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Abstract

This paper looks at the scope for individual adaptation to flood risk in the South of France. From a survey of 418 respondents in two flood-prone areas, we collected data on the adoption of individual adaptation measures and the willingness to pay for individual and collective measures. First, we study the determinants of adoption and of the willingness to pay. We then compare willingness to pay for individual versus collective measures. We end with a cost-benefit analysis of individual adaptation. Results show a willingness to pay for adaptation measures, although few have yet been adopted. Perceptions of hazards and damage have different influences: the first favours the adoption of measures, the second increases the willingness to pay for measures. Finally, the cost-benefit analysis suggests that completely dry proofing a house up to a certain height may not be economically viable. This calls for the promotion of cheaper and potentially more cost-efficient measures.

Keywords: contingent valuation; cost-benefit analysis; damage mitigation; dichotomous choice; individual adaptation; flood; France; willingness to pay
JEL Classification: Q54; Q51

Word count: excluding figures and tables 5263
Data availability statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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1 Introduction

In France floods are considered the main natural hazard, with 70% of municipalities at risk. Of the risk-reduction tools available, adaptions at the household level have received greater attention in recent decades. Measures, such as erecting flood barriers, raising electrical fittings and protecting valuables (e.g. upstairs) appear to be effective and relatively low-cost options (Bubeck, Botzen, Kreibich and H. Aerts, 2012; Kreibich et al., 2005, 2011, 2015). We refer to these as individual adaptation measures (Erdlenbruch and Bonté, 2018; Richert, Erdlenbruch and Grelot, 2019) as opposed to collective mitigation measures.[1] This paper investigates willingness to reduce flood risks at the household level. We look at the adoption of measures and assess the willingness to pay for further measures.

A vast literature has focused on the determinants of individual adaptation measures. For example, Osberghaus (2015) conducted a nation-wide study of 4200 households in Germany and found that adaptations such as adapted building use, structural measures and flood barriers were especially made when individuals had experienced flooding and believed that damage would increase in the future as a result of climate-change. Direct experience was also found to be important in several other, smaller case studies, e.g. Grothmann and Reusswig (2006); Richert et al. (2017). Bubeck, Botzen and Aerts (2012); Bubeck et al. (2013) stressed the importance of coping appraisal as a determinant of adaptation decisions[2] in line with other studies based on the protection motivation theory (Grothmann and Reusswig, 2006; Reynaud et al., 2013; Richert et al., 2017). For instance, in a survey of 752 German households exposed to flood risk along the river Rhine, Bubeck, Botzen and Aerts (2012); Bubeck et al. (2013) showed that 'self-efficacy' is a significant factor in the implementation of structural measures and flood barriers, and that 'response efficacy' is significant in explaining the implementation of flood-adapted building use and flood barriers. Risk perception plays a minor role. Bubeck, Botzen, Suu and Aerts (2012) studied the role of risk perception in adaptation decisions by distinguishing two aspects: perceived probability and perceived consequences. They showed that both are weak predictors of the intention to adopt measures. Interestingly, they found that the variable 'perceived consequences' is a strong predictor of the demand for flood mitigation policies in general. Finally, there are various studies showing the importance of socio-demographic variables, such as home-ownership, education and income (Grothmann and Reusswig, 2006; Richert et al., 2017).

Although individual adaptation measures can be cost-efficient (Bubeck, Botzen, Kreibich and H. Aerts, 2012; Kreibich et al., 2005, 2011, 2015; Owusu et al., 2015; Poussin et al., 2012, 2015; Richert, Erdlenbruch and Grelot, 2019; Sairam et al., 2019), many factors can prevent their adoption such as underestimating the likelihood of flooding, focusing on the short-term, financial constraints, or relying on governmental assistance, as discussed in Kunreuther (2006). Other concerns include expense, aesthetics and the idea that flood protection should be provided by the state(Owusu et al., 2015; Kazmierczak and Bichard, 2010), as well as feeling protected by collective flood mitigation (Richert, Erdlenbruch and Grelot, 2019). Whether there is a general demand for more individual adaptation measures and for policies to broaden their implementation (Grothmann and Reusswig, 2006; Owusu et al., 2015) can be tested through stated preference methods.

Stated preference methods, particularly contingent valuation (Carson, 2012), have been used to assess a variety of collective flood-mitigation policy approaches (Glenk and Fischer, 2010; Champonnois and Chanel, 2016; Champonnois, 2018; Chanel et al., 2016; Kuo, 2016). Indeed, willingness to pay (WTP) may express a monetary expected benefit (increased land-use value) or other benefit (reduced anxiety and community disruption), as discussed in Thunberg and Shabman (1991). For example, Champonnois and Chanel (2016) used contingent valuation to estimate the WTP of French households for a collective flood-protection scenario and an insurance scenario. They found mean WTP of 93 euros for the collective scenario and 100 euros for the insurance scenario (with maximum values at 1,500 euros and 1,300 euros respectively).

Valuation studies on the benefits of individual adaptation are scarce (Botzen et al., 2009; Kazmierczak and Bichard, 2010; Kuo, 2016; Owusu et al., 2015). Kazmierczak and Bichard (2010) estimated WTP for individual adaptation measures in flood-prone areas in England. They found median WTP values of less than 100 pounds (although 10% of the respondents were willing to pay more than 1,000 pounds). Moreover, they found no significant difference in WTP between people who had been flooded previously

[1] Alternative names found in the literature are precautionary measures (Grothmann and Reusswig, 2006; Kreibich et al., 2015), (damage) mitigation measures (Botzen et al., 2009; Bubeck, Botzen, Suu and Aerts, 2012; Bubeck et al., 2013) and property-level flood protection (Owusu et al., 2015).

