managing the probability of a flood through dike reinforcements and measures that limit flood damage. Experiences in various countries suggest that mitigation measures at the household level can be an effective means to limit flood damage during floods. For example, households who undertook certain measures ex-ante of the 2002 extreme Elbe flood in Germany suffered lower damage than households who did not do so. Therefore, it is of interest to examine whether homeowners in the Netherlands can be stimulated to undertake mitigation measures, if they would get discounts on flood insurance policies.

Currently, flood insurance is not available in the Netherlands. Increased attention has been paid to the role that insurance arrangements could play in providing financial security against residual flood risks in the Netherlands and providing incentives to households to limit potential flood damage. The latter has been examined for four possible mitigation measures, namely the purchase of sandbags for a premium discount, the purchase of a water resistant floor type if damage from other floors is not covered, moving of machines (laundry and dryer machines), and central heating boiler to higher floors for a premium discount.

The results of the survey indicate that homeowners can be stimulated to undertake investments to mitigate potential flood damage by offering certain benefits on insurance policies. Especially offering homeowners a premium discount in case they buy water barriers before a flood event, such as sandbags, seems a promising strategy to prepare a considerable proportion of inhabitants in the Dutch river delta for flooding. In addition, the survey reveals that a large majority of Dutch homeowners have a floor type that is vulnerable to flooding on the ground floor, indicating that considerable damage could be prevented in case such floors are replaced by flood resistant floor types. About a fifth of the respondents are actually willing to do so in the face of restrictions on their insurance policy. Moving laundry and dryer machines to a higher floor seems to be the least promising measure, while a larger proportion of homeowners are willing to move their central heating boiler to a floor safe for flooding. Indicative estimates of the effectiveness of each mitigation measure for a representative dike ring area confirm that prevented damage is considerable for mitigation with water barriers and replacing vulnerable floors with tile floors (see Table 2). Examination of the benefits of mitigation for all 1 in 1250 norm dike ring areas showed that reductions in (yearly) flood risk could be substantial, especially if flood probabilities rise due to climate change (see Table 3).

A model has been estimated to identify the factors behind the decision to buy sandbags, which can serve as a water barrier. The results provide three main insights. First, the current institutional setting characterized by availability of partly compensation of flood damage by the government reduces private incentives to undertake mitigation. Second, perceptions of risk and climate change play an important role in the decision to undertake mitigation. In particular, the higher the risk of flooding is perceived the more likely are homeowners to invest in water barriers. From these results follows that homeowners may be stimulated to undertake mitigation investments by abolishing the current scheme of government compensation and raising awareness of flood risk. The second finding suggests that provision of information about changing climate risks could through perception influence the mitigation behavior of homeowners. Third, geographical characteristics, like elevation of the house, distance to a

¹⁸ This data is based on 4-digit and 2-letters postal codes for 494 respondents, which is highly accurate because it gives street location. The data for 15 respondents are based on postcode numbers only because letters are incomplete.

¹⁹ The elevation of the postal code areas is obtained using the AHN elevation map and potential water levels are based on the "RWS dijkkruihoogtesbestand".

main river and living in a rural area, determine the decision to invest in mitigation.

The results of this study provide insight into the willingness of homeowners to undertake mitigation measures for benefits on insurance policies. Preliminary estimates of the effectiveness of stimulating mitigation with insurance suggest that prevented damage and reduced flood risk can be substantial. We note that uncertainties about these estimates remain, because few detailed data about flood damage and effects of mitigation exist. Future research should focus on determining various cost-effective mitigation measures and how these can be complementary to traditional water management as well as a comprehensive risk reduction strategy. Moreover, including mitigation measures in catastrophe models may provide detailed estimates of the benefits of mitigation in the face of uncertainties about flood probabilities. The analysis of this paper, which shows that homeowners can be encouraged to undertake mitigation with the use of insurance policies, provides a good basis for assessing the effectiveness of mitigation as an instrument to adapt to rising flood risk in the river delta of the Netherlands.

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Appendix A. Questions about mitigation and insurance

1. Suppose that you have insurance coverage against flood damage. Would you spend € 15 one time to buy twenty (empty) sandbags if you would get a discount on your insurance premium of € 5 each year?

