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An experimental study of charity hazard: The effect of risky and ambiguous government compensation on flood insurance demand

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Abstract

This paper examines the problem of "charity hazard," which is the crowding out of private insurance demand by government compensation. In the context of flood insurance and disaster financing, charity hazard is particularly worrisome given current trends of increasing flood risks as a result of climate change and more people choosing to locate in high-risk areas. We conduct an experimental analysis of the influence on flood insurance demand of risk and ambiguity preferences and the availability of different forms of government compensation for disaster damage. Certain and risky government compensation crowd out demand, confirming charity hazard, but this is not observed for ambiguous compensation. Ambiguity averse subjects have higher insurance demand when government compensation is ambiguous relative to risky. Policy recommendations are discussed to overcome charity hazard.

Keywords Ambiguity preferences · Charity hazard · Economic experiment · Flood insurance demand · Risk preferences

JEL Classification C91 · G52

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1 Introduction

Individuals typically underinsure low-probability/high-impact natural disaster risks (Kunreuther & Pauly, 2004). These risks tend to be underestimated by individuals (Viscusi & Zeckhauser, 2006). Systematic behavioural biases and heuristics can explain lack of demand for insurance and protective measures, as well as low risk perceptions (Meyer & Kunreuther, 2017; Slovic et al., 1977). However, underinsurance by individuals may also result from rational expectations that governments provide compensation after disaster strikes. The "Samaritan's dilemma" describes a situation whereby the government cannot credibly commit not to help an individual in case of a loss, even though the receipt of unconditional financial assistance from the government incentivizes the individual not to take protective measures (Buchanan, 1975). Crowding out of private insurance by government compensation for disaster damage has also been termed the "charity hazard" (Browne & Hoyt, 2000). Reliance on government compensation can have negative efficiency effects (Coate, 1995). This is partly due to weak incentives by governments to manage resources carefully, and to examine where disaster relief is most needed (Raschky & Weck-Hannemann, 2007). Another source of inefficiency relates to politically motivated government compensation payments. For example, Garrett and Sobel (2003) find that disaster expenditures made by the Federal Emergency Management Agency (FEMA) as well as U.S. presidential disaster declarations are politically motivated, and in particular depend on election years and states considered important to the outcome of elections.

This study focusses on insurance against flood risk, which is the most costly natural disaster risk worldwide (Miller et al., 2008). During the 2017 Atlantic hurricane season, which ranked as one of the most destructive in U.S. history (Chew et al., 2018), National Flood Insurance Program (NFIP) policyholders filed approximately 133,000 claims. Moreover, FEMA paid more than \$2 billion in federal disaster assistance, which is a form of ad hoc government compensation for uninsured losses.[1] The co-existence of the NFIP and disaster compensation by FEMA means that the charity hazard is a potential issue for the flood insurance market in the U.S., as is also the case in many European countries (Porrini & Schwarze, 2014).

In the Netherlands (our policy context) the government may provide partial compensation for flood damage via the Calamities and Compensation Act (WTS[2]) (Botzen & van den Bergh, 2008). However, the WTS has no established funds and no clear rules outlining under what circumstances flood damage will be compensated and by how much. Moreover, there is no legal obligation for the Dutch government to compensate damages. Therefore, it is currently ambiguous whether households will receive compensation for flood damages in the Netherlands (Surminski et al., 2015). Efforts have been made in recent years to make private flood insurance more widely available, but this insurance is purchased by only a small fraction of the Dutch population (Suykens et al., 2016). In addition to the high costs of offering

[1] These data are available on the FEMA website.

[2] Acronym in Dutch.

flood insurance in the Netherlands, the potential for charity hazard may slow the uptake of this insurance by homeowners. Given increasing flood risks from climate change and socio-economic developments (IPCC, 2012), having adequate flood insurance coverage becomes more important for offering financial protection against residual flood risk, which implies that the charity hazard is especially problematic. Therefore, it is relevant to understand under which conditions charity hazard occurs, which is the focus of this paper.

Other forms of government compensation for natural disaster damages exist across Europe. Contrary to the ad hoc Dutch compensation scheme, Austria accumulates funds through mandatory taxation, to be used for financing relief payments to cover flood damages (Schwarze et al., 2011). Although individuals have no legal entitlement to government compensation, the well-functioning nature of the Austrian catastrophe fund generates certainty about compensation receipt according to Raschky et al. (2013). In other countries like Germany, relief is not controlled by formal legislation, and payout can depend on factors like media coverage and election years (Thieken et al., 2006). Nevertheless, high levels of compensation have typically been granted in Germany following flood events in the past (Surminski & Thieken, 2017). Other examples of high levels of government relief to homeowners can be found in Hungary, where extensive compensation was provided after the 2001 Tisza flood (Vari et al., 2003). Similar to the U.S. but in contrast to the other European examples, France requires an official natural disaster declaration before individuals can receive compensation. However, this is not based on pre-defined levels of flood damage, so compensation is also ambiguous in France (Paudel et al., 2012). Given the apparent differences in the extent and degree of riskiness and/or ambiguity in government compensation across different countries, it is relevant to examine which forms of compensation crowd out private demand for insurance the least.

According to Jaspersen (2016) and Robinson and Botzen (2019), we define a decision under risk as a situation where the probability of each possible outcome is known. If the probabilities are not known, and a distribution of probabilities over possible probabilities is not known either, the decision is considered one under ambiguity. Ambiguity and/or riskiness in government compensation is perhaps also relative to the number of times individuals have received flood-related compensation in the past. If individuals have been flooded many times in the past, it may be easier for them to accurately assign a probability to the likelihood of receiving compensation (it becomes riskier vs. more ambiguous). On the contrary, if somebody has never been flooded in the past it may be very difficult to assign a precise probability to the likelihood of receiving government compensation. The latter is more relevant to the Dutch context where experience with flooding is scarce due to high levels of flood protection.

So far empirical evidence on the charity hazard is rather mixed (Andor et al., 2020). Contrary to expectations, Browne and Hoyt (2000) showed with NFIP policies-in-force data, that disaster relief expenditures by FEMA positively relate to flood insurance demand. The authors proposed that their positive result can arise because their analysis insufficiently controls for risk exposure which affects both demand for insurance and the receipt of government relief. Another potential source of endogeneity in their dataset concerns reverse causality, i.e., the more insured an area is, the less government compensation may be required after a flood. Kousky et al. (2018) control for endogeneity by employing a two-stage least squares analysis.[3] Their instrumental variable is an interaction term between timing of presidential elections and states considered important for the outcome of elections. According to Garrett and Sobel (2003), the variable provides a useful exogenous source of variation in relief payments. Kousky et al. (2018) showed that individual assistance grants have a negative impact on flood insurance demand once endogeneity has been controlled for.

Survey research conducted in coastal regions by Petrolia et al. (2013) in the U.S. find that perceived eligibility for post-disaster relief has a positive effect on the probability of holding flood insurance, in contrast to the charity hazard. In light of these findings, the authors suggested that their measure of disaster assistance expectations may be biased if individuals relying on this assistance are ashamed to admit it. In a follow-up study using the same survey data, Landry et al. (2019) instrumented for post-disaster relief expectations using data on congressional members that served on subcommittees which have direct oversight of FEMA spending, as well as payment history of the FEMA public assistance grant program. They found that perceived eligibility for post-disaster relief has a negative effect on flood insurance demand in the follow-up analysis. In another survey study by Botzen et al. (2019), the purchase of flood insurance in the U.S. is negatively related to previous receipt of federal disaster assistance. Moreover, Botzen and van den Bergh (2012) reported in a stated preference study in the Netherlands that when hypothetical flood insurance demand is elicited in a survey version which may grant government compensation, demand is less than a version in which compensation is not available.

Raschky et al. (2013) conducted a survey about flood insurance demand in Austria where partial certain government compensation is provided, and in Germany which has granted full ambiguous government compensation in the past. Their survey results show that expectations about disaster relief crowd out insurance demand more in Austria than in Germany. We aim to re-examine this finding in an experimental setting, allowing for better control over extraneous factors, which are typically challenging to control for in the field. For example, other factors of influence on flood insurance demand, like objective risk levels, may differ between Germany and Austria and partly drive the results by Raschky et al. (2013), while our experimental setting controls for such factors. In general, experimental studies which have an explicit environmental context can be useful to study the impact of certain types of variables (Gsottbauer & van den Bergh, 2011), like the influence of government compensation on insurance demand.

Despite the relatively large literature on insurance demand in experimental research (Jaspersen, 2016), to our knowledge Brunette et al. (2013) are the only ones to have directly incorporated government compensation into their design. They also find that partial certain government compensation crowds out demand for

[3] See also Deryugina and Kirwan (2018).

insurance.[4] However, their evidence is based on a hypothetically incentivized experiment, even though incentives have been shown to significantly reduce insurance demand choice anomalies (Jaspersen, 2016; Laury et al., 2009). Moreover, Brunette et al. (2013) implement uncertainty in the probability of loss, whereas we investigate how ambiguity in government compensation affects insurance decisions. This is relevant because in practice government compensation for disaster damage is often ambiguous, albeit to different degrees.

We employ an incentivized experiment to study several theoretical predictions related to the charity hazard hypothesis, risk preferences, ambiguity preferences and insurance pricing. Our theory analysis is informed by previous studies by Kelly and Kleffner (2003) and Raschky and Weck-Hannemann (2007), who investigated the effect of government compensation on insurance demand in an Expected Utility framework. However, our analysis also examines the charity hazard under imprecise knowledge about government compensation, for which we utilize the Klibanoff et al. (2005) smooth model of decision making under ambiguity. Some examples of ambiguity preference elicitation underthis model are Chakravarty and Roy (2009) and Attanasi et al. (2014).[5] An examination such as ours highlights the usefulness of an experiment to disentangle the effect of different schemes of government compensation (certain, risky and ambiguous compensation), which is a challenge when using data for actual insurance purchases as well as hypothetical survey methods.

Our experimental findings show that flood insurance demand is negatively impacted by anticipated government compensation, except when the compensation is ambiguous. We also find that ambiguity averse subjects have higher demand for insurance when government compensation is ambiguous relative to risky, according to ambiguity preferences elicited using multiple price list tasks. Furthermore, ambiguity preferences elicited in the gain domain predict a unique effect on insurance demand better under ambiguous government compensation, relative to those elicited in the loss domain. Regarding risk preferences, a stated risk aversion measure which has been shown to correlate well with risk taking behaviour in practice better predicts flood insurance demand than risk preferences elicited in multiple price list tasks. Moreover, we do not find that risk averse subjects demand more insurance when the compensation provided is risky as opposed to certain. Lastly, the insurance loading factor has a negative impact on flood insurance demand, as expected.

The paper is structured as follows: Section 2 outlines the hypotheses. Section 3 describes our experimental design and implementation. Section 4 reports the experimental findings based on a non-parametric and parametric analysis. Section 5 discusses these findings in relation to the hypotheses, and suggests several recommendations for policy. Section 6 concludes the paper.

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4 Their examination of the charity hazard was conducted within-subjects, so contrast effects cannot be ruled out (Greenwald, 1976).

5 The Klibanoff et al. (2005) smooth model has also been applied in various empirical and theoretical papers in this journal, such as Bajtelsmit et al. (2015), Snow (2011), Conte and Hey (2013) and Qiu and Weitzel (2016).

2 Hypotheses

Several predictions can be made based on the parameters that change within our experiment according to Expected Utility Theory under risk as well as the Klibanoff et al. (2005) smooth model of decision making under ambiguity. In decisions involving risk only, willingness-to-pay for full insurance (WTP) is defined by:

$$\begin{aligned} EU_{NI} &= \pi\{pU[W-(1-\theta)L]+(1-p)U[W]\} \\ &+(1-\pi)\{pU[W-L]+(1-p)U[W]\} \\ &= U[W-WTP] \end{aligned} \tag{1}$$

Consider an individual in this case who has initial wealth, W, and faces a loss, $L \in (0, W)$, with probability p $(0 < p < 1)$ and no loss with probability $1-p$ (we assume that the probability of loss is objectively known, as it is in our experiment). There is also an objective probability of receiving government compensation, θ $(0 < \theta < 1)$, to pay for a proportion of the uninsured loss, equal to π. The individual has a strictly increasing utility function $U(\bullet)$, defined on final wealth. Expected Utility (EU) with no insurance is EU_{NI}. The insurance premium is given by $P(\alpha) = L\alpha p\lambda$, and the loading factor is λ, where $\lambda = 1$ for actuarially fair insurance, $0 \leq \lambda < 1$ for subsidized insurance and $\lambda > 1$ for commercial (positively loaded) insurance. Furthermore, insurance coverage, $V = L\alpha$, may be purchased to protect against the potential loss, where $\alpha \in (0,1)$ is the extent of coverage. Furthermore, we assume that the individual is willing-to-purchase full insurance if and only if $WTP \geq P(1)$, otherwise the individual will choose not to insure.