[2] Coping appraisal is defined in protection motivation theory as whether individuals believe the recommended behaviour to be efficient ('response efficacy') and that they can successfully enact this behaviour ('self-efficacy'). For our purposes, this means selecting appropriate adaptation measures and implementing them in the home.

and those who had not. Owusu et al. (2015) studied WTP for individual adaptation measures in Scotland among households living in flood-prone areas. They reported slightly lower means for those who had previously been flooded (734 pounds) than for those who had never been flooded (834 pounds). The main determinants of a willingness to pay for flood-mitigation policies found in the literature are income, home-ownership, objective measures of flood risks, flood experience and risk perception (see the literature review in Champonnois and Chanel (2016)).

Botzen et al. (2009) used a choice experiment to evaluate Dutch households' willingess to pay for individual adaptation measures in exchange for reduced insurance premiums. They found that households would consider adopting low-cost, potentially effective measures: 68% were willing to buy sandbags for a cost of 20 euros in exchange for a 5 euro discount on their annual premium (the mean WTP for flood insurance was 120 euros per year). Similarly, 24% of the sample would move central-heating boilers to a higher floor, for a discount of 10 euros. However, such moves would only protect against relatively small floods. In this study sandbags were expected to prevent water from entering homes in 60% of all cases in one scenario and 30% in another scenario. On the other hand, Botzen et al. (2013) found that households were willing to make a substantial investment if the flood risk could be eliminated entirely. In their study of over 400 Dutch households 52% of homeowners were willing to spend up to 10,000 euros to elevate a new house to a safe level. They estimate the 'safety premium' that individuals place on risk elimination at between 35 and 45 euros per month.

This paper assesses the willingness of households in the South of France to reduce flood risk. First we analyse the extent of individual adaptations and their determinants, and whether other measures are planned. We then use stated preferences to test whether people are in favour of further flood mitigation and adaptation measures. In particular, we reveal whether people would be in favour of individual adaptation measures if they were implemented collectively. Finally, we compare the WTP of individually targeted adaptations to that of collective mitigation measures.

The paper is organised as follows: in section 2 we present the survey and the context in which it took place. In section 3 we provide descriptive statistics of the main variables and identify the determinants of individual adaptation and the willingness to pay for individual and collective protective measures. In section 4 we perform a cost-benefit analysis based on our survey and some results from the literature. In section 5 we discuss the scope for flood mitigation and adaptation measures in France and conclude.

2 Presentation of the study area and survey

2.1 Study area and survey method

We conducted our survey in two departments in the South of France: the Var and Haute-Garonne (see figures 1 and 2). The Var is an area at high risk of flooding. Floods in 2010 (15-16 June) caused extensive damage (around 1 billion euros) and left 25 dead. These were followed by another major flood in 2011 (4-10 November). Bagnères de Luchon, and the surrounding areas in the Haute-Garonne, suffered a flash flood in 2013 that also caused significant damage.

A total of 418 interviews were carried out in spring 2019 across 10 municipalities, of which, 6 were in the Var - Draguignan, Le Muy, Les Arcs, Trans-en-Provence, Taradeau and Vidauban - and 4 were in the Haute-Garonne department - Bagnères de Luchon, Montauban de Luchon, Saint-Mamet and Juzet de Luchon. Face-to-face interviews took place in the respondents' homes. The selection of respondents was made by random walk.

The questionnaire was divided into sections as follows: the sociodemographic features of the household, the type of property, flood experience, attitudes to risk and time, flood-risk perception, individual adaptations and the willingness to pay for individual adaptation and collective protection measures. Our paper focuses on the degree of individual adaptation, its determinants and on the willingness to pay for individual and collective adaptation.

2.2 Flood-prevention policy in France

To evaluate the scope for further adaptation and mitigation, it is useful to give a quick overview of some of the existing flood-prevention measures in France.

First, the national disaster compensation scheme (the CatNat system) provides cover to the majority of citizens through a compulsory surcharge of 12% on their home insurance premium. This entitles them to compensation for damage caused by various natural disasters, provided that the event is recognised