You can prevent damage by placing filled sandbags in the front of doors during floods.

- No
- Yes

2. Do you (partly) have parquet, wood, laminate, or carpet on the ground floor of your house?

- No
- Yes

Follow up question 2 (this question is asked if the respondent has answered “yes” at 2)

Suppose that you have insurance coverage against flood damage. Will you select a tile floor if you would buy a new floor and the flood insurance does not cover damage to your current floor?

- No
- Yes

3. Do you have a laundry machine or dryer at your cellar, ground floor, garage or shed?

- No
- Yes

Follow up question 3 (this question is asked if the respondent has answered “yes” at 3)

Suppose that you have insurance coverage against flood damage. Will you move your laundry machine and dryer to the first floor or higher, if you would get a yearly discount of € 5 on your insurance premium?

- This is not possible since my house does not have a first floor or higher.
- I do have a first floor but will not do this.
- Yes, I will do this.

4. Do you have a central heating boiler placed in your cellar or ground floor?

- No
- Yes

Follow up question 4 (this question is asked if the respondent has answered “yes” at 4)

Suppose that you have insurance coverage against flood damage. In case you need to replace your boiler in the future and you can get a yearly discount on your insurance premium of € 10 if you install the new boiler on the first floor or higher, will you do this?

- This is not possible since my house does not have a first floor or higher.
- I do have a first floor but will not do this.
- Yes, I will do this.

Appendix B. The statistical model and overview of the variables and descriptive statistics

As the dependent variable is binary, a probit model is estimated to analyze the influence of the explanatory variables on the mitigation decision. This is done by maximum likelihood estimation of the function (e.g., Heij et al., 2004):

$$\log(L(\beta)) = \sum_{\{i: y_i = 1\}} \log(\Phi(x_i' \beta)) + \sum_{\{i: y_i = 0\}} \log(1 - \Phi(x_i' \beta)) \quad (B1)$$

where β is the parameter vector to be estimated, Φ represents the cumulative normal distribution, x_i is a vector of explanatory variables and y_i is the outcome for the i th observation. A detailed description of the variables and their coding as well as their descriptive statistics are given in Tables B1 and B2 below. Different methods of coding categorical variables have been applied depending on the type of variable. A continuous variable is created from the categorical variable income, which represents monetary classes (e.g., Blumenschein et al., 2008). Ordinal qualitative variables,²⁰ which are partitioned into J intervals, can be included using $J - 1$ dummies or can be transformed into values on the real axis using an approach proposed by Terza (1986), who advocates to transform ordinal qualitative variables as follows:

$$\phi^j = (n(\theta_{j-1}) - n(\theta_j)) / (N(\theta_j) - N(\theta_{j-1})) \quad (B2)$$

where n and N are the pdf and cdf of the standard normal distribution, respectively, and

$$\begin{aligned} \theta_1 &= N^{-1}(p_1) \\ \theta_2 &= N^{-1}(p_1 + p_2) \\ &\vdots \\ \theta_{j-1} &= N^{-1}(p_1 + p_2 \dots + p_{j-1}) \end{aligned}$$

and p_j is the percentage of the sample observed in category j .²¹

An advantage of the dummy approach is that interpretation of the coefficients is straightforward. The transformation of Terza (1986) can result in gains in efficiency and bias, especially if the number of categories is large. For this reason the latter approach has been applied in several studies (e.g., van Praag et al., 2003), even though applications in the environmental valuation literature are scarce. We

²⁰ These variables are characterized by a continuous unobservable ordinal latent index and each interval is ranked (1 through J) in increasing order according to its supremum (Terza, 1986).

²¹ For the lowest and highest categories (B2) reduces to $\phi^j = -n(\theta_j)/N(\theta_j)$ and $\phi^j = n(\theta_{j-1})/(1 - N(\theta_{j-1}))$.

apply dummy variable coding for variables with a small number of categories, such as the rating of the flood risk compared with an average resident and the effect of climate change on the flood probability. The transformation is used for variables with a large number of categories, which are the negative effects of climate change and the education level.