Five hypotheses can be derived according to this basic setup using comparative statics. Individuals are willing to pay more for full insurance as they become more risk averse. Whereas, they are willing to pay less for full insurance for higher values of: λ, p (for risk averse individuals, holding the expected value of loss constant), θ and π (for risk averse individuals, holding the expected value of government compensation constant).

H1: Willingness-to-pay for full insurance is positively related to the degree of risk aversion.

H2: Willingness-to-pay for full insurance is negatively related to the loading factor.

H3: Willingness-to-pay for full insurance is negatively related to the probability of loss for risk averse individuals, holding the expected value of loss constant.

H4: Willingness-to-pay for full insurance is negatively related to government compensation.

H5: Willingness-to-pay for full insurance is negatively related to the probability of government compensation for risk averse individuals, holding the expected value of government compensation constant.

When ambiguity is present, there is a second-order probability distribution, $F(\overline{\pi})$, where $\overline{\pi}$ is a possible value of π.[6] We assume the individual has ambiguity

[6] For simplicity, the extent of relief, θ, is assumed to be objectively known to the individual, as it is in our experiment.

preference, represented by the strictly increasing function, $\varphi(\bullet)$ defined over EU.[7] Under ambiguous government compensation, decisions can be made in accordance with the second order EU function, which we shall call the Klibanoff et al. smooth model value (KMM):

$$\begin{aligned} KMM_{NI} &= \sigma_1 \varphi\{U[W]\} + \sigma_0 \varphi\{pU[W-L] + (1-p)U[W]\} \\ &= E\left\{\varphi\left\{EU(\overline{\pi})\right\}\right\} = \varphi\{U[W-WTP]\} \end{aligned} \quad (2)$$

The Klibanoff et al. smooth model value with no insurance is KMM_{NI} and $E(\bullet)$ is the expectation with respect to $F(\overline{\pi})$. In our experiment, under ambiguous government compensation, there are two possible objective probability distributions regarding $\overline{\pi}$, either the individual is compensated by the government fully in case of a loss with certainty, or she/he is not compensated by the government, as indicated in Eq. 2. There are subjective probability beliefs represented by $\sigma = (\sigma_1, \sigma_0)$, where σ_1 is the belief that the probability of government compensation is certain and σ_0 is the belief that the probability of no government compensation is certain, and $\sigma_1 + \sigma_0 = 1$.

Two more hypotheses can be derived according to this extension to the basic setup that considers ambiguity. Individuals are willing to pay more for full insurance as they become more ambiguity averse when government compensation is ambiguous. Additionally, if we compare Eq. 1 evaluated at $\pi = 0.5$ and $\theta = 1$ (we call this risky full government compensation in our experiment) to Eq. 2, assuming[8] $\sigma = (0.5,0.5)$ and ambiguity aversion, willingness-to-pay for full insurance will be higher under ambiguous full government compensation relative to risky full government compensation.

H6: Willingness-to-pay for full insurance is positively related to the degree of ambiguity aversion when government compensation is ambiguous.

H7: Willingness-to-pay for full insurance is higher under ambiguous full government compensation vs. risky full government compensation for ambiguity averse individuals.

We refer those who are interested in the formal derivation of the hypotheses to Appendix 1.

3 Experiment

A sample of 200 subjects were recruited to participate in this study from the student population of VU University Amsterdam. Prior to the experiment implementation, we conducted several pre-tests to refine the experiment instructions. We did not

[7] In our experiment, we examine attitude towards ambiguity due to the existence of multiple non-excludable priors.

[8] See Chakravarty and Roy (2009, pp. 215–216) for a discussion of this assumption. More specifically, the assumption has the potential to confound ambiguity preference parameters. Indeed, values of σ may be impacted by factors like fear and hope (Viscusi & Chesson, 1999). We acknowledge, as do Chakravarty and Roy (2009), that the assumption is a limitation of our study.

have sufficient study data on every condition to conduct a power analysis to choose our sample sizes. Instead we used observations per condition in Laury et al. (2009) to inform our overall sample size. Moreover, an advantage of our panel data setup (compared to cross-section data) is multiple observations per individual, which allows us to control for unobserved heterogeneity and increases the precision and efficiency of estimators (Cameron & Trivedi, 2005).

55.5% of subjects were male, 62% were Dutch and the average age was 22.3 years. Subjects were also from a wide range of disciplines. The experiment consisted of two phases, the first of which elicited risk and ambiguity preferences (Section 3.1). In the second phase, subjects faced a series of flood insurance purchase decisions with different types of government compensation available to cover uninsured flood damages (Section 3.2).[9] Section 3.3 describes how the subjects in the experiment were paid (see Online Resource 2 for a detailed overview of the experiment instructions).

3.1 Phase one

3.1.1 Earnings task

At the beginning of phase one, subjects were told that they would be paid a participation fee of €15, and that this payment would not be at risk during the experiment. Subjects were then informed that there would be four decision making tasks in the first phase, and that the first two tasks would involve losses. To make sure subjects could not make a net loss and owe money to the experimenters, they were given the opportunity to earn an endowment. The endowment was earned by opening boxes on their computer screen (for each box that contained money subjects received 2,000 CU – currency units). Once thirty boxes containing money had been opened, subjects could proceed with the first decision making task with their endowment of 60,000 CU to be used in both the first and second tasks.[10]

3.1.2 Risk preference elicitation

To elicit risk preferences we developed a modified version of the multiple price list (MPL) task of Drichoutis and Lusk (2016), as well as eliciting a stated measure of risk preference according to Dohmen et al. (2011). An advantage of the MPL measure over the stated measure is that it is an incentivized measure which can be

[9] It was a design choice to elicit risk and ambiguity attitudes first, then insurance choices. One could argue that subjects have some subconscious motivation to restate their risk and ambiguity preferences in their insurance decisions for some desire to be consistent. We could have studied order effects, although Harrison and Ng (2016) mention that it is likely to be empirically unimportant whether insurance choices or preferences are elicited first. Moreover, we randomly select one decision from either phase one or phase two to be paid, so it was in subjects' best interest to treat all decisions independently as the only one that they were facing (Papon, 2008). We acknowledge that there are also possible disadvantages of only paying one choice (see e.g., Cubitt et al., 1998).

[10] The rationale for this earnings task was to eliminate the potential for a "house money effect", where subjects are more risk taking when endowed with a prior monetary gain (Thaler & Johnson, 1990).

used to elicit (bounds of) risk preference parameters under EU. It can be argued that in order to associate actual risky behaviour with risk preferences their elicitation should be incentivized so that they reflect true preferences towards risk (Charness et al., 2013). However, MPL measures have been criticized because they are complex which may result in a high incidence of decision making errors (Dave et al., 2010). A stated measure of risk preference may overcome the latter concern. Moreover, Dohmen et al. (2011) showed that a stated general measure of risk preference is a good all-round predictor of risky behaviour across a number of real-life domains of risk taking.

The MPL task involves a series of ten decisions between two prospects with constant probabilities, but modifying outcomes.[11] We favored their format over the MPL developed by Holt and Laury (2002) which varies probabilities instead of outcomes, because the measure used by Drichoutis and Lusk (2016) has been shown to have greater consistency and more predictive power (Csermely & Rabas, 2016). Csermely and Rabas (2016) advise using this task over all other commonly used MPL tasks to derive risk preferences.

In Drichoutis and Lusk's (2016) MPL, the probability of all outcomes is held constant at 0.5. Using this framework we developed the MPL in Table 1 for the first decision making task. We set the highest absolute outcome in this task equal to the greatest loss subjects could face in the second phase. Subjects could switch between preferring Option A to preferring Option B only once (similar to other tasks in this phase). If a subject chose to switch at either decision line 5 or 6, they were presented with a follow-up question asking whether they are indifferent between prospects (0.5: -480 CU, 0.5: -720 CU) and (0.5: -1,200 CU, 0.5: 0 CU), yes or no.[12] That way we could determine whether subjects had risk neutral preferences which is consistent with being indifferent between these prospects.

Risk preferences were derived in both the gain and loss domains. Assuming outcomes are processed in the gain domain, under constant relative risk aversion the utility function equals $U[x] = x^r$, and when outcomes are processed as losses, the utility function is $U[x] = -(-x)^b$. In addition to the MPL utilized in Table 1, we presented subjects an analogous MPL in the gain domain in the third decision making task, with all outcomes converted into gains and the left hand outcomes of Option A and B presented in reverse order. More risk averse subjects chose the left hand option, with less variable potential outcomes, a greater number of times in the first and third tasks. It is an open question whether subjects in our experiment integrated their endowment and (possible) government compensation into potential losses, or viewed flood losses in isolation in deciding whether or not to insure (e.g., Read et al., 1999). Risk preferences elicited in the gain (loss) domain would better predict the former (latter) type of mental accounting.

[11] For an earlier risk preference elicitation where probabilities are held constant see also Wakker and Deneffe (1996).

[12] The prospects are written: (probability: monetary outcome in currency units, probability: monetary outcome in currency units).

Table 1 Multiple price list used to elicit risk preferences in the loss domain, with the probability (Pr.) of outcomes in currency units (CU) and expected value (EV) differences as well as loss domain risk preference parameters ***(b)***

#	Option A				Option B				EV difference	*b* implied by indifference
	Pr	CU	Pr	CU	Pr	CU	Pr	CU		
1	0.5	-560	0.5	-720	0.5	-60,000	0.5	0	29,360	0.15
2	0.5	-540	0.5	-720	0.5	-5,600	0.5	0	2,170	0.32
3	0.5	-520	0.5	-720	0.5	-2,400	0.5	0	580	0.51
4	0.5	-500	0.5	-720	0.5	-1,560	0.5	0	170	0.73
5	0.5	-480	0.5	-720	0.5	-1,200	0.5	0	0	1
6	0.5	-460	0.5	-720	0.5	-1,000	0.5	0	-90	1.33
7	0.5	-440	0.5	-720	0.5	-876	0.5	0	-142	1.78
8	0.5	-420	0.5	-720	0.5	-795	0.5	0	-172.5	2.42
9	0.5	-400	0.5	-720	0.5	-744	0.5	0	-188	3.56
10	0.5	-380	0.5	-720	0.5	-720	0.5	0	-190	No solution

The stated measure of risk preference was elicited at the end of the experiment (after phase one and two) with the question: "How do you see yourself: are you generally a person who is willing to take risks or do you try to avoid taking risks? Please use a scale from 1 to 10, where a 1 means you are "completely unwilling to take risks", and a 10 means you are "very willing to take risks". You can also answer values in-between to indicate where you fall on the scale." Note that we reverse-coded the data for the analysis so that higher values represent more risk aversion.

3.1.3 Ambiguity preference elicitation

In the second decision making task we used another type of MPL to elicit ambiguity preferences in the loss domain according to procedures in Chakravarty and Roy (2009). Their MPL experiments allow for the derivation of ambiguity preferences given the Klibanoff et al. (2005) smooth model framework. Subjects were told that there exists two bingo cages, bingo cage X and bingo cage Y. Bingo cage X contains 5 black balls and 5 white balls, and bingo cage Y contains 10 balls which are either all black or all white. Subjects were then asked to bet on one colour (black or white). They were also asked to imagine that a ball will be drawn from bingo cage X if Option X is chosen, or bingo cage Y if Option Y is chosen on a given decision line. Subjects expressed their preferences between the two options in the MPL in Table 2.