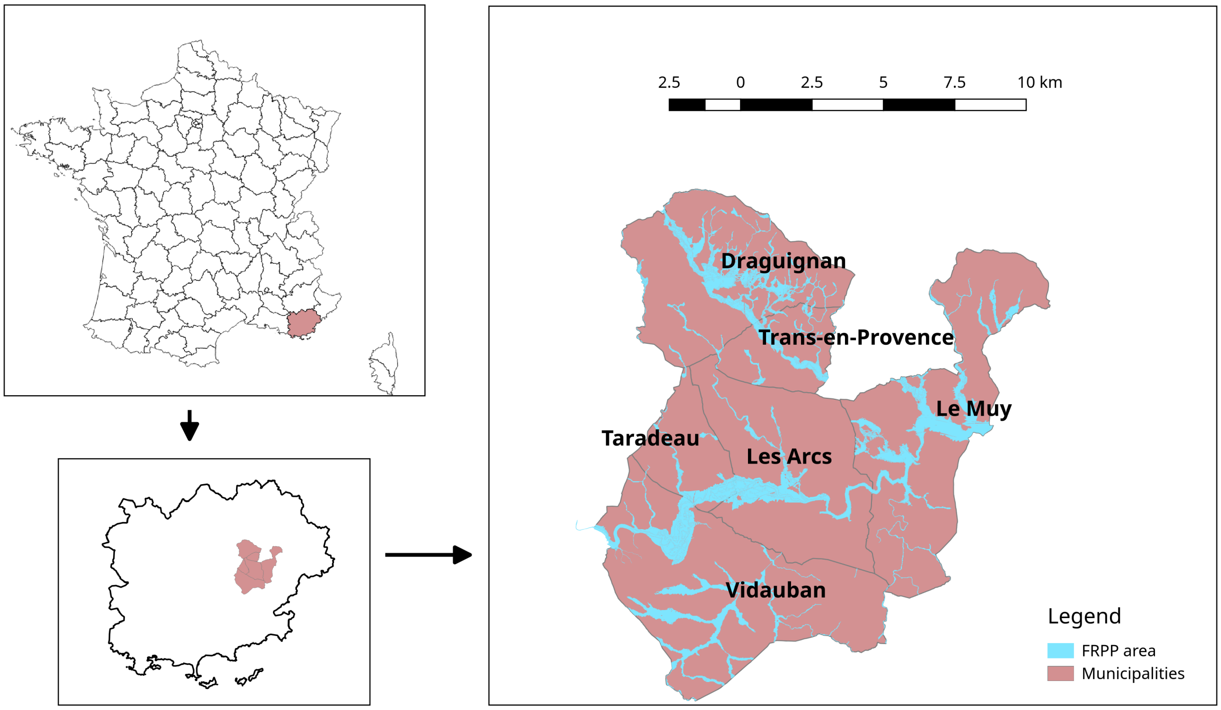

Figure 1: Surveyed municipalities in the Var

officially as such. The average contribution to this system is smaller than 20 euros per household per year (see Grislain-Letrémy and Peinturier (2010); Richert, Boisgontier and Grelot (2019) for further details).

Second, flood-prone areas are provided with Flood Risk Prevention Plans (FRPPs). These are in two parts: a map of the at risk area (usually determined by to the worst historical flood and the 100-year flood) and a regulatory document specifying the extent to which new construction is allowed and whether specific individual adaptation measures are recommended or mandatory in each area (Richert, Erdlenbruch and Grelot, 2019). Each municipality in our study area has an FRPP: the plans for the Var were drawn up in 2010, following a major flood event, and approved in 2014. In the Haute-Garonne they were drawn up in 1997 and approved in 1999. Certain individual adaptations are either recommended or compulsory within the FRPPs and are subsidised by the government. Prior to 2020 40 % of the costs could be recovered. However, these subsidies are rarely requested and there are no incentives from insurers to implement them (see also Thieken et al. (2006)). From 2020 80 % of the costs can be recovered.

Third, most local flood-prevention policies are part of the so-called Flood Prevention Action Programmes, or PAPIs. These are policy packages designed locally and selected for financial support by the government following competitive bidding (see Erdlenbruch et al. (2009) for greater detail). The local water manager can choose the strategies they implement such as restoring natural flood plains, erecting dykes, or reducing individual vulnerability. In the study areas of the Var the latest PAPI covers the period 2016-2022. In total 96 million euros were allocated to flood-prevention measures, of which 90.5 million was for investment in flood-mitigation and over 1.3 million to actions that reduce vulnerability. Included in the PAPI were recommendations for individual adaptation measures based on expert assessments of each property, although these had yet to be carried out at the time of our study.

Finally, within a general reform of flood- and water-management policy in France, greater responsibility has been granted to local authorities since 2018. According to a new law local water managers can levy an additional tax of up to 40 euros per year and per resident for flood and water management. At the time of our study this tax was being discussed but had not yet been brought in in our case study areas.