Table B1

Overview of the variables used in the statistical analysis.

| Dependent variables | |
|---|--|
| Sandbags | Binary variable, 1 = respondent is willing to buy sandbags for a premium discount, 0 = otherwise. |
| Explanatory variables | |
| Government compensation is available | Dummy variable, 1 = it is explained in the survey that it is possible to receive party compensation of flood damage by the government |
| Government is perceived as responsible | Dummy variable, 1 = the respondent states that the government is responsible for compensating flood damage or guaranteeing adequate protection |
| Negative effects of climate change ^a | Categorical variable, respondent expects effects to be 1 = very small, 2 = small, 3 = not small/not large, 4 = large, 5 = very large |
| Climate change causes higher flood risk ^b | Dummy variable, 1 = respondent expects that climate change causes higher flood risks |
| Lower flood risk than average resident ^c | Dummy variable, 1 = respondent expects that his/her flood risk is lower than that of an average resident in the Netherlands |
| Zero expected return period | Dummy variable, 1 = respondent expects return period to be zero |
| Expected return period flood | Continuous variable, return period in thousand years |
| Experience with evacuation | Dummy variable, 1 = the respondent has been evacuated for threat of flooding |
| Knowledge about floods | Dummy variable, 1 = respondent is able to state causes of flooding |
| Elevation house and barrier is lower than water level | Dummy variable, 1 = the area plus the water barrier of 1 m is below the potential water level of a flood |
| House is close to main river | Dummy variable, 1 = distance of the respondent's postcode area is within 4 km from the nearest main river |
| Rural area | Dummy variable, 1 = the area is a rural area |
| Female | Dummy variable, 1 = respondent is female |
| Age | Continuous variable of age |
| Income ^d | Continuous variable of the monthly after tax household income in € |
| Education | Categorical variable, (range 1–7) of the education level, where 1 = elementary education and 7 = university degree |

Notes. ^aMissing values are “don't know” responses.

^bThe question reads: “How do you estimate the consequences of climate change for the likelihood of flooding in the Netherlands?” The answer options are: “floods will become more frequent, floods will be as frequent as currently, floods will become less frequent, and don't know.”

^cThe question reads: “How would you rate your flood risk compares to an average person in the Netherlands?” The answer options are: “I have an average flood risk, I have a higher than average flood risk, and I have a lower than average flood risk.”

^dFor income the respondent could mark one of the following categories: <€ 750, € 751–€ 1000, € 1001–€ 1250, € 1251–€ 1500, € 1501–€ 2000, € 2001–€ 2500, € 2501–€ 3000, € 3001–€ 3500, € 3501–€ 4000, > € 4000. A continuous income variable was constructed by setting the income of each respondent to the midpoint of the interval (€ 4500 was used for the highest category).

Table B2

Descriptive statistics.

| Variable | N. obs. | Mean | Std. dev. |
|---|---------|------|-----------|
| Dependent variable | | | |
| Sandbags | 509 | 0.62 | 0.486 |
| Explanatory variables | | | |
| Government compensation is available | 509 | 0.43 | 0.495 |
| Government is perceived as responsible | 509 | 0.02 | 0.152 |
| Negative effects of climate change ^a | 494 | 3.57 | 0.897 |
| Climate change causes higher flood risk | 509 | 0.65 | 0.476 |

Table B2 (continued)

| Variable | N. obs. | Mean | Std. dev. |
|---|---------|------|-----------|
| Explanatory Variables | | | |
| Lower flood risk than average resident | 509 | 0.47 | 0.499 |
| Zero expected return period flood | 509 | 0.03 | 0.164 |
| Expected return period flood | 509 | 19 | 118 |
| Experience with evacuation | 509 | 0.09 | 0.287 |
| Knowledge about floods | 509 | 0.82 | 0.385 |
| Elevation house and barrier is lower than water level | 509 | 0.41 | 0.492 |
| House is close to main river | 509 | 0.45 | 0.498 |
| Rural area | 509 | 0.05 | 0.216 |
| Female | 509 | 0.43 | 0.496 |
| Age | 509 | 45 | 12 |
| Income | 509 | 2861 | 1010 |
| Education ^a | 509 | 5.39 | 1.404 |

Notes. ^aThe statistics of this variable are in accordance with the coding in Table B1. This original coding has been transformed for the analysis according to Terza (1986), as is described above.

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