Bingo cage X induces a risky prospect which we assume subjects evaluate in terms of its EU. Chakravarty and Roy (2009) showed that bingo cage Y induces two potential degenerate prospects, which are two prospects yielding one fixed outcome with probability 1, i.e., (1: 0 CU, 0: -28,000 CU) and (0: 0 CU, 1: -28,000 CU). Assuming the subjective probability belief over the set: {B: all-black, W: all-white}, which is represented by $\sigma = (\sigma_B, \sigma_W)$, and $\sigma_B + \sigma_W = 1$, for a subject betting on black, Option Y is evaluated as follows:

Table 2 Multiple price list used to elicit ambiguity preferences in the loss domain, with outcomes in currency units (CU) and loss domain ambiguity preference parameters (*c*)

#	Option X (Cage X: 5 black, 5 white)				Option Y (Cage Y: either all black or all white)				
	Colour match	**CU**	**Colour match**	**CU**	**Colour match**	**CU**	**Colour match**	**CU**	***c* implied by indifference**
1	Yes	0	No	-800	Yes	0	No	-28,000	0.65
2	Yes	0	No	-37,00	Yes	0	No	-28,000	0.8
3	Yes	0	No	-12,000	Yes	0	No	-28,000	0.92
4	Yes	0	No	-17,000	Yes	0	No	-28,000	0.95
5	Yes	0	No	-22,000	Yes	0	No	-28,000	0.98
6	Yes	0	No	-28,000	Yes	0	No	-28,000	1
7	Yes	0	No	-35,000	Yes	0	No	-28,000	1.02
8	Yes	0	No	-43,000	Yes	0	No	-28,000	1.04
9	Yes	0	No	-50,000	Yes	0	No	-28,000	1.06
10	Yes	0	No	-60,000	Yes	0	No	-28,000	1.07

$$KMM = \sigma_B \varphi\{U[0]\} + \sigma_W \varphi\{U[-28{,}000]\} \tag{3}$$

If φ also takes the power form, such that $\varphi(z) = -(-z)^c$, for losses we have:

$$KMM = -(1 - \sigma_B)[28{,}000]^{bc} \tag{4}$$

Equation 4 can be used to derive c given that we assume, similar to Chakravarty and Roy (2009), that $\sigma = (0.5{,}0.5)$ and EU when subjects evaluate bingo cage X. In the gain domain, preferences towards ambiguity can be elicited in a similar way. More ambiguity averse subjects preferred the risky Option X more times than the ambiguous Option Y. The fourth decision making task elicited ambiguity preferences in the gain domain. Analogous to the second task, subjects were invited to bet on either one of two coloured balls (blue or red), and then made a series of decisions between two options (Option V and Option W). Ambiguity preferences may differ in the gain and loss domains in addition to risk preferences (Trautmann & van de Kuilen, 2015), which provides sufficient reasoning to elicit them in both decision domains to test their relative predictive power. To the best of our knowledge there exists no widely used stated measure of ambiguity preferences, therefore we did not elicit stated ambiguity aversion.

3.2 Phase two

The setup of phase two of the experiment was close to Laury et al. (2009), who examined whether individuals insure low-probability/high-impact risks more often than high-probability/low-impact risks with the same expected value of loss. Their design provided a useful setup for our experiment because homeowners in the Netherlands who face low-probability flood risks can experience very costly flood damages, whereas homeowners located in high-probability areas typically experience lower flood water levels and damages due to property elevation (de Moel et al., 2014). We adapt the basic features of the Laury et al. (2009) experiment to our study, i.e., subjects first faced an earnings task, and then insurance decisions from an endowed bank balance involving different loading factors and loss probabilities (holding expected values of loss constant).

3.2.1 Earnings task

Subjects completed fifteen general knowledge multiple choice questions to earn their endowment in the second phase. If eight or more questions were answered correctly, subjects were endowed a bank balance of 60,000 CU, and otherwise they were paid 30,000 CU.[13] The endowments were equal to the highest flood loss subjects could face in the insurance decisions to avoid bankruptcy concerns. Subjects could either pay for flood insurance or flood damages from their endowment within a given insurance decision. We chose a relatively easy knowledge task to avoid confounding the endowment

[13] 60,000 CU was endowed to all subjects since every subject answered eight or more questions correctly.

with knowledge (Laury et al., 2009), and to ensure the task required approximately the same level of effort as the phase one earnings task. Requiring subjects to complete the phase one earnings task again may have been perceived as monotonous and confusing.

3.2.2 Flood insurance purchase decisions

Upon completion of the earnings task, subjects were randomly assigned to face one of several versions of phase two, based on the following written information:

Insurance purchase decision instructions

A current insurance policy for house and contents in the Netherlands does not cover damage caused by flooding from dike failure. The government can provide compensation for flood damage, however, this compensation may be influenced by political decision making

Suppose that it is now possible to buy flood insurance [text about government compensation that differs between versions.]

You will now make a series of decisions about purchasing flood insurance in situations with different levels of flood risk

Our experiment is a framed one (i.e., in the context of flood risk), therefore some context was warranted regarding the source of certain, risky and ambiguous government compensation. There are advantages to framing an insurance experiment in a specific context as summarized in a recent literature review by Robinson and Botzen (2019), such as external validity and in the absence of contextual framing individuals may make up their own. We tried to keep the source of certain, risky and ambiguous government compensation as neutral as possible, because offering more contextual richness (e.g., political factors and flooding experience), may have led subjects to base their priors about government compensation more on contextual elements rather than the riskiness and ambiguity by and of itself.

In one version, (52) subjects read the following text about government compensation: "… it is no longer possible to receive compensation for flood damage via the government." This serves as our baseline condition, from which we will evaluate the influence of several government compensation schemes.[14] In total there were three government compensation schemes, certain half government compensation, risky full government compensation, and ambiguous full government compensation. Each scheme had the following respective texts about government compensation: "There are two political commentators, who both agree that you will be compensated by the government for flood damages for certain. You will be compensated for 50% of damages in the event you are flooded and don't hold insurance." (certain half); "There are two political commentators, who both agree that your chances of being compensated by the government for flood damages are 1 in 2. You will be compensated for 100% of damages in the event you are flooded, don't hold insurance and

[14] More subjects were randomly assigned to the baseline condition to increase statistical power, given that subjects in this condition faced half as many insurance decisions as in the other versions of the experiment. Subjects were 1.5 times more likely to face the baseline condition than either of the other versions. Otherwise, there was an equal chance subjects would face the other government compensation versions according to the random assignment.

Table 3 Distribution of subjects over the experiment versions

Subjects	Government compensation scheme
52	Baseline no government compensation
36	Risky full then certain half government compensation
39	Certain half then risky full government compensation
32	Risky full then ambiguous full government compensation
41	Ambiguous full then risky full government compensation

compensation is approved by the government." (risky full); "There are two political commentators, who disagree about whether you will be compensated by the government for flood damages. The first commentator believes that you will be compensated for 100% of damages in the event you are flooded and don't hold insurance for certain. The second commentator believes that you will not receive any compensation. It is uncertain which commentator is the most trustworthy." (ambiguous full).[15] Immediately prior to the insurance decisions, we asked subjects to complete four questions to ensure that they fully understood the procedures.

For subjects assigned to face the government compensation versions, midway through the flood insurance decisions subjects were informed that given a change in political circumstances, the type of government compensation would change. One follow-up question was then asked to ensure subjects understood the policy change. 36 subjects faced risky full government compensation first, then certain half. A further 39 subjects faced the schemes in the opposite order. This enables us to examine whether subjects' risk preferences influenced their flood insurance decisions, given the mean-preserving spread in government compensation. Moreover, 32 subjects were exposed to risky full government compensation first, then ambiguous full. The remaining 41 subjects faced the latter schemes in the opposite order. This allows us to investigate whether subjects' ambiguity preferences influenced their flood insurance decisions, given the varying degrees of ambiguity in government compensation. Table 3 displays the distribution of subjects over the experiment versions. Given that subjects did not face certain half government compensation, then ambiguous full or vice versa, we cannot compare these conditions at the individual level.

In a given decision period, subjects faced one of three flooding probabilities, 0.001, 0.01 and 0.1. These probabilities represent realistic flood risks for the Netherlands. For example, in dike-ring areas in the River Rhine delta, the likelihood of river dike failure is 1 in 1,250, although 1 in 1,000 may be less cognitively challenging for individuals to imagine. For homeowners located in less protected areas, the annual probability of flooding can exceed 1 in 100, and reach as high as 1 in 10, although flood damages are likely to be less severe due to both low flood water velocity and depth (Ermolieva et al., 2017). Higher probabilities like 0.1 are also useful to incorporate, because previous experiments report a large change in the proportion of subjects purchasing insurance when the likelihood reaches this level

[15] We acknowledge that there are potential confounding variables, given our flood risk context. We do not claim our results are transferrable to other contexts.

Table 4 Flood insurance purchase decisions

#	Loading Factor	Flood loss in currency units (CU)	Flooding probability	Premium in currency units (CU)
1	0.5	60,000	0.001	30
2	0.75	60,000	0.001	45
3	1	60,000	0.001	60
4	4	60,000	0.001	240
5	0.5	6,000	0.01	30
6	0.75	6,000	0.01	45
7	1	6,000	0.01	60
8	4	6,000	0.01	240
9	0.5	600	0.1	30
10	0.75	600	0.1	45
11	1	600	0.1	60
12	4	600	0.1	240

(Slovic et al., 1977). This allows for sufficient variation in our data to estimate the effect of flood probability on insurance demand.

The loading factor, λ, was fixed at either 0.5, 0.75, 1 or 4. We include 0.5 because Online Resource 1 reports that this level of loading is the threshold by which risk averse (seeking) subjects insure (do not insure) when government compensation is present. The latter two loading factors are included in the study by Laury et al. (2009), who showed a significant negative effect of insurance loading on insurance demand.

Combining the three flooding probabilities with the four loading factors provides the twelve flood insurance purchase decisions displayed in Table 4 for subjects who earned 60,000 CU (every subject). Subjects faced these decisions in a random order. In the government compensation versions of the experiment subjects faced twenty four insurance decisions in total (twelve under each scheme).

3.3 Payment

Below we describe the mechanisms by which subjects could earn money in the experiment. These mechanisms were explained to subjects in detail throughout the experiment instructions. We used a variety of visualizations to explain how payments would be calculated based on bingo cage drawings, for example. We favored manual operationalization methods like bingo cage drawings to less transparent computerized randomizations.

In addition to the participation fee of €15, a randomly selected group of subjects were paid according to one of their decisions selected at random from either phase one or phase two. That is, subjects were informed that sealed envelopes would be distributed at random after the experiment, which would contain either a green, an orange or a red card. 151 subjects received an envelope containing a red card, and were not paid based on their experiment decisions. 1 subject received a green card, and was paid at an exchange rate of 1% (10,000 CU = €100), therefore they could earn up to €600. 48 subjects received an orange card and the exchange rate was 0.1%, so they could earn up to €60.[16] In some previous experimental studies, high-impact losses are implemented without performance-based payment (Brunette et al., 2013; Etchart-Vincent, 2004, 2009; Kunreuther & Pauly, 2018). Our mechanism of paying only a subgroup of subjects according to an exchange rate is consistent with Kunreuther and Michel-Kerjan (2015) who also implemented high numerical losses. According to Charness et al. (2016), there is little difference empirically between paying a subgroup of subjects vs. paying everybody in terms of decisions made. Given budget constraints we could only pay a subgroup.

One of the two phases was selected at random using a two-sided coin flip. In phase one, a decision making task was selected by rolling a four-sided die. According to the selected task, we made random bingo cage drawings to determine payment.[17] Given the second phase was selected to be paid, one insurance choice was selected according to a randomly drawn lottery ticket. Drawings of balls from a bingo cage decided whether or not subjects were flooded in the chosen decision, as well as whether government compensation covered uninsured flood damages under the risky full and ambiguous full government compensation schemes.

4 Experiment results

Section 4.1 conducts non-parametric tests to examine whether insurance demand differs under the alternate probabilities of flooding and different versions of government compensation. Section 4.2 uses a parametric regression analysis, to investigate the impact of government compensation, flooding probability, loading factor, risk preferences and ambiguity preferences on insurance demand.

An overview of descriptive statistics and coding of the dependent and independent variables is included in Table 8 in Appendix 2. Figure 2 displays the distribution of risk and ambiguity preferences in the gain and loss domains according to the MPL tasks.On average, subjects are slightly risk seeking in the loss domain and slightly risk averse in the gain domain. Subjects are also on average more ambiguity averse in the gain domain than in the loss domain, where they are closer to ambiguity neutral. These results are broadly in line with previous studies (Wakker, 2010; Trautmann & van de Kuilen, 2015). Figure 3 displays the distribution of risk preferences according to the stated measure of risk preference. Subjects appear to be slightly risk averse on average according to the stated measure. This stated risk

[16] In a recruitment flyer individuals were told that in addition to the participation fee, they have ~ 25% chance of earning up to €60 based on their decisions, and a small chance of earning up to €600 based on the one randomly selected subject. In addition to the €15 participation fee, the green card subject earned €599.70. On average the orange card subjects earned €53.73 (min: €0, max: €60).

[17] If subjects were risk neutral, i.e., indifferent between the risky prospects with the same expected value in the risk preference tasks, we flipped a coin to decide which option would decide payment (in the case that the decision line was selected for payment).

aversion measure is coded as a dummy variable using the median category as the cut-off (stated risk aversion dummy = 1 if stated risk aversion > 5, = 0 otherwise) for the analysis in Section 4.2.