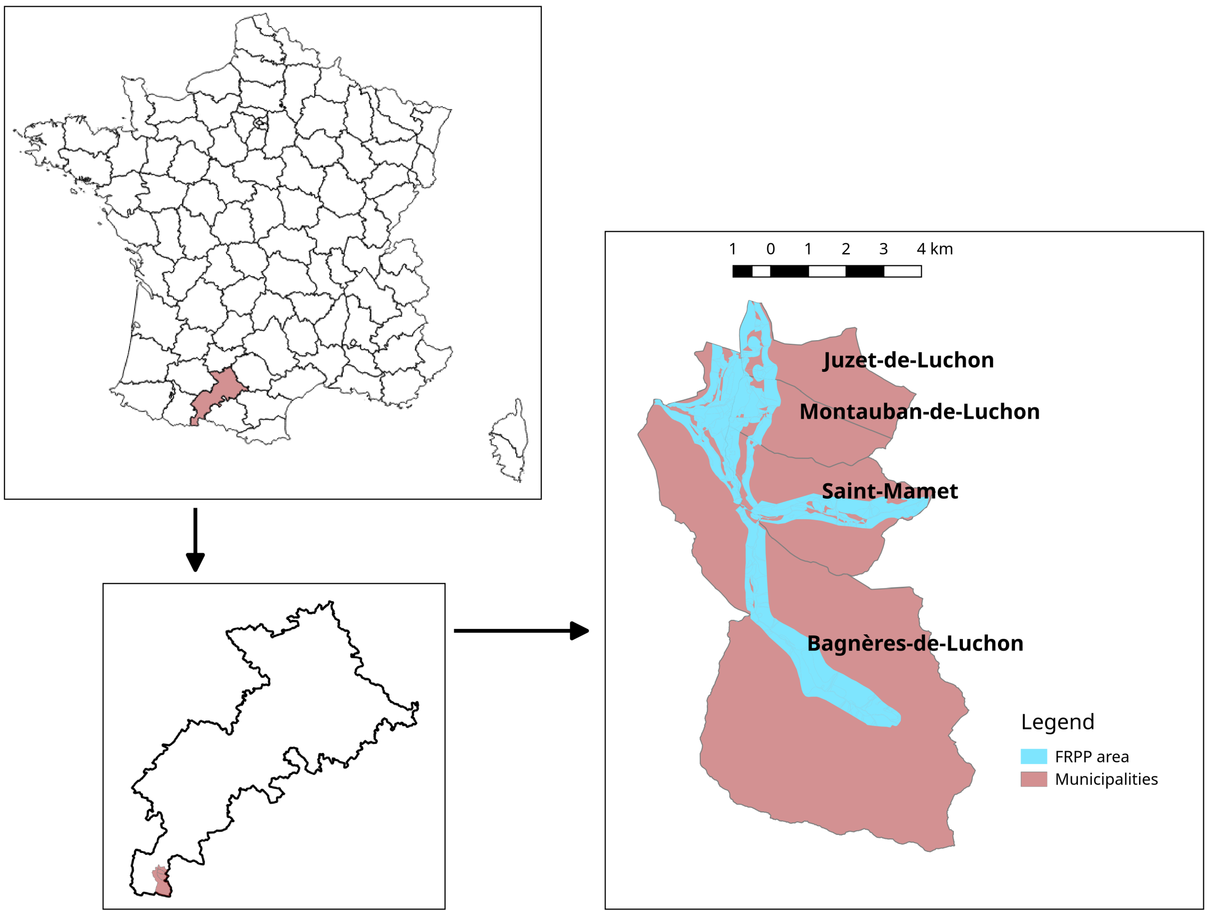

Figure 2: Surveyed municipalities in the Haute-Garonne

Variable	Description
Risk perception	'Do you live in a flood area?' (Yes/No/Don't know)
Flood experience	'Have you already experienced a flood?'
Age	Age of the respondent
Household size	Number of persons in the household
Education	Education level of the respondent
Income	Individual income of the respondent
Risk perception	'What is the likelihood of a flood below one metre in your street in the next ten year'
Damage perception	'If your house was flooded, would there be important damage ?'
Measure installed	At least one individual protection measure was installed by the household
Within FRPP	Property located in an FRPP area
Duration since installation	Number of years since installation
Owner	Household is the owner of the property
Var	Property in the Var department
Responsibility	Responsibility of flood protection (state authority, individuals, everyone)
WTP individual	WTP for the individual scenario
WTP collective	WTP for the collective scenario

Table 1: Description of the variables

2.3 Individual adaptation measures

We asked respondents about specific individual adaptation measures: slot-in flood barriers, sewer non-return valves, main rooms and valuables placed upstairs, and electrical fittings set higher up the walls. These are the most common measures, according to previous surveys by Richert et al. (2017). We also asked respondents if they had taken any other measures. Effort to improve water flow, pumps and manholes were each mentioned several times.

2.4 Willingness to pay for individual and collective measures

We asked respondents about their willingness to pay for individual and collective adaptations. The scenarios are presented in the Appendix. The first proposes the implementation of collective flood-protection measures and the second proposes expert assessment and implementation of individual protective measures in the at-risk properties. Both scenarios are equally efficient in terms of avoiding damage to the property: they would both prevent damage if the water in the street were to remain below one metre. The main difference between the two scenarios is that the individual scenario prevents water from entering the properties while the collective scenario prevents water from flooding the streets at all (including the properties). The payment vehicle is the same, namely a compulsory local tax. Therefore, both WTP amounts should be comparable and informative as to the relative preference for individual and collective adaptation.

Regarding the design of the willingness to pay question we followed the most recent guidelines in stated preference surveys (Johnston et al. (2017)). The elicitation format is a dichotomous choice with bids randomly chosen among the following values: 10, 30, 50, 80, 100 and 130 euros (there is one draw per scenario). This format is recommended because it is incentive compatible. The payment vehicle considered is a local tax, which is binding (non-voluntary), as is also required for incentive compatibility and to prevent free riding. The availability bias was reduced because the scenario was close to the real policy context, in which the introduction of a local tax for flood-mitigation was in process.

The stated preference literature finds that respondents do not always state their true value for the good or service in question. It is therefore usual to check whether respondents stated a protest answer, i.e. that they reject (protest against) some aspect of the proposed scenario. We asked what motivated the answer with an open question in order not to influence the response with the proposition of answers. Following the literature, we group responses, such as 'I don't trust the institutions', 'it's not me who should pay', 'I don't have enough information', 'I pay too much tax' and classify them as protest responses. There are 45% and 47% of protest respondents for the individual and collective scenarios respectively.

3 Results

3.1 The dataset

The main variables used in our study are summarised in Table 1. Table 2 shows summary statistics of these variables. The average respondent is 60 years old, is an owner of their property, has lived in their property for 17 years and is in a household of 2 or 3 persons. Most of the respondents (74%) have prior experience of flooding, although only a third live in an area with a Flood Risk Prevention Plan (FRPP).