4.1 Non-parametric analysis

In Fig. 1 we display the mean of flood insurance purchase under probabilities 0.001, 0.01 and 0.1, per government compensation version and loading factor. McNemar tests are conducted to investigate whether significant differences exist between insurance purchase under flood probability 0.1 vs. 0.01 and 0.001, because the comparisons are within-subjects.

Under the two lowest loading factors (0.5 and 0.75), there are no significant differences in flood insurance demand under probability 0.1 compared to lower probabilities (p-values > 0.05). For actuarially fair insurance, only in the no government compensation (baseline) condition is there a significant positive difference in demand under flood probability 0.001 relative to 0.1 (p-value < 0.05). With respect to loading factor 4, positive significant differences exist in seven of the eight comparisons under flood probabilities 0.001 and 0.01 compared to 0.1 (p-values < 0.05). These findings of higher insurance demand under probabilities lower than 0.1 are consistent with Laury et al., (2009, Fig. 4), who showed that the impact of probability on insurance demand is the greatest when loading factor is 4. Moreover, for the greatest expected loss in Laury et al. (2009), which may remove subjects' entire endowment when the probability is low, there is an insignificant effect of loss probability on insurance demand when insurance is subsidized or actuarially fair.[18]

Additionally, in most cases subjects insure slightly less when the flood probability is 0.001 relative to 0.01 despite theoretical predictions. It is sometimes hypothesized that risks are ignored when the perceived probability of that risk is below a threshold level of concern (Kunreuther & Pauly, 2004; Robinson & Botzen, 2018; Slovic et al., 1977). We speculate that a sub-group of subjects find flood probability 0.001 to be below their threshold level of concern.

There is a general trend of lower flood insurance demand under higher loading factors. Between loading factors 0.5 and 0.75 as well as 0.75 and 1, there is a lower incremental reduction in demand, compared to 1 and 4. This is unsurprising given that the relative flood insurance premium increases more in the latter case. In only three of the possible thirty six loading factor comparisons the impact of loading factor is not in the predicted direction.

In Table 5 we investigate the difference in the percentage of subjects insuring in the versions of government compensation (certain half, risky full and ambiguous full), relative to the baseline no government compensation condition. Chi-square tests are conducted to examine whether significant differences exist, because the comparisons are between-subjects.

[18] This finding is comparable to ours because in our experiment there is one expected loss, which may remove subjects' entire endowment when flooding probability = 0.001.

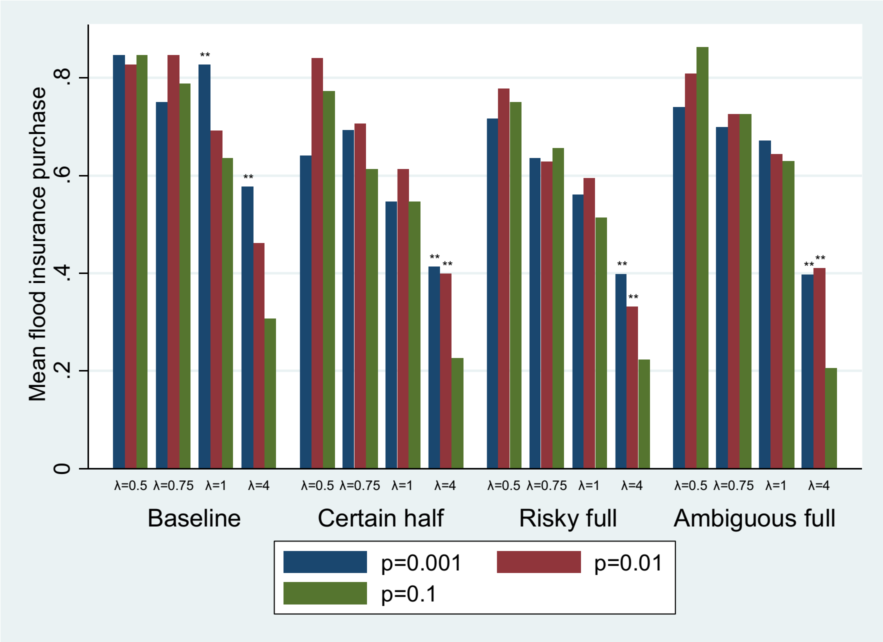

Fig. 1 Mean insurance purchases under flooding probabilities (p) 0.001, 0.01 and 0.1, per government compensation version and loading factor (λ) 0.5, 0.75, 1 and 4. ** indicates a significant difference at the 5% level with respect to flooding probability = 0.1 according to McNemar's test

The table shows that subjects were less likely to purchase insurance under the versions of government compensation relative to the no government compensation condition in nearly all cases, which is consistent with the charity hazard. This effect appears to be strongest and most significant when comparing the no government compensation condition to the certain half and risky full versions of compensation. Only in one case (under flood probability 0.001 and loading factor 4), is there a significantly negative effect of the ambiguous full government compensation version relative to no government compensation (p-value < 0.05). The results imply that flood insurance demand is highest when no government compensation is present, and that certain half as well as risky full compensation have a significantly negative impact on demand. Ambiguous full compensation reduces demand marginally compared to no government compensation, but this effect has little significance. This may suggest that subjects were on average ambiguity averse when facing ambiguous government compensation, and insured more often because of this.

There is no clear evidence to suggest that differences in charity hazard are responsive to the loading factor. Regarding the flood probability, in many cases differences are larger for probability 0.001 except for when the loading factor is 0.75.

Table 5 Percentage difference in insurance purchase under the different conditions of government compensation relative to the baseline (no government compensation condition)

Loading factor	Flooding probability	Certain half	Risky full	Ambiguous full
0.5	0.001	-20.6% (0.011)	-13% (0.063)	-10.6% (0.154)
	0.01	1.3% (0.845)	-5% (0.447)	-1.9% (0.790)
	0.1	-7.3% (0.310)	-9.6% (0.153)	1.7% (0.791)
0.75	0.001	-5.7% (0.486)	-11.5% (0.131)	-5.1% (0.528)
	0.01	-13.9% (0.069)	-21.8% (0.004)	-12% (0.112)
	0.1	-17.5% (0.037)	-13.3% (0.074)	-6.8% (0.426)
1	0.001	-28% (0.001)	-26.6% (0.001)	-15.6% (0.052)
	0.01	-7.9% (0.360)	-9.8% (0.212)	-4.8% (0.572)
	0.1	-8.8% (0.323)	-12.1% (0.131)	0% (0.959)
4	0.001	-16.4% (0.070)	-17.8% (0.026)	-18% (0.047)
	0.01	-6.2% (0.490)	-13% (0.093)	-5.1% (0.574)
	0.1	-8.1% (0.306)	-8.5% (0.222)	-10.2% (0.192

Percentage differences are: % insuring in government compensation versions—% insuring in baseline. The values in parentheses are p-values of Chi-square tests

4.2 Parametric analysis

Table 6 displays results of a random effects Probit regression analysis, to examine the influence of our variables of interest on flood insurance purchase. The random effects model is used because we have panel data with multiple responses from individual subjects, and we estimate coefficients of time-invariant regressors.[19] We cluster standard errors by subject to account for potential non-independence within subject responses, although our qualitative results do not depend on clustering standard errors.

We will first investigate pooled regression results in models 1, 2, 3 and 4. Model 1 examines the influence of the flood probability (flooding probability = 0.1 is the reference category), loading factor (loading factor = 4 is the reference category), government compensation versions (no government compensation is the reference category), risk aversion and ambiguity aversion[20] (elicited in the gain domain with the MPL measures) on insurance purchase for the entire sample. This model can be

[19] It can also be assumed that unobserved subject-specific effects are uncorrelated with government compensation versions, because the versions were randomly assigned across subjects. Our qualitative results are robust to pooled Probit and pooled OLS estimates with clustered standard errors by subject.

[20] As suggested by a reviewer, we investigated in OLS regressions the correlation between risk aversion and ambiguity aversion and the control variables, gender, age, being Dutch, flood risk perceptions and perceptions about government compensation. A Probit model is used when the outcome variable is the stated risk aversion dummy. Males and Dutch subjects are more risk seeking according to risk preferences elicited in the gain domain and regarding the stated risk aversion dummy variable (p-values < 0.05). This gender effect is in line with a large literature base on the impact of gender on risk preferences (Croson & Gneezy, 2009). Moreover, risk preferences can change depending on country-specific variables like cultural factors (Rieger et al., 2015).

Table 6 Random effects Probit regression of variables of influence on flood insurance purchases with risk and ambiguity preferences elicited in the gain domain

	Pooled				Risky full vs. certain half				Risky full vs. ambiguous full			
	MPL		Stated		MPL		Stated		MPL		Stated	
Variable	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Flooding probability = 0.001	0.17	0.26	0.17	0.07	0.13	0.58	0.13	0.24	0.14	0.20	0.14	-0.14
	(0.12)	(0.35)	(0.12)	(0.15)	(0.16)	(0.43)	(0.16)	(0.21)	(0.20)	(0.69)	(0.20)	(0.27)
	0.04		*0.04*		*0.03*		*0.03*		*0.04*		*0.04*	
Flooding probability = 0.01	0.24***	0.10	0.24***	0.12	0.29**	0.29	0.29**	0.28*	0.17	0.18	0.17	-0.05
	(0.09)	(0.27)	(0.09)	(0.12)	(0.13)	(0.35)	(0.13)	(0.16)	(0.15)	(0.51)	(0.15)	(0.19)
	*0.06****		*0.06****		*0.08***		*0.08***		*0.04*		*0.05*	
Loading factor = 0.5	1.52***	1.52***	1.52***	1.52***	1.40***	1.41***	1.40***	1.41***	1.67***	1.68***	1.67***	1.69***
	(0.09)	(0.09)	(0.09)	(0.09)	(0.15)	(0.15)	(0.15)	(0.15)	(0.14)	(0.14)	(0.14)	(0.15)
	*0.40****		*0.40****		*0.37****		*0.37****		*0.43****		*0.44****	
Loading factor = 0.75	1.18***	1.18***	1.18***	1.18***	1.09***	1.10***	1.09***	1.10***	1.27***	1.27***	1.27***	1.29***
	(0.08)	(0.08)	(0.08)	(0.08)	(0.11)	(0.11)	(0.11)	(0.11)	(0.12)	(0.12)	(0.12)	(0.13)
	*0.31****		*0.31****		*0.29****		*0.29****		*0.33****		*0.33****	
Loading factor = 1	0.88***	0.88***	0.88***	0.88***	0.68***	0.69***	0.68***	0.68***	1.08***	1.09***	1.08***	1.10***
	(0.07)	(0.07)	(0.07)	(0.07)	(0.10)	(0.10)	(0.10)	(0.10)	(0.11)	(0.11)	(0.11)	(0.11)
	*0.23****		*0.23****		*0.18****		*0.18****		*0.28****		*0.28****	
Certain half	-0.39**	-0.39**	-0.33**	-0.33**								
	(0.16)	(0.16)	(0.16)	(0.16)								
	*-0.10***		*-0.09***									
Risky full	-0.39**	-0.39**	-0.33**	-0.33**	0.01	-0.13	0.01	-0.04	-0.29***	0.46	-0.29***	0.47
	(0.16)	(0.16)	(0.16)	(0.16)	(0.09)	(0.27)	(0.09)	(0.10)	(0.09)	(0.36)	(0.09)	(0.36)
	*-0.10***		*-0.09***		*0.00*		*0.00*		*-0.08****		*-0.08****	
Ambiguous full	-0.11	-0.11	-0.06	-0.06								
	(0.17)	(0.17)	(0.17)	(0.17)								
	-0.03		*-0.02*									

Table 6 (continued)

Variable	Pooled				Risky full vs. certain half				Risky full vs. ambiguous full			
	MPL		Stated		MPL		Stated		MPL		Stated	
	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Risk aversion gain domain	0.01	0.01			0.03	0.04			-0.04	-0.04		
	(0.03)	(0.03)			(0.04)	(0.05)			(0.04)	(0.05)		
	0.00				*0.01*				*-0.01*			
Stated risk aversion dummy			0.44***	0.29*			0.42*	0.44			0.44**	0.08
			(0.14)	(0.16)			(0.24)	(0.27)			(0.22)	(0.26)
			*0.11****				*0.11**				*0.11***	
Ambiguity aversion gain domain	0.08**	0.08**	0.07*	0.07*	0.10	0.10	0.08	0.08	0.09	0.16**	0.08	0.15*
	(0.04)	(0.04)	(0.04)	(0.04)	(0.06)	(0.07)	(0.06)	(0.06)	(0.08)	(0.08)	(0.07)	(0.08)
	*0.02***		*0.02**		*0.03*		*0.02*		*0.02*		*0.02*	
Flooding probability = 0.001 × risk aversion gain domain		-0.01				-0.06				-0.01		
		(0.05)				(0.06)				(0.09)		
Flooding probability = 0.01 × risk aversion gain domain		0.02				0.00				-0.00		
		(0.04)				(0.05)				(0.07)		
Flooding probability = 0.001 × stated risk aversion dummy				0.22				-0.28				0.62
				(0.23)				(0.33)				(0.41)
Flooding probability = 0.01 × stated risk aversion dummy				0.26				0.04				0.49*
				(0.17)				(0.26)				(0.29)
Risky full × risk aversion gain domain						0.02						
						(0.04)						
Risky full × stated risk aversion dummy								0.12				
								(0.20)				
Risky full × ambiguity aversion gain domain										-0.13**		-0.13**
										(0.06)		(0.06)

Table 6 (continued)

Variable	Pooled				Risky full vs. certain half				Risky full vs. ambiguous full			
	MPL		Stated		MPL		Stated		MPL		Stated	
	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Order	0.11*	0.11*	0.11*	0.11*	0.01	-0.00	0.01	0.00	0.22**	0.25***	0.22**	0.25***
	(0.06)	(0.07)	(0.06)	(0.07)	(0.09)	(0.10)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)
	*0.03**		*0.03**		*0.00*		*0.00*		*0.06***		*0.06***	
Constant	-1.40**	-1.38**	-1.55***	-1.48**	-3.19**	-3.28**	-2.98**	-3.00**	-0.84	-1.30	-1.01	-1.29
	(0.64)	(0.63)	(0.58)	(0.58)	(1.27)	(1.32)	(1.26)	(1.28)	(0.97)	(0.95)	(0.86)	(0.90)
Observations	4176	4176	4176	4176	1800	1800	1800	1800	1752	1752	1752	1752
Subjects	200	200	200	200	75	75	75	75	73	73	73	73

Dependent variable: insurance purchase. Model coefficients are shown and standard errors are reported in parentheses clustered by subject. The average marginal effects are displayed in italicized text in regressions that contain main effects only. *, ** and *** indicate significance at the 10, 5 and 1% level respectively. Regressions control for gender, age, being Dutch, flood risk perceptions and perceptions about government compensation. Model 1 (M1) is a pooled regression model of the influence of the flood probability, loading factor, government compensation versions, risk aversion and ambiguity aversion (both elicited in the gain domain with the multiple price list (MPL) measures) on insurance purchase. Model 2 (M2) adds to M1 interaction terms between the flood probability and risk aversion. Model 3 (M3) and model 4 (M4) implement the same analysis as M1 and M2 respectively, except the stated measure of risk aversion is used instead of the MPL measure. Model 5 (M5) investigates subjects who faced both risky full government compensation and certain half, and the effect of the former relative to the latter on insurance purchase. Model 6 (M6) adds to M5 interaction terms between the flood probability and risk aversion, as well as risky full government compensation and risk aversion (elicited in the gain domain with the MPL measure). Model 7 (M7) and model 8 (M8) implement the same analysis as M5 and M6 respectively, except the stated measure of risk aversion is used instead of the MPL measure. Model 9 (M9) investigates subjects who faced both risky full government compensation and ambiguous full, and the effect of the risky version relative to the ambiguous version on insurance purchase. Model 10 (M10) adds to M9 interaction terms between the flood probability and risk aversion, and between the degree of ambiguity in government compensation and ambiguity aversion (both risk and ambiguity aversion are elicited in the gain domain with the MPL measures). Model 11 (M11) and model 12 (M12) implement the same analysis as M9 and M10 respectively, except the stated measure of risk aversion is used instead of the MPL measure. An order variable is included in all models to control for the effect of being presented with a version of the government compensation first used to test **H1**, **H2** and **H4**. Model 2 takes into account the potential interaction between the flood probability and risk aversion to test **H3**. An order variable is also included in models 1 and 2 to control for the effect of being presented with either the risky full, certain half or ambiguous full version of government compensation first. Models 3 and 4 carry out the same analysis as models 1 and 2 respectively, except the stated measure of risk aversion is used instead of the MPL measure.

The models show that there is a negative relation between the loading factor and flood insurance demand. That is, subjects were less likely to purchase flood insurance as the insurance premium increased. Moreover, relative to no government compensation, compensation in the form of risky full or certain half reduces the probability of insurance purchase, although this is not the case for ambiguous full compensation. Regarding ambiguity and risk preferences, more ambiguity averse subjects are more likely to purchase flood insurance, whereas there is no impact of risk aversion measured according to the MPL task on insurance purchase. However, we do find a positive impact of risk aversion on insurance purchase with the stated measure. Lastly, models 1 and 3 show that a decrease in the flood probability from 0.1 to 0.01 increases the probability of flood insurance purchase, consistent with the findings of Laury et al. (2009). However, lowering the flood probability to 0.001 does not significantly influence the likelihood of insurance purchase relative to probability 0.1. This may be due to a sub-group of subjects perceiving probability 0.001 to be below their threshold level of concern. There are also no interaction effects between the flood probability and risk aversion according to the MPL measure and stated risk aversion.

Now consider the results from models 5, 6, 7 and 8. Model 5 examines observations from subjects who faced both risky full government compensation and certain half, and the effect of the former relative to the latter on insurance purchase. Model 6 accounts for the potential interactions included in model 2, as well as the possible interaction between the riskiness of government compensation and risk aversion measured according to the MPL task to test **H5**. An order variable is also included in models 5 and 6 to control for the effect of being presented with either the risky full or certain half version of government compensation first. Models 7 and 8 perform the same respective analysis as models 5 and 6, except the stated measure of risk aversion is used instead of the MPL measure.

Consistent with models 1, 2, 3 and 4, the loading factor is negatively related to flood insurance demand. In addition, relative to certain half government compensation, compensation in the form of risky full does not impact the probability of insurance purchase, and there is no interaction between the riskiness of government compensation and risk aversion either measured with the MPL task or stated. There is also no unique effect of risk aversion measured with the MPL task or ambiguity aversion on the likelihood of insurance purchase, but there is a (marginally significant) unique effect of stated risk aversion. The non-significance of ambiguity aversion is unsurprising, because there is no ambiguity in the risky full and certain half government compensation versions. Despite the positive effect of a lower flood probability (from 0.1 to 0.01) on the probability of insurance purchase in models 5 and 7, including interactions between the flood probability and risk aversion results in insignificant coefficient estimates, using both the MPL measure and stated. Lastly, there are no order effects between the risky full and certain half government compensation versions of the experiment.

Moving on to the results of regression models 9, 10, 11 and 12, model 9 considers observations from subjects who faced both risky full government compensation and ambiguous full, and the effect of the risky version relative to the ambiguous version on insurance purchase. Model 10 accounts for the potential interactions included in model 2, as well as the interaction between the degree of ambiguity in government compensation and ambiguity aversion. In model 10, the coefficient estimate on the ambiguity aversion gain domain variable can be used to test **H6**. The interaction between the risky full government compensation and ambiguity aversion gain domain variables can be used to test **H7**. An order variable is also included in models 9 and 10 to control for the effect of being presented with either the risky full or ambiguous full version of government compensation first. Models 11 and 12 provide the same analysis as models 9 and 10, except the stated measure of risk aversion is used instead of the MPL measure (which is utilized in models 9 and 10).

The loading factor negatively affects the probability of insurance purchase, consistent with the other regression results. Moreover, relative to ambiguous full government compensation, compensation in the form of risky full has a negative impact on the probability of insurance purchase in models 9 and 11. Interpreting models 10 and 12, there is a negative interaction between risky full government compensation and ambiguity aversion, as well as a positive coefficient estimate on the ambiguity aversion variable. This implies that ambiguity aversion positively affects insurance demand under ambiguous full government compensation. In addition, more ambiguity averse subjects demanded less insurance in the risky full relative to the ambiguous full version of the experiment. In other words, ambiguity averse subjects have lower insurance demand when government compensation is less ambiguous. Consistent with the prior results, we also find no effect of risk aversion measured with the MPL task on the likelihood of insurance purchase. Furthermore, although there are positive coefficient estimates on the 0.01 flood probability variable in models 9 and 11, we find no significant probability effect in models 9 and 11, nor in model 10 which considers potential interactions between the flood probability and risk aversion according to the MPL measure. Nevertheless, there is a marginally significant interaction between flood probability 0.01 and stated risk aversion in model 12. Finally, we do find order effects between the risky full and ambiguous full government compensation versions. Importantly, the effect we find, regarding the impact of risky vs. ambiguous government compensation on flood insurance demand, is not due to order of government compensation, because order has been controlled for in our regression results.[21]

[21] We examined different specifications of models 1 to 12, with interaction terms between the order variable and the risk and ambiguity aversion variables, as well as the control variables, gender, age, being Dutch, flood risk perceptions and perceptions about government compensation. The interaction terms are included separately across all specifications to avoid concerns of multi-collinearity that may occur if one were to include all of these terms in the same model. The coefficients on all of these interacting terms are insignificant (p-values > 0.05), which suggests that any learning effects in our experiment are driven by unobserved factors. As an aside, our results are robust to dropping the flood risk and government compensation perceptions variables, which may be perceived as bad controls as they were elicited after the experiment.

Table 9 in Appendix 3 displays results of a random effects Probit regression analysis, with risk and ambiguity preferences elicited in the loss domain. The qualitative conclusions remain the same, except we find no unique effect of ambiguity aversion elicited in the loss domain on insurance demand. Nevertheless, there is still a negative interaction between risky government compensation and ambiguity aversion elicited in the loss domain in Table 9. Ambiguity preferences elicited in the gain domain may better predict the unique effect on insurance demand under ambiguous government compensation if the compensation and the endowment were often integrated by subjects into potential losses, so the insurance decisions were viewed in the gain domain.

Note that our main conclusions are robust to fixed effects (within) specifications where the time-variant variables are retained as well as their interactions with risk and ambiguity preferences. Furthermore, we conducted a series of Hausman tests across all models in Tables 6 and 9 that retain these variables only. In all cases we accept the null hypothesis (the p-values are close to 1 in nearly all cases) that the subject-specific effects are uncorrelated with these variables, therefore the estimated coefficients are insignificantly different overall between the random effects and fixed effects models, but the random effects estimator is more efficient than the fixed effects estimator.

5 Discussion

5.1 Hypotheses

Table 7 describes how the hypotheses fared. Experimentally revealed risk preferences according to the MPL measure were not a significant predictor of flood insurance decisions. This result is consistent with some other experimental studies finding that risk preferences elicited experimentally do not explain insurance demand (e.g., Aseervatham et al., 2015; Harrison & Ng, 2016; Sauter et al., 2016). We cannot rule out that risk preferences may be different in insurance decisions compared to those elicited in standard gamble tasks due to a framing effect (Hershey & Schoemaker, 1980). We find that risk aversion according to a stated measure of risk preference in Dohmen et al. (2011) is positively related to insurance demand. Dohmen et al. (2011) showed that the stated measure is a good all-round predictor of risk taking behaviour in practice, and may better capture risk aversion in relation to flood insurance demand in our experiment. Overall, we find partial support for **H1**.

Our results also suggest that a decrease in the flood probability from 0.1 to 0.01 increases flood insurance demand, consistent with Laury et al. (2009). Interestingly, the regression results find that a further reduction in the flood probability to 0.001, has no significant impact on flood insurance demand relative to 0.1. It may be that a sub-group of subjects find that flood probability 0.001 falls below their threshold level of concern. This sub-group may treat this very low-probability of flooding as negligible. This type of behaviour is typical of individuals facing low-probability risks in practice (Camerer & Kunreuther, 1989), and has been observed in another experiment of flood insurance demand among Dutch homeowners by Robinson and

Table 7 Summary of hypotheses results

Hypothesis	Explanation	Result
H1	There is a positive unique effect of stated risk aversion on insurance demand, but not with the MPL measure of risk aversion	Partial support
H2	There is a negative effect of the loading factor on insurance demand	Support
H3	There is no positive interaction effect between flood probability and risk aversion on insurance demand	Not supported
H4	There is a negative effect of certain half and risky full government compensation on insurance demand, but not with ambiguous full government compensation	Partial support
H5	There is not an interaction effect between risky full government compensation and risk aversion on insurance demand	Not supported
H6	There is a positive unique effect of ambiguity aversion in the gain domain on insurance demand, but not with ambiguity aversion in the loss domain	Partial support
H7	There is a negative interaction effect between risky full government compensation and ambiguity aversion on insurance demand	Support

Botzen (2018). Moreover, we find insignificant interaction effects between flood probability 0.01 as well as 0.001 (relative to flood probability 0.1) and risk aversion on insurance demand, therefore we reject **H3**.