	Mean	SD	Median	Min	Max	N
Age	59.40	18.28	63	19	95	343
Household size	2.34	1.14	2	1	6	343
Owner	0.80	0.40	1	0	1	343
Risk perception	1.36	1.54	1	0	5	343
Damage perception	0.24	0.43	0	0	1	343
Within FRPP	0.32	0.47	0	0	1	343
Resp. of the state authority	0.43	0.50	0	0	1	343
Resp. of everyone	0.08	0.27	0	0	1	343
Flood experience	0.74	0.44	1	0	1	343
Duration since installation	17.11	16.53	12	0	83	343
Order scenario	0.46	0.50	0	0	1	343
Income < 1000	0.08	0.27	0	0	1	343
Income 1000 - 1700	0.19	0.39	0	0	1	343
Income 1700 - 2500	0.15	0.36	0	0	1	343
Income 2500 - 4000	0.05	0.22	0	0	1	343
Income 4000+	0.03	0.16	0	0	1	343
Education 1	0.23	0.42	0	0	1	343
Education 2	0.22	0.42	0	0	1	343
Education 3	0.22	0.41	0	0	1	343
Education 4	0.33	0.47	0	0	1	343

Table 2: Descriptive statistics

3.2 Individual adaptation measures

40% of the respondents live in elevated accommodation (with raised floor or crawl space) and are therefore better protected against flooding. However, this does not seem to have been an active choice, since respondents rarely took flood risk into account when choosing their property. As shown in our dataset, flood risk had a greater influence on property choice prior to 1960, but the receded in the period from 1960 to 2000, only reappearing in 2010.

	Present	Planned	Neither present nor planned	Don't know
Valuables upstairs	10	0	404	4
Flood barriers	11	1	365	41
Sewer non-return valves	10	1	358	49
Improving water flow	4	0	414	0
Electrical fittings higher up the walls	26	0	388	4
Pumps	7	0	411	0
Manhole	3	0	0	415
Others	9	2	0	407
Total average	5.5	0.375	302	5.625

Table 3: Individual adaptation measures

	Someone else before you moved in	Your household	Don't know
Valuables upstairs	0.10	0.90	0.00
Flood barriers	0.10	0.90	0.00
Sewer non-return valves	0.50	0.50	0.00
Improving water flow	0.00	1.00	0.00
Electrical fittings higher up the walls	0.48	0.48	0.04
Pumps	0.14	0.86	0.00
Manhole	0.33	0.67	0.00
Others	0.14	0.82	0.05
Total	0.26	0.71	0.02

Table 4: Who took the decision to install?

	No	Yes
because it is up to the authorities to protect people from floods	0.99	0.01
because it is too expensive	0.98	0.02
because floods are rare	0.83	0.17
because your property is already well protected	0.98	0.02
because you are a tenant and it is not your responsibility	0.81	0.19
because you do not have time	0.99	0.01
because you are not exposed to flood risk	0.63	0.37
because you feel inadequately informed about protection measures	0.98	0.02
because you are thinking of moving soon	0.99	0.01
because you think it would be ineffective in the event of a flood	0.97	0.03
because you think it would not do much good in the event of a flood	0.97	0.03

Table 5: Reasons for not installing adaptation measures (whole sample)

As shown in Table 3, only a few individual adaptation measures were present in the households surveyed. Overall, 14% of respondents have individual adaptation measures to reduce their vulnerability at home, of which most common is having placed electrical fittings higher up the walls. Table 4 shows that this was most commonly undertaken by the respondent's household. Overall, 9% of respondents have adopted measures themselves. Almost no respondent has further action planned. This is perhaps due to the fact that the last major floods (2010 for the Var and 2013 for the Haute-Garonne) took place several years ago. Indeed, as shown in our dataset there was a peak in the adoption of new measures in the Var immediately after the 2010 flood, and then a rapid decrease to very low levels.

Two main factors explain why the respondents do not take protective measures. First, they feel that their accommodation is not at risk and/or they think that floods are rare. However, a third of respondents state that their accommodation was in a flood-prone area (Table 5). Moreover, Table 6 shows that even among those actually living in a flood-prone area (defined here as lying in an FRPP area) reasons such as 'floods are rare' or 'my property is not exposed' are still the most commonly cited. This suggests a discrepancy between flood-risk perception and official information about this risk.

We estimated probit models to analyse the determinants of adoption. Results are given in Table 11. The analysis shows that the main determinants of adaptation are having experienced a flood and the perception of risk, both having a positive effect on individual adaptation. Although not displayed here, when we use the discrete specification of the risk-perception variable we find that only residents with a very acute perception of risk adopt further measures.

The effect of coping appraisal, which is often found to be an important determinant of adaptation in the literature, was not found to be significant here and so was not included in our results. (We measured coping appraisal by the strenght of rejection of the statement: 'I don't think I will be able to avoid the consequences of flooding in my home. I don't have enough understand of the subject', see Grothmann and Reusswig (2006).)