Concerning the loading factor, our results show that there is an inverse relationship between flood insurance demand and the price of insurance, in support of **H2**.

In addition, certain half and risky full government compensation negatively impacts flood insurance demand relative to the baseline, in support of **H4** and the charity hazard hypothesis. However, the ambiguous full government compensation does not significantly influence flood insurance demand. This result is consistent with the field survey results of Raschky et al. (2013), who find that partial certain government compensation drives a stronger crowding out of flood insurance demand, than ambiguous full government relief which is subject to political influences.

We reject **H5** given that flood insurance demand is approximately the same under risky full vs. certain half government compensation, and more risk averse subjects demand no more or less insurance under either condition. Overall, insurance demand is highest under no government compensation and ambiguous full government compensation and lowest under certain half and risky full government compensation.

Based on the Klibanoff et al. (2005) smooth model of decision making under ambiguity, we expand upon the analysis in Kelly and Kleffner (2003) and Raschky and Weck-Hannemann (2007), to examine insurance demand under ambiguous government compensation.[22] We find that there is a significant positive unique effect of ambiguity aversion on the likelihood of flood insurance purchase under ambiguous full government compensation, according to ambiguity preferences elicited in the gain domain, supporting **H6**. Whereas, this is not the case with ambiguity preferences elicited in the loss domain. Perhaps gain domain ambiguity preferences were a better predictor of this unique effect because compensation and the endowment were often integrated into potential losses by subjects, so the insurance decisions were viewed as a gain. That is, subjects may have kept the endowment in mind when making insurance choices. Klibanoff et al. (2005) also assume *EU* under risk, and therefore that individuals process outcomes in terms of final wealth.

For our final hypothesis **H7** we find that insurance demand is significantly higher under ambiguous full government compensation vs. risky full government compensation for more ambiguity averse individuals, which is consistent with **H7.** This is regardless of whether preferences are elicited in the gain or loss domain.

5.2 Policy recommendations

One might argue that our findings are more general than only pertaining to flood risk. Our results are consistent with Laury et al. (2009), who framed the decisions in their

[22] The smooth model is commonly used in theoretical examinations of insurance demand under ambiguity or uncertainty of the loss probability (e.g., Alary et al., 2013; Bajtelsmit et al., 2015; Berger, 2016; Brunette et al., 2013; Snow, 2011). Ambiguity aversion increases insurance demand when the probability of loss is more ambiguous according to these studies.

experiment in a neutral way outside the context of flood risk, regarding how individuals respond to changes in the loss probability. Furthermore, it has been shown that precautionary decision processes are impacted by the perceived frequency of risky events (Kusev et al., 2009), which suggests that similar types of decisions may prevail among natural disaster risks that are perceived as low-probability/high-impact. Nevertheless, we note that there are also some characteristics of our study that may lower the transferability of our findings to decisions made by homeowners. Our findings pertain to a sample of students who are not the population of interest insofar as flood insurance purchase decisions are concerned. It is reasonable to assume that subgroups who do make these decisions, e.g., homeowners, are older and have higher incomes than students. However, similar conclusions have been arrived at regarding a moral hazard effect in the purchase of insurance against low-probability/high-impact flood risk among students and Dutch homeowners (Mol et al., 2020a, b). The main objective of our study was to empirically test theoretical predictions concerning the influence of different types of government compensation on insurance demand in a controlled experiment. If one were able to validate our results in a field experiment setting among homeowners (which we think is a fruitful avenue for future research), several policy recommendations may follow.

Our between-subjects analysis of the charity hazard shows that certain half and risky full government compensation crowd out flood insurance demand. The findings also suggest that ambiguous government compensation does not significantly reduce insurance demand after taking into account the impact of loading factor, flood probability, as well as risk and ambiguity preferences. Therefore, if eliminating government compensation completely is infeasible, perhaps it should be made ambiguous because crowding out of insurance demand appears to be less persistent. However, this is practically difficult given the high political incentives to offer compensation for uninsured losses after a disaster (Dari-Mattiacci & Faure, 2015). It has also been shown that individuals generally support government compensation being granted after major natural disasters. But note that a significantly lower percentage favor such compensation when individuals voluntarily choose to live in high risk areas (Viscusi & Zeckhauser, 2006), suggesting that a large proportion of the population may have little sympathy for those who knowingly place themselves at greater risk. Nevertheless, broad media coverage which often accompanies disaster assistance can lead households to expect that uninsured losses will indeed be compensated in the future (Seifert et al., 2013). Finding solutions to lessen reliance on government support schemes is a necessity, given that flood risks are likely to increase with socio-economic developments and climate change (IPCC, 2012). Perhaps increasing flood insurance demand, so that uninsured losses are hardly present is the best way forward.

Raschky and Weck-Hannemann (2007) suggest that redirecting the funds used for government relief to insurance subsidies, may be an economically attractive solution to overcoming the charity hazard. This would also reduce homeowners' ambiguity about whether their flood losses will be covered, assuming that flood insurance demand increases and there is no risk of insurer default. Our results show that the price of flood insurance is a strong determinant of demand, therefore subsidies may work well. An exception is if an individual perceives the subjective likelihood of flood risk to fall below their threshold level of concern. Empirical evidence from the U.S. suggests that demand for subsidized flood insurance is quite low (Dixon et al., 2006), perhaps due to individuals dismissing flood risks. A disadvantage of subsidizing flood insurance is that it reduces the price signal of flood risk, thereby encouraging individuals to settle into high-risk areas at the potential expense of the tax-payer (Young, 2008). Moreover, subsidies may reduce incentives for risk mitigation (Kousky, 2018), i.e., premium discounts for risk mitigation are less effective if flood insurance premiums are subsidized rather than risk-based.

Another solution to the charity hazard is strengthening/introducing flood insurance purchase requirements in high-risk areas, so that individuals who are incognizant of their flood risk or those who have a tendency to dismiss it, would be automatically covered. However, other types of regulatory intervention which overcome insurance demand choice anomalies while preserving an individual's freedom of choice may provide a better solution (Schwarcz, 2010). An example of such a choice anomaly in our experiment is that despite predictions of *EU* Theory, there is no significant difference in the rate of flood insurance purchase when the probability attached to flood risk is 0.001, compared to when the probability is 0.1 with the same expected value. We conjecture that this may be due to a sub-group of subjects finding that flood probability 0.001 falls below their threshold level of concern. Overcoming systematic biases in judgment may require re-framing information about flood risks. Schwarcz (2010) discusses how the latter could be used to overcome threshold probabilities, by framing flood risks over periods in excess of a single year. Empirical findings suggest that flood risk perceptions are higher when the probability of one flood is described as 1 in 3 over 40 years, relative to 1 in 100 every year (Keller et al., 2006). Alternatively, bundling flood risk with other low-probability risks into a single insurance policy may raise perceived loss probabilities above individual threshold levels (Kunreuther & Pauly, 2004). The empirical evidence on bundling so far is mixed (Schoemaker & Kunreuther, 1979; Slovic et al., 1977), and more research may be needed to confirm whether it is a feasible solution.

6 Conclusion

In this paper we examine the charity hazard hypothesis in relation to various degrees of ambiguity in government compensation, as well as the influence of risk preferences, ambiguity preferences and insurance pricing on flood insurance demand. We compare several theoretical predictions to our results, according to *EU* Theory and the Klibanoff et al. (2005) smooth model of decision making under ambiguity.

Our results are based on an incentivized economic experiment, conducted with 200 subjects. We conclude that flood insurance demand is negatively related to certain and risky government compensation, although ambiguous compensation does not significantly crowd out demand. We also find that ambiguity averse subjects have higher demand for insurance when government compensation is ambiguous relative to risky, according to experimentally elicited ambiguity preferences. Ambiguity preferences elicited in the gain domain also better predicted the unique effect on insurance demand under ambiguous government compensation, relative to those elicited in the loss domain.

Stated risk aversion better predicts flood insurance demand than risk preferences elicited in MPL tasks. Moreover, premium loading is inversely related to flood insurance demand regardless of the type of government compensation granted.

In addition to whether or not compensation is provided, the extent of relief is influenced by political factors in practice. Future research may consider examining whether ambiguity in the extent of government compensation affects flood insurance decision making. Another useful next step may be to investigate ambiguity in the probability of flooding as well as ambiguity in government compensation simultaneously, since in some countries the flood probability may be not well studied and unknown.

We suggest several recommendations for policy to improve flood risk preparedness, including mandatory insurance, re-framing probability information and bundling. The effectiveness of these policies can also be useful topics for future research.

Appendix 1 Derivation of the hypotheses

Without government compensation the individual will choose a level of α to maximize his/her Expected Utility (EU):

$$EU = pU[W - P(\alpha) - (L - V(\alpha))] + (1 - p)U[W - P(\alpha)] \tag{5}$$

Assuming the individual anticipates the government will provide compensation, θ $(0 < \theta < 1)$, to pay for a proportion of the uninsured damage, Eq. 5 is modified to:

$$EU = pU[W - P(\alpha) - (1 - \theta)(L - V(\alpha))] + (1 - p)U[W - P(\alpha)] \tag{6}$$

If the individual decides not to purchase insurance, her/his EU_{NI} (EU with no insurance) is:

$$EU_{NI} = pU[W - (1 - \theta)L] + (1 - p)U[W] \tag{7}$$

We denote willingness-to-pay for full insurance ($\alpha = 1$) as WTP, defined by:

$$EU_{NI} = U[W - WTP] \tag{8}$$

Under linear $U(\bullet)$ (risk neutrality), EU_{NI} is equal to the utility of the expected value:

$$U[W - WTP_{RN}] = EU_{NI} = U[p[W - (1 - \theta)L] + (1 - p)[W]] \tag{9}$$

Under concave $U(\bullet)$ (risk aversion), EU_{NI} is less than the utility of the expected value:

$$U[W - WTP_{RA}] = EU_{NI} < U[p[W - (1 - \theta)L] + (1 - p)[W]] = U[W - WTP_{RN}] \tag{10}$$

Under convex $U(\bullet)$ (risk seeking), EU_{NI} is greater than the utility of the expected value:

$$U[W - WTP_{RS}] = EU_{NI} > U[p[W - (1 - \theta)L] + (1 - p)[W]] = U[W - WTP_{RN}] \tag{11}$$

Assuming p, θ, α and λ remain constant across levels of risk aversion, we can infer from Eqs. 9, 10, and 11 that $U\left[W - WTP_{RA}\right] < U\left[W - WTP_{RN}\right] < U[W - WTP_{RS}]$, hence $WTP_{RS} < WTP_{RN} < WTP_{RA}$. That is, willingness-to-pay for full insurance increases with the degree of risk aversion.[23]

H1: Willingness-to-pay for full insurance is positively related to the degree of risk aversion.

We assume that the individual will purchase full insurance if her/his *EU* with full insurance is greater than *EU* without insurance, therefore $WTP > P(1)$:

$$EU_{NI} = U[W - WTP] < U[W - P(1)] \tag{12}$$

More insurance premium loading reduces *EU* with full insurance because $P(1) = Lp\lambda$ is increasing in λ.[24] Consequently, the gap between *EU* with full insurance and *EU* without insurance becomes smaller. There is a critical value of λ where *EU* without insurance becomes greater than the *EU* with full insurance, and so the individual chooses not to insure, i.e., $WTP < P(1)$.

H2: Willingness-to-pay for full insurance is negatively related to the loading factor.[25]

Consider two risks of loss, $R_1(p_1, L_1)$ and $R_2(p_2, L_2)$, i.e., a loss L_1 (L_2) occurs with probability p_1 (p_2). The two risks have the same expected value, but $L_2 > L_1$ and $p_2 < p_1$. That is, R_1 and R_2 have equal mean but R_2 has higher variance than R_1. Under concave $U(\bullet)$ (risk aversion), without insurance *EU* across the two scenarios are given by:

$$EU^1_{NI} = p_1 U\left[W - (1 - \theta)L_1\right] + \left(1 - p_1\right)U[W] = U\left(W - WTP^1_{RA}\right) \tag{13}$$

$$EU^2_{NI} = p_2 U\left[W - (1 - \theta)L_2\right] + \left(1 - p_2\right)U[W] = U\left(W - WTP^2_{RA}\right) \tag{14}$$

When loss occurs, since $L_2 > L_1$:

$$U\left[W - (1 - \theta)L_1\right] > U\left[W - (1 - \theta)L_2\right] \tag{15}$$

[23] This is true for any insurance coverage level $\alpha \in (0,1)$. We consider full insurance is a pure simplification.

[24] An increase in the loading factor (λ) increases the insurance premium of full insurance ($P(1)$) and hence reduces the utility of buying full insurance ($U[W - P(1)]$).