	No	Yes
because it is up to the authorities to protect people from floods	0.99	0.01
because it is too expensive	0.97	0.03
because floods are rare	0.80	0.20
because your property is already well protected	0.96	0.04
because you are a tenant and it is not your responsibility	0.89	0.11
because you don't have time	0.98	0.02
because you are not exposed to flood risk	0.65	0.35
because you feel inadequately informed about protection measures	0.98	0.02
because you are thinking of moving soon	0.98	0.02
because you think that it would be ineffective in the event of a flood	0.96	0.04
because you think it would not do much good in the event of a flood	0.97	0.03

Table 6: Reasons for not installing adaptation measures (respondents in FRPP area)

	No	Yes	Did not answer
10	0.15	0.77	0.08
30	0.63	0.31	0.06
50	0.58	0.34	0.08
80	0.69	0.25	0.06
100	0.72	0.25	0.04
130	0.81	0.16	0.03

Table 7: Proportion of respondents accepting to pay given the proposed amount: individual scenario

	No	Yes	Did not answer
10	0.24	0.71	0.05
30	0.37	0.56	0.07
50	0.50	0.41	0.09
80	0.67	0.25	0.08
100	0.75	0.16	0.10
130	0.82	0.13	0.05

Table 8: Proportion of respondents accepting to pay given the proposed amount: collective scenario

3.3 Willingness to pay for individual and collective measures

Tables 7 and 8 show the proportion of respondents who accept to pay, given the proposed amount, for the individual and collective scenarios. As expected, the share decreases monotonically as the amount increases.

As shown in Table 9, the mean willingness to pay for the whole sample is 35 euros for the individual scenario and 46 for the collective scenario. When we remove the respondents with a protest attitude, the mean WTP increases to 95 euros for the individual scenario and 91 euros for the collective scenario (Table 9). Recall that the main difference between the two scenarios is that the individual scenario prevents water from entering the home, while the collective scenario prevents water from flooding the streets at all(including the homes). The impact on the respondent's home is the same in each scenario and the number of protest responses is similar (around 45%).

	Individual scenario	Collective scenario
Whole sample	34.89	45.92
Without protests	94.28	90.85
Without protests who refuse to contribute	99.93	95.09

Table 9: Mean WTP

	Individual scenario	Collective scenario
Whole sample	32.54	42.03
Without protests	113.97	98.23
Without protests who refuse to contribute	120.23	105.84

Table 10: Mean WTP, respondents in FRPP area

According to Table 10, the willingness to pay increases when we focus only on respondents in the FRPP area, albeit not to a great extent. This increase applies only for non-protest respondents, and even decreases slightly for the whole sample. This is because the share of protest respondents is greater in the FRPP area (e.g. for the individual scenario, there are 60% of protests among the respondents living in the FRPP area but only 46% outside the area). This is a surprising result given that respondents whose homes are at greater risk have more to gain from adaptation.

	Adoption	WTP collective scenario	WTP individual scenario
(Intercept)	$-4.35\ (1.10)^{***}$	-0.17 (0.84)	-0.38 (0.76)
Age	0.01 (0.01)	-0.01 (0.01)	-0.00 (0.01)
Household size	0.14 (0.12)	-0.02 (0.10)	0.11 (0.09)
Education 2	0.08 (0.36)	$0.71\ (0.31)^{*}$	0.14 (0.28)
Education 3	-0.15 (0.39)	$0.84\ (0.32)^{**}$	0.31 (0.29)
Education 4	0.21 (0.35)	$0.82\ (0.31)^{**}$	0.39 (0.27)
Income 1000 - 1700	-0.13 (0.48)	0.30 (0.39)	0.06 (0.35)
Income 1700 - 2500	-0.00 (0.49)	0.50 (0.42)	0.34 (0.38)
Income 2500 - 4000	0.59 (0.59)	$1.10\ (0.51)^{*}$	0.37 (0.48)
Income 4000+	-0.17 (0.78)	1.19 (0.61)	0.62 (0.55)
Income_na	0.11 (0.43)	0.37 (0.38)	-0.09 (0.33)
Owner	0.78 (0.43)	-0.30 (0.26)	0.01 (0.24)
Risk perception	$0.20\ (0.08)^{*}$	-0.06 (0.07)	-0.01 (0.06)
Damage perception	0.12 (0.30)	0.47 (0.25)	$0.63\ (0.24)^{**}$
Within FRPP	$-0.58\ (0.29)^{*}$	-0.12 (0.22)	-0.06 (0.21)
Resp. of the state authority	0.26 (0.56)	0.20 (0.41)	0.21 (0.38)
Resp. of everyone	0.44 (0.54)	0.37 (0.40)	0.51 (0.37)
Flood experience	$1.05\ (0.49)^{*}$	0.28 (0.24)	0.08 (0.23)
Duration since installation	-0.01 (0.01)	-0.00 (0.01)	-0.00 (0.01)
Order_scenario	-0.08 (0.23)	0.25 (0.19)	-0.32 (0.18)
Bid_coll		$-0.02\ (0.00)^{***}$	
Bid_indiv			$-0.01\ (0.00)^{***}$
AIC	201.00	298.90	337.27
BIC	272.97	373.19	411.88
Log Likelihood	-80.50	-128.45	-147.63
Deviance	161.00	256.90	295.27
Num. obs.	270	254	258

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

Table 11: Probit model

Due to the binary nature of the WTP variable, we estimated probit models to study determinants of the willingness to pay, as shown in Table 11. The regression analysis shows that education, individual income and the perception of the damage to the home that a flood would cause all positively affect the WTP in the collective scenario.[3]

The perception of damage also positively affects the WTP in the individual scenario. This determinant is a measure of the vulnerability of the property. It is interesting to note that the hazard is a determinant of adaptation behaviour and the vulnerability is a determinant of WTP. It is clear that the respondents have taken into account the amount offered to them, because the proportion of positive responses decreases with the amount.[4]

[3]We also estimated a model with the perception variables treated discretely to capture possible non-linearities, but the results are almost the same.