[25] Mossin (1968) and Smith (1968) showed that risk averse *EU* maximizers should demand full insurance when $\lambda = 1$, although partial coverage is optimal when $\lambda > 1$. However, in our experiment we observe only full insurance and zero insurance.

For both R_1 and R_2, the alternative utility without loss is the same ($U[W]$). Also, $U[W] > U\left[W - (1-\theta)L_1\right] > U\left[W - (1-\theta)L_2\right]$. Under concave $U(\bullet)$ (risk aversion), $EU^1_{NI} > EU^2_{NI}$, hence $U\left(W - WTP^1_{RA}\right) > U\left(W - WTP^2_{RA}\right)$ and $WTP^1_{RA} < WTP^2_{RA}$.

H3: Willingness-to-pay for full insurance is negatively related to the probability of loss for risk averse individuals, holding the expected value of loss constant.

Consider again Eq. 8. Higher levels of government compensation increases the EU without insurance because the share of uninsured loss L becomes lower.[26] Consequently, $U[W - WTP]$ increases and WTP decreases. This result follows from the charity hazard highlighted in the introduction section.

H4: Willingness-to-pay for full insurance is negatively related to government compensation.

Assuming an objective probability of receiving government compensation equal to π, EU is given by:

$$EU = \pi\left\{pU\left[W_{LG}\right] + (1-p)U\left[W_{NL}\right]\right\} + (1-\pi)\left\{pU\left[W_L\right] + (1-p)U\left[W_{NL}\right]\right\} \tag{16}$$

We define $W_{LG} = W - P(\alpha) - (1-\theta)(L - V(\alpha))$ as final wealth in the loss with government compensation state. Similarly, let $W_L = W - P(\alpha) - (L - V(\alpha))$ be final wealth in the loss state without government compensation, and $W_{NL} = W - P(\alpha)$ be final wealth in the no loss state. Note that $W_{LG} > W_L$ when $\theta > 0$.[27] There is a risk of government compensation $G(\pi, \theta)$ in Eq. 16, i.e., the individual receives government compensation θ with probability π in the event of a loss. Assume two risks of government compensation, $G_1(\pi_1, \theta_1)$ and $G_2(\pi_2, \theta_2)$ with the same expected value, but $\theta_2 > \theta_1$ and $\pi_2 < \pi_1$. Under concave $U(\bullet)$ (risk aversion), without insurance EU across the two scenarios are given by:

$$\begin{aligned} EU_{NI,1} &= \pi_1\left\{pU\left[W - \left(1-\theta_1\right)L\right] + (1-p)U[W]\right\} + \left(1-\pi_1\right)\{pU[W-L] + (1-p)U[W]\} \\ &= p\left\{\pi_1 U\left[W - \left(1-\theta_1\right)L\right] + \left(1-\pi_1\right)U[W-L]\right\} + (1-p)U[W] \\ &= U[W - WTP_{RA,1}] \end{aligned} \tag{17}$$

$$\begin{aligned} EU_{NI,2} &= \pi_2\left\{pU\left[W - \left(1-\theta_2\right)L\right] + (1-p)U[W]\right\} + \left(1-\pi_2\right)\{pU[W-L] + (1-p)U[W]\} \\ &= p\left\{\pi_2 U\left[W - \left(1-\theta_2\right)L\right] + \left(1-\pi_2\right)U[W-L]\right\} + (1-p)U[W] \\ &= U[W - WTP_{RA,2}] \end{aligned} \tag{18}$$

Comparing $\pi_1 U\left[W - \left(1-\theta_1\right)L\right] + \left(1-\pi_1\right)U[W-L]$ with $\pi_2 U\left[W - \left(1-\theta_2\right)L\right] + \left(1-\pi_2\right)U[W-L]$, because $\theta_2 > \theta_1$, we can infer that $W - \left(1-\theta_2\right)L > W - \left(1-\theta_1\right)L$ and $U\left[W - \left(1-\theta_2\right)L\right] > U\left[W - \left(1-\theta_1\right)L\right]$. Moreover, $W - L < W$

[26] An increase in government compensation (θ) leads to an increase in final wealth in the loss state ($W - (1-\theta)L$), and the corresponding EU without insurance.

[27] In our experiment we consider Eq. 16 evaluated at $\pi = 0.5$ and $\theta = 1$ (risky full government compensation), as well as Eq. 16 evaluated at $\pi = 1$ and $\theta = 0.5$ (certain half government compensation).

$-(1-\theta_1)L < W - (1-\theta_2)L$, therefore $U[W-L] < U[W-(1-\theta_1)L] < U[W-(1-\theta_2)L]$. Similar to **H3**, the concavity of $U(\bullet)$ implies that $EU_{NI,1} > EU_{NI,2}$, or equivalently $U[W - WTP_{RA,1}] > U[W - WTP_{RA,2}]$, hence $WTP_{RA,1} < WTP_{RA,2}$.[28]

H5: Willingness-to-pay for full insurance is negatively related to the probability of government compensation for risk averse individuals, holding the expected value of government compensation constant.

Under ambiguous government compensation, decisions can be made in accordance with the second order *EU* function, i.e., the Klibanoff et al. smooth model value (*KMM*):

$$KMM = E\{\varphi\{\overline{\pi}\{pU[W_{LG}] + (1-p)U[W_{NL}]\} + (1-\overline{\pi})\{pU[W_L] + (1-p)U[W_{NL}]\}\}\} \tag{19}$$

In our experiment, under ambiguous government compensation, there are two possible objective probability distributions regarding $\overline{\pi}$, either probability 1 is assigned to $\{pU[W_{LG}] + (1-p)U[W_{NL}]\}$, or probability 1 is assigned to $\{pU[W_L] + (1-p)U[W_{NL}]\}$. Evaluation of the insurance decision is then given by:

$$KMM = \sigma_1\varphi\{pU[W_{LG}] + (1-p)U[W_{NL}]\} + \sigma_0\varphi\{pU[W_L] + (1-p)U[W_{NL}]\} \tag{20}$$

If the individual decides not to purchase insurance:

$$KMM_{NI} = \sigma_1\varphi\{U[W]\} + \sigma_0\varphi\{pU[W-L] + (1-p)U[W]\} = E\{\varphi\{EU(\overline{\pi})\}\} \tag{21}$$

Under linear $\varphi(\bullet)$ (ambiguity neutrality):

$$\varphi\{U[W - WTP_{AN}]\} = KMM_{NI} = \varphi\{E(EU(\overline{\pi}))\} \tag{22}$$

Under concave $\varphi(\bullet)$ (ambiguity aversion):

$$\varphi\{U[W - WTP_{AA}]\} = KMM_{NI} < \varphi\{E(EU(\overline{\pi}))\} = \varphi\{U[W - WTP_{AN}]\} \tag{23}$$

Under convex $\varphi(\bullet)$ (ambiguity seeking):

$$\varphi\{U[W - WTP_{AS}]\} = KMM_{NI} > \varphi\{E(EU(\overline{\pi}))\} = \varphi\{U[W - WTP_{AN}]\} \tag{24}$$

We can infer from Eqs. 22, 23, and 24 that $\varphi\{U[W - WTP_{AA}]\} < \varphi\{U[W - WTP_{AN}]\} < \varphi\{U[W - WTP_{AS}]\}$, therefore $WTP_{AS} < WTP_{AN} < WTP_{AA}$. That is, willingness-to-pay for full insurance increases with the degree of ambiguity aversion under ambiguous government compensation.

[28] This holds so long as $U[W-(1-\theta_1)L] > \pi_2 U[W-(1-\theta_2)L] + (1-\pi_2)U[W-L]$, which always holds in our experiment under risk aversion where we compare $\pi_1 = 1$ and $\theta_1 = 0.5$ to $\pi_2 = 0.5$ and $\theta_2 = 1$.

H6: Willingness-to-pay for full insurance is positively related to the degree of ambiguity aversion when government compensation is ambiguous.

Under risky full government compensation (Eq. 16 evaluated at $\pi = 0.5$ and $\theta = 1$), and without insurance *EU* becomes:

$$EU_{NI,RF} = 0.5U[W] + 0.5\{pU[W-L] + (1-p)U[W]\} = U\left[W - WTP_{RF}\right] \tag{25}$$

Assuming $\sigma = (0.5, 0.5)$, under ambiguous full government compensation, without insurance *KMM* becomes:

$$KMM_{NI} = 0.5\varphi\{U[W]\} + 0.5\varphi\{pU[W-L] + (1-p)U[W]\} = \varphi\{U[W - WTP]\} \tag{26}$$

Under linear $\varphi(\bullet)$ (ambiguity neutrality), the individual is a (subjective) *EU* maximizer:

$$U\left[W - WTP_{RF}\right] = EU_{NI,RF} = KMM_{NI} = \varphi\left\{U\left[W - WTP_{AN}\right]\right\} \tag{27}$$

Under concave $\varphi(\bullet)$ (ambiguity aversion):

$$U\left[W - WTP_{RF}\right] = EU_{NI,RF} > KMM_{NI} = \varphi\{U\left[W - WTP_{AA}\right]\} \tag{28}$$

Under convex $\varphi(\bullet)$ (ambiguity seeking):

$$U\left[W - WTP_{RF}\right] = EU_{NI,RF} < KMM_{NI} = \varphi\{U\left[W - WTP_{AS}\right]\} \tag{29}$$

We can infer from Eqs. 27, 28, and 29 that $\varphi\left\{U\left[W - WTP_{AA}\right]\right\} < \varphi\{U\left[W - WTP_{AN}\right]\} = U\left[W - WTP_{RF}\right] < \varphi\left\{U\left[W - WTP_{AS}\right]\right\}$, therefore $WTP_{AA} > WTP_{AN} = WTP_{RF} > WTP_{AS}$.[29]

H7: Willingness-to-pay for full insurance is higher under ambiguous full government compensation vs. risky full government compensation for ambiguity averse individuals.

H6 and **H7** are robust to other ambiguity theories like Maxmin *EU* (Gilboa & Schmeidler, 1989), because an ambiguity averse individual following Maxmin *EU* will consider the minimal *EU* under ambiguous full compensation, which is *EU* under no government compensation. Note that Maxmin *EU* is a special case of the Klibanoff et al. (2005) smooth model, where φ places all of the weight on the worst *EU*. Online Resource 1 provides a welfare evaluation of the insurance decision over the experimental parameters involved in our study using simulations that illustrate our hypotheses numerically.

[29] Note that this also holds under the more general condition: $\sigma = \pi$.

Appendix 2 Descriptive statistics and coding of variables

Table 8 Descriptive statistics and coding of the dependent and independent variables

Variable	Coding	Mean	Std dev	Max	Min
Insurance purchase	1 = purchased insurance, 0 = insurance not purchased	0.602		1	0
Flooding probability = 0.001	1 = flooding probability is 0.001, 0 = otherwise	0.333		1	0
Flooding probability = 0.01	1 = flooding probability is 0.01, 0 = otherwise	0.333		1	0
Loading factor = 0.5	1 = loading factor is 0.5, 0 = otherwise	0.250		1	0
Loading factor = 0.75	1 = loading factor is 0.75, 0 = otherwise	0.250		1	0
Loading factor = 1	1 = loading factor is 1, 0 = otherwise	0.250		1	0
Certain half	1 = compensation scheme is certain half government compensation, 0 = otherwise	0.216		1	0
Risky full	1 = compensation scheme is risky full government compensation, 0 = otherwise	0.425		1	0
Ambiguous full	1 = compensation scheme is ambiguous full government compensation, 0 = otherwise	0.210		1	0
Risk aversion gain domain	Switching point in the gain domain risk aversion task (higher values represent more risk aversion)	7.425	2.354	11	1
Risk aversion loss domain	Switching point in the loss domain risk aversion task (higher values represent more risk aversion)	5.825	2.446	11	1
Stated risk aversion	Stated risk preference (higher values represent more risk aversion)	5.545	1.928	10	1
Stated risk aversion dummy	1 = stated risk aversion > 5, = 0 otherwise	0.490		1	0
Ambiguity aversion gain domain	Switching point in the gain domain ambiguity aversion task (higher values represent more ambiguity aversion)	6.190	1.806	10	1
Ambiguity aversion loss domain	Switching point in the loss domain ambiguity aversion task (higher values represent more ambiguity aversion)	6.170	1.614	10	1
Order	1 = first twelve insurance decisions, 0 = last twelve insurance decisions	0.575		1	0
Male	1 = male, 0 = female	0.555		1	0
Age	Age in years	22.265	3.406	45	18

Table 8 (continued)