[4]The variable 'Order of scenarios' is equal to one when the collective scenario is posed first. It has a negative impact on the WTP for the individual scenario, which means that the WTP for this scenario is weaker when it is posed second.

4 Cost-benefit analysis

Here we compare the willingness to pay results with measures of cost and avoided damage of dry-proofing a home as provided in the literature.

4.1 Benefits

According to our scenario the average annual WTP for individual adaptation to prevent water from entering the property - if the water remains below one metre - is 35 euros.

With a discount rate δ of 2.5% (as in Richert, Boisgontier and Grelot (2019) and a time horizon of 30 years the discounted benefits in euros are:

$$\sum_{i=1}^{30} WTP/(1+\delta)^i = \sum_{i=1}^{30} 35/(1+0.025)^i = 733.$$

On the other hand, we can use the WTP of non-protesters, which is 100 euros, and with the same discount rate and time period, we find discounted benefits of 2093 euros. Other values of discounted benefits for different time horizons, discount rates and WTP subsets are given in Table 12.

		Discounted benefits for a household (Euros)	
Time horizon (years)	Discount rate	WTP = 35	WTP = 100
30	0.010	903	2581
50	0.010	1372	3920
30	0.025	733	2093
50	0.025	993	2836
30	0.050	538	1537
50	0.050	639	1826

Table 12: Total discounted benefits depending on time horizon, discount rate and WTP sample

Property type	Mean benefits for a dwelling (Euros)
Two storey house in France	1100
Flat in France	1100
Bungalow in France	1600

Table 13: Mean benefits from dry-proofing a property according to the literature (Richert, Boisgontier and Grelot, 2019)

One can compare our results to average values of avoided damage. Richert, Boisgontier and Grelot (2019) calculated the costs and benefits of dry-proofing based on expert assessments and numerical models of properties. One of the options they look at is dry-proofing techniques that prevent water from entering the building if it is below one metre, which corresponds with our WTP scenarios. They found the mean annual benefits of dry-proofing to be 1,600, 1,100 and 1,100 euros for a bungalow, two-storey house and a flat respectively (see Table 13). This is the order of magnitude of the WTP estimations that exclude protest answers. It is lower than the estimations of the whole sample.

4.2 Costs

Richert, Boisgontier and Grelot (2019) find that the average cost of dry-proofing a house up to one metre is 10,400 euros for a bungalow, 7,700 euros for a two storey house and 9,400 euros for a flat. The international literature proposed similar average costs for dry-proofing: 6,100 euros for an average house in Germany and 8,000 euros for a single-family house in the Netherlands (Richert, Boisgontier and Grelot, 2019) - see Table 14.

Property type	Individual costs (Euros)
House in Germany	6100
Two storey house in France	7700
House in Netherlands	8000
Flat in France	9400
Bungalow in France	10400

Table 14: Costs of dry-proofing a property according to the literature (Richert, Boisgontier and Grelot, 2019)

Municipality	Number of hh. at risk	Total number of hh.	Ratio
Bagnères-de-Luchon	925	1049	0.88
Juzet-de-Luchon	129	165	0.78
Montauban-de-Luchon	165	215	0.77
Saint-Mamet	130	246	0.53
Les Arcs	1532	3093	0.50
Draguignan	7018	17194	0.41
Le Muy	1341	4009	0.33
Taradeau	227	785	0.29
Trans-en-Provence	834	2557	0.33
Vidauban	2324	5133	0.45
Average	1462	3444	0.53

Table 15: Estimated number of households per municipality

Property type	Individual costs (Euros)	Total costs (Euros)
House in Germany	6100	8,918,200
Two storey house in France	7700	11,257,400
House in the Netherlands	8000	11,696,000
Flat in France	9400	13,742,800
Bungalow in France	10400	15,204,800

Table 16: Individual and total costs

Individual WTP (Euros)	Total WTP (Euros)
35	120,540
100	344,400

Table 17: Individual and total WTP

		Net present value for the study area (Euros)	
Time horizon (years)	Discount rate	WTP = 35	WTP = 100
30	0.010	-10,290,806	-4,513,492
50	0.010	-8,676,967	97,476
30	0.025	-10,878,730	-6,193,274
50	0.025	-9,982,874	-3,633,687
30	0.050	-11,548,672	-8,107,395
50	0.050	-11,201,098	-7,114,326

Table 18: Net present value depending on time horizon, discount rate and WTP sample

Time horizon (years)	Discount rate	WTP needed (Euros)
30	0.010	151
50	0.010	99
30	0.025	186
50	0.025	137
30	0.050	253
50	0.050	213

Table 19: WTP necessary to reach positive NPV for costs in at risk area of -13.4 million Euros

4.3 Costs and benefits

In a more complete cost-benefit analysis, we compare the total cost of dry-proofed homes in the risk area with total benefits estimated through willingness to pay in the survey area. To this end, we first estimate the average number of households at risk using data from ONRN[5], which provides the number of residents in flood-prone areas.[6] We divide the number of residents by the average household size from our survey to estimate the total number of households in the area, as displayed in Table 15. Next, we compute total costs by multiplying individual costs for dry-proofing and the total number of households at risk, as indicated in Table 16. We compute the average benefits by multiplying individual WTP by the total number of households, as displayed in Table 17.

For the cost-benefit analysis we assume an equal distribution of flats, bungalows and two-story dwellings, hence a cost of C=(11,257,400+13,742,800+15,204,800)/3=13,401,667 euros. With a discount rate δ of 2.5% (as in Richert, Boisgontier and Grelot (2019)) and a time horizon of 30 years, the net present value (NPV) using the whole sample (i.e. a willingness to pay of 35 euros) is :

$$NPV = -C + \sum_{i=1}^{30} WTP/(1+\delta)^i = -13,401,667 + \sum_{i=1}^{30} 120,540/(1+0.025)^i = -10,878,730.$$

Other results of net present values for different time horizons, discount rates and WTP subsets are given in Table 18. It is clear that net present values are nearly always negative, using standard assumptions. Only with high WTP, low discount rates and long time horizons does investment in complete individual dry-proofing prove to be efficient. This is the case for example for the sample of non-protesters, a discount rate of 1% and a time horizon of 50 years.

Alternatively, the WTP needed to make complete dry-proofing efficient could be computed. For example, for the net-present value to be greater than zero when investing in the flood-proofing of a two storey house given a discount rate of 2.5% and a time horizon of 30 years one would need a WTP of 186 euros (see Table 19). More generally, for a net-present value greater than zero the WTP would need to be of several hundred euros.

[5] the 'Observatoire National des Risques Naturels'

[6] The ONRN 'Observatoire National des Risques Naturels' is a nation-wide observatory. Flood-prone areas used here correspond to the EAIP area 'Enveloppe Approchée des Inondations Potentielles', which is larger than the FRPP area.

5 Discussion and conclusion

This study found a relatively low adoption rate of individual adaptation measures, similar to earlier findings in the literature (Kunreuther, 2006; Owusu et al., 2015; Kazmierczak and Bichard, 2010). One factor underlined in the literature was low coping appraisal (Bubeck, Botzen and Aerts, 2012; Bubeck et al., 2013). However, our measure of coping appraisal did not have a significant effect on the adoption variable. Moreover, in our willingness-to-pay scenario the assessment, purchase and installation of adaptation measures are not made by the respondents, so coping appraisal should not play a role in this decision. Thus, low coping does not explain the low willingness to adopt measures in France.

Another reason for low adoption rates is the relative low cost-efficiency of individual adaptation in France. Even when respondents have a positive WTP for dry-proofing their house, it seems quite low compared to the cost. Indeed, given a time horizon of thirty years and a discount rate of 0.25, our highest WTP estimates (without protesters) is one third of what would be needed to cover the lowest cost estimate. This result suggests that dry-proofing might not be economically sound for residents in the surveyed area. This contrasts with many findings in the literature (Bubeck, Botzen, Kreibich and H. Aerts, 2012; Kreibich et al., 2005, 2011, 2015; Owusu et al., 2015; Poussin et al., 2012, 2015; Richert, Erdlenbruch and Grelot, 2019; Sairam et al., 2019).[7] However, fully dry-proofing a property is only one adaptation measure among many options. Some inexpensive adaptations, such as installing sandbag barriers, as in Botzen et al. (2009), could still be economically viable.

Further, in comparison to the levels found by expert assessment (Richert, Boisgontier and Grelot, 2019) the benefits revealed by our WTP are low. This might be surprising as expert assessments only value tangible benefits whereas WTP includes intangible values. One explanation for low WTP values could lie in the cap that we placed on the proposed bids (a maximum of 130 euros). However, our mean values are close to those found by Champonnois and Chanel (2016). In contrast to previous studies, we measure willingness to pay for both collective and individual measures and find very similar results. A possible explanation for this is that the scenarios provide the property with the same level of protection. It is also important to note that the individual scenario is somehow 'collective' in the sense that it proposes to set up measures in 'at-risk' households but not necessarily in the respondent's home.

Finally, it is interesting to note that the perceptions of risk and of the consequences of risk are different determinants. Risk perception only affects adoption while the perception of damage affects willingness to pay for collective mitigation. This differs from findings by Bubeck, Botzen, Suu and Aerts (2012): the perception of consequence was the determinant of intention to adopt, while the perception of risk had no effect.

To conclude, we can derive some policy implications from our study: if French flood managers wish to continue to promote the adoption of individual adaptation measures, they should target their information, and the subsidies, towards low-cost adaptation measures, such as sandbags or adapted property use, rather than the complete dry proofing of buildings with costly devices.

[7] Note that residents in the FRPP area are subsidised at 40% (80% since 2020) when adopting individual adaptation measures. Yet, even with the subsidy the net cost at the lowest estimate is 3,660 euros, which is still above the total discounted benefits calculated for a range of parameters in Table 12.

Appendix

A WTP scenario

The description of scenario 1 was: 'Let's imagine that the government created a Flood Management Fund to finance the construction of collective flood protection works (dykes, retention basins, improvement of rainwater drainage networks). The works would protect you from floods that would cause the water to rise up to one metre in your street. The fund would be financed by an additional local tax compulsory for all households in the communes.'
The description of scenario 2 was 'Let's imagine that the government created a Flood Management Fund to finance expert assessments and implement protective measures in high-risk areas. These would prevent water from entering homes provided the level in your street was no more than one metre high. The fund would be financed by an additional local tax compulsory for all households in the communes.'

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