Variable	Coding	Mean	Std dev	Max	Min
Dutch	1 = Dutch national, 0 = non-Dutch national	0.620		1	0
Flood risk perceptions	Best estimate of how often a flood would occur at subject's residence (1 = once every 10 years, 2 = once every 100 years, …, 6 = less than once every 100,000 years)	2.855	1.132	6	1
Government compensation perceptions	Perceptions about the likelihood the government would compensate any flood damage to a homeowner in the Netherlands (1 = very likely, …, 5 = very unlikely)	2.930	1.039	5	1

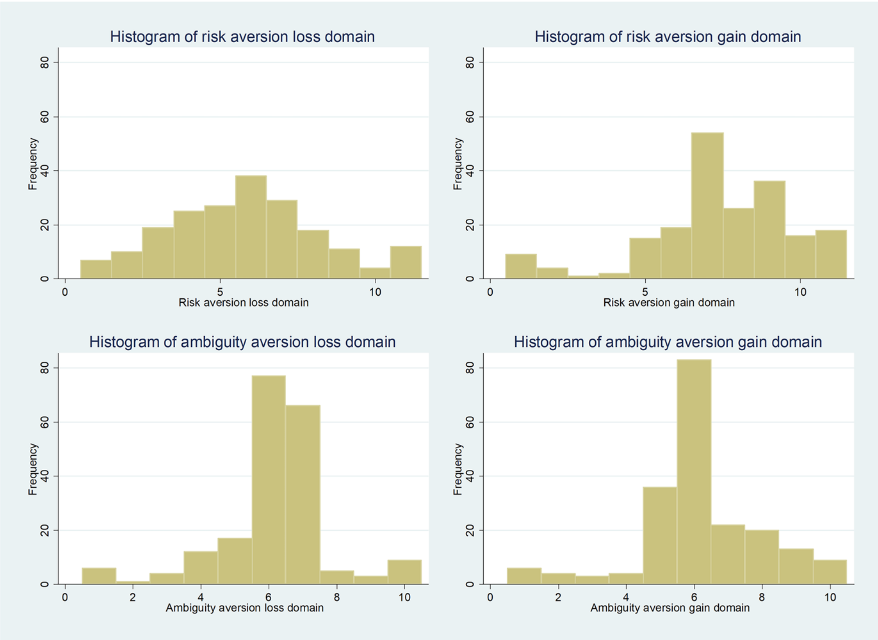

Fig. 2 Distributions of risk and ambiguity preferences in the gain and loss domain with the MPL tasks. Higher values represent more risk and ambiguity aversion; 1 means a switch from left to right in the first row (very risk or ambiguity seeking) and 11 or 10 means a subject never switches (very risk or ambiguity averse, respectively); risk neutral = 6 for risk aversion loss domain, and = 7 for risk aversion gain domain; the ambiguity neutral switching point is on decision line 6 in the loss domain, and decision line 5 in the gain domain

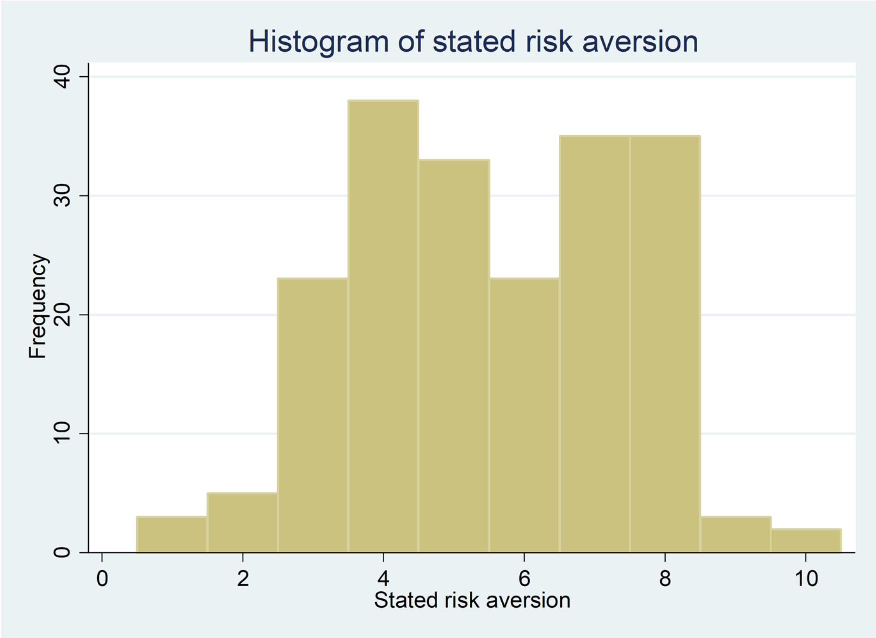

Fig. 3 Distribution of stated risk preference. Higher values represent more risk aversion

Appendix 3 Results from additional analyses

Table 9 Random effects Probit regression of variables of influence on flood insurance purchases with risk and ambiguity preferences elicited in the loss domain

	Pooled				Risky full vs. certain half				Risky full vs. ambiguous full			
	MPL		Stated		MPL		Stated		MPL		Stated	
Variable	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Flooding probability = 0.001	0.17	0.09	0.17	0.07	0.13	0.01	0.13	0.24	0.14	-0.25	0.14	-0.14
	(0.12)	(0.31)	(0.12)	(0.15)	(0.16)	(0.40)	(0.16)	(0.21)	(0.20)	(0.66)	(0.20)	(0.27)
	0.04		*0.04*		*0.03*		*0.03*		*0.04*		*0.04*	
Flooding probability = 0.01	0.24***	0.06	0.24***	0.12	0.29**	0.04	0.29**	0.28*	-0.13	0.18	0.17	-0.05
	(0.09)	(0.23)	(0.09)	(0.12)	(0.13)	(0.29)	(0.13)	(0.16)	(0.15)	(0.52)	(0.15)	(0.19)
	*0.06****		*0.06****		*0.08***		*0.08***		*0.04*		*0.04*	
Loading factor = 0.5	1.52***	1.52***	1.52***	1.52***	1.40***	1.40***	1.40***	1.41***	1.67***	1.68***	1.67***	1.69***
	(0.09)	(0.09)	(0.09)	(0.09)	(0.15)	(0.15)	(0.15)	(0.15)	(0.14)	(0.14)	(0.14)	(0.15)
	*0.40****		*0.40****		*0.37****		*0.37****		*0.43****		*0.44****	
Loading factor = 0.75	1.18***	1.18***	1.18***	1.18***	1.09***	1.09***	1.09***	1.10***	1.27***	1.28***	1.27***	1.29***
	(0.08)	(0.08)	(0.08)	(0.08)	(0.11)	(0.11)	(0.11)	(0.11)	(0.12)	(0.12)	(0.12)	(0.13)
	*0.31****		*0.31****		*0.29****		*0.29****		*0.33****		*0.33****	
Loading factor = 1	0.88***	0.88***	0.88***	0.88***	0.68***	0.68***	0.68***	0.68***	1.08***	1.09***	1.08***	1.10***
	(0.07)	(0.07)	(0.07)	(0.07)	(0.10)	(0.10)	(0.10)	(0.10)	(0.11)	(0.11)	(0.11)	(0.11)
	*0.23****		*0.23****		*0.18****		*0.18****		*0.28****		*0.28****	
Certain half	-0.42**	-0.42**	-0.35**	-0.35**								
	(0.17)	(0.17)	(0.16)	(0.16)								
	*-0.11***		*-0.09***									
Risky full	-0.42**	-0.42**	-0.35**	-0.35**	0.01	-0.06	0.01	-0.04	-0.29***	0.48	-0.29***	0.49
	(0.16)	(0.16)	(0.16)	(0.16)	(0.09)	(0.19)	(0.09)	(0.10)	(0.09)	(0.35)	(0.09)	(0.35)
	*-0.11***		*-0.09***		*0.00*		*0.00*		*-0.08****		*-0.08****	

Table 9 (continued)

	Pooled				Risky full vs. certain half				Risky full vs. ambiguous full			
	MPL		Stated		MPL		Stated		MPL		Stated	
Variable	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Ambiguous full	-0.15	-0.15	-0.08	-0.08								
	(0.17)	(0.17)	(0.17)	(0.17)								
	-0.04		*-0.02*									
Risk aversion loss domain	0.00	-0.01			0.06	0.03			-0.04	-0.08		
	(0.03)	(0.03)			(0.04)	(0.04)			(0.05)	(0.07)		
	0.00				*0.02*				*-0.01*			
Stated risk aversion dummy			0.47***	0.32**			0.45*	0.47*			0.41*	0.06
			(0.14)	(0.16)			(0.25)	(0.28)			(0.23)	(0.26)
			*0.12****				*0.12**				*0.11***	
Ambiguity aversion loss domain	0.01	0.01	0.00	-0.00	0.06	0.06	0.07	0.07	-0.09	-0.02	-0.09	-0.02
	(0.04)	(0.04)	(0.04)	(0.04)	(0.06)	(0.06)	(0.06)	(0.06)	(0.07)	(0.08)	(0.08)	(0.08)
	0.00		*-0.00*		*0.02*		*0.02*		*-0.02*		*-0.02*	
Flooding probability = 0.001 × risk aversion loss domain		0.01				0.02				0.07		
		(0.05)				(0.07)				(0.10)		
Flooding probability = 0.01 × risk aversion loss domain		0.03				0.05				0.05		
		(0.04)				(0.05)				(0.08)		
Flooding probability = 0.001 × stated risk aversion dummy				0.22				-0.28				0.62
				(0.23)				(0.33)				(0.41)
Flooding probability = 0.01 × stated risk aversion dummy				0.26				0.04				0.48*
				(0.17)				(0.26)				(0.29)
Risky full × risk aversion loss domain						0.01						
						(0.03)						

Table 9 (continued)

	Pooled				Risky full vs. certain half				Risky full vs. ambiguous full			
	MPL		Stated		MPL		Stated		MPL		Stated	
Variable	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**M10**	**M11**	**M12**
Risky full × stated risk aversion dummy								0.12				
								(0.20)				
Risky full × ambiguity aversion loss domain										-0.12**		-0.13**
										(0.05)		(0.05)
Order	0.11*	0.11*	0.11*	0.11*	0.01	0.01	0.01	0.00	0.22**	0.24***	0.22**	0.24***
	(0.06)	(0.06)	(0.06)	(0.07)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)
	*0.03**		*0.03**		*0.00*		*0.00*		*0.06***		*0.06***	
Constant	-0.78	-0.70	-1.06*	-1.00*	-2.62**	-2.46**	-2.70**	-2.71**	0.13	-0.05	-0.01	-0.26
	(0.57)	(0.58)	(0.58)	(0.57)	(1.22)	(1.24)	(1.24)	(1.25)	(1.00)	(1.02)	(0.95)	(0.97)
Observations	4176	4176	4176	4176	1800	1800	1800	1800	1752	1752	1752	1752
Subjects	200	200	200	200	75	75	75	75	73	73	73	73

Dependent variable: insurance purchase. Model coefficients are shown and standard errors are reported in parentheses clustered by subject. The average marginal effects are displayed in italicized text in regressions that contain main effects only. *, ** and *** indicate significance at the 10, 5 and 1% level respectively. Regressions control for gender, age, being Dutch, flood risk perceptions and perceptions about government compensation. Model 1 (M1) is a pooled regression model of the influence of the flood probability, loading factor, government compensation versions, risk aversion and ambiguity aversion (both elicited in the loss domain with the multiple price list (MPL) measures) on insurance purchase. Model 2 (M2) adds to M1 interaction terms between the flood probability and risk aversion. Model 3 (M3) and model 4 (M4) implement the same analysis as M1 and M2 respectively, except the stated measure of risk aversion is used instead of the MPL measure. Model 5 (M5) investigates subjects who faced both risky full government compensation and certain half, and the effect of the former relative to the latter on insurance purchase. Model 6 (M6) adds to M5 interaction terms between the flood probability and risk aversion, as well as risky full government compensation and risk aversion (elicited in the loss domain with the MPL measure). Model 7 (M7) and model 8 (M8) implement the same analysis as M5 and M6 respectively, except the stated measure of risk aversion is used instead of the MPL measure. Model 9 (M9) investigates subjects who faced both risky full government compensation and ambiguous full, and the effect of the risky version relative to the ambiguous version on insurance purchase. Model 10 (M10) adds to M9 interaction terms between the flood probability and risk aversion, and between the degree of ambiguity in government compensation and ambiguity aversion (both risk and ambiguity aversion are elicited in the loss domain with the MPL measures). Model 11 (M11) and model 12 (M12) implement the same analysis as M9 and M10 respectively, except the stated measure of risk aversion is used instead of the MPL measure. An order variable is included in all models to control for the effect of being presented with a version of the government compensation first

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