The impact of flood management policies on individual adaptation actions: Insights from a French case study

Claire Richert, Katrin Erdlenbruch, Frédéric Grelot

▶ To cite this version:

Claire Richert, Katrin Erdlenbruch, Frédéric Grelot. The impact of flood management policies on individual adaptation actions: Insights from a French case study. Ecological Economics, 2019, 165, pp.106387. 10.1016/j.ecolecon.2019.106387 . halshs-02189117

HAL Id: halshs-02189117

https://shs.hal.science/halshs-02189117

Submitted on 19 Jul 2019

The impact of flood management policies on individual adaptation actions: insights from a French case study

Claire Richert[1], Katrin Erdlenbruch*[1,2], and Frédéric Grelot[1]

[1]G-EAU, Irstea, AgroParisTech, Cirad, IRD, Montpellier SupAgro, Univ. Montpellier, Montpellier, France.

[2]CEE-M, Univ. Montpellier, CNRS, INRA, Montpellier SupAgro, Montpellier, France.

Abstract

Floods can be managed at the collective and individual level. Knowing the interaction between measures taken at both scales can help design more efficient flood risk management policies. Here, we combine the data collected during a survey of 331 inhabitants of flood-prone areas in the South of France and spatial databases to empirically examine the interaction between individual adaptation measures and three types of collective management tools: a national insurance scheme, dikes, and zoning instruments. In line with the levee effect hypothesis, we found that dike protection reduces the probability to have or take individual adaptation measures and that this effect could be mitigated by zoning instruments. Moreover, we found that the national insurance scheme does not crowd out individual adaptation.

Keywords: Flood policies ; Levee effect; Individual adaptation decisions ; Zoning ; Insurance

JEL Classification: Q54; Q58

---

*Corresponding author: Irstea, UMR G-EAU, 361 rue Jean François Breton, 34196 Montpellier cedex 5, France. Tel: +33 467046387. E-mail: katrin.erdlenbruch@irstea.fr

1 Introduction

Flooding constitutes a major threat worldwide. For instance, the overall losses caused by the 5 costliest floods in the world between 2007 and 2017 accounted for almost 100 billion of dollars (Munich RE, 2018). To mitigate the negative consequences of these natural disasters, measures can be taken at the collective and individual levels. On the one hand, zoning policies, national flood insurance programs, and structural flood defences, such as dikes, are collective measures aimed at reducing the damage due to floods. On the other hand, to reduce their vulnerability to floods, individuals may take individual actions such as installing pumps in their dwellings, or avoiding locating the main rooms on the ground floor (Bubeck et al., 2012, 2013, Grothmann and Reusswig, 2006, Poussin et al., 2014, Reynaud et al., 2013). Following Blanco et al. (2017), we call these kinds of devices or behaviours individual adaptation measures. In this study, we explored the influence of collective measures on individual adaptation measures.

In recent years, integrated flood risk management has been promoted in many places. For instance, countries such as France and the United States try to reduce people's vulnerability to floods by implementing zoning policies, offering a national flood insurance program, and fostering private adaptation to floods while they still provide and maintain structural flood defences (Erdlenbruch et al., 2009, Samuels et al., 2006). This trend is in line with recent studies that argue that risks might be reduced more effectively if measures at different scales are combined (Erdlenbruch and Bonté, 2018, Filatova, 2014).

However, it could be difficult to reconcile the different aspects of an integrated flood risk management. For instance, in a historical analysis of the Mississippi flood of 1993, Tobin (1995) identified the levee effect, which is the fact that structural flood defences can provide a feeling of safety and consequently stimulate the settlement of populations and activities in the floodplains they protect. As a result, several socio-hydrological models integrated this insight to simulate the dynamic effect of dikes on the evolution of flood hazards and human settlements (Di Baldassarre et al., 2013, Grames et al., 2016, Viglione et al., 2014) and several authors advised to take the levee effect into account in flood management policy design (Burby, 2006, Pielke, 1999, Pinter, 2005). The levee effect is in line with people's tendency to neglect low probability events, such as the breaching or overtopping of a dike (Kunreuther et al., 2001). The literature that deals with the relationship between trust and risk perception provides another explanation for the levee effect. Indeed, Wachinger et al. (2013) found in a literature review that trust in authorities and experts is the second most important factor to explain the perception of the risk from natural hazards, after personal experience: people who have a high level of trust in the ability of authorities to manage natural hazards tend to have a lower perception of the risk posed by these hazards. Since risk perception has been found to be positively correlated with the willingness to take adaptation measures (e.g. Grothmann and Reusswig (2006), Richert et al. (2017)), trust in authorities is expected to have a negative effect on individual adaptation. In surveys of inhabitants of flood-prone areas in Germany, France, or Vietnam, Grothmann and Reusswig (2006), Poussin et al. (2014) and Reynaud et al. (2013) found evidence of this negative effect. The presence of a dike could act as a visual signal that indicates that public authorities are taking actions to deal with the risk of flooding, and thus enhance trust in these authorities. Few studies provide direct empirical evidence for the levee effect. In an Italian case study conducted by Scolobig et al. (2012), interviewed households indicated the presence of protection works as one of the three main reasons for not adopting individual adaptation measures. In a survey in Ireland, Bradford et al. (2012) found that the respondents who were not aware of being exposed to the risk of flooding were those who lived near structural flood protection works. Similarly, Ludy and Kondolf (2012) found that almost half of the residents who lived in an area protected by a dike in California underestimated the consequences of a flood for their dwelling.

Besides, insurance schemes and governmental relief can crowd out individual actions. This kind of effect has been found in several theoretical studies. For instance, Ehrlich and Becker (1972) showed that self-insurance and market insurance are theoretically substitutes. Since individual adaptation measures can be viewed as self-insurance, this result implies that the presence of an insurance scheme may induce people to rely on compensations rather than on individual adaptation measures. A mandatory compensation scheme with an insurance premium that does not depend on exposure could even prevent the adoption of individual adaptation measures, according to Latruffe and Picard (2005) and Picard (2008). Other theoretical studies have shown that governmental relief may crowd out self-insurance (Lewis and Nickerson, 1989) or both insurance and adaptation measures (Kelly and Kleffner, 2003). Several empirical studies have also explored the links between insurance schemes, governmental relief, and individual actions. Kousky et al. (2018) found in a study in the United States that federal aid can crowd out individual insurance. Raschky et al. (2013) studied the effect of governmental relief on the adoption of individual insurance in Germany and Austria. They found that the crowding out effect is stronger when people are certain of being compensated. Botzen et al. (2009) found that federal post-disaster compensation negatively affects self-protection (e.g. through sandbags) in the Netherlands. On the other hand, Hudson et al. (2017) found no link between private insurance and the adoption of individual adaptation measures in Germany.

Finally, the adoption of adaptation measures may also be influenced by regulatory requirements, which in turn rely on other policy tools, as part of integrated flood risk management. For example, some national insurance schemes are specifically designed to foster the adoption of some adaptation measures (Burby, 2001). In the United States, for instance, the National Flood Insurance Program (NFIP) requires that new buildings in flood-prone areas meet some adaptation standards: their lowest floor must be elevated to the estimated level of the 100 year flood. Regulatory requirements in many countries rely on the use of risk maps indicating the areas in which particular actions are prescribed. The effectiveness of different risk-maps to increase risk-awareness among the general public has been the topic of recent research in risk communication (Dransch et al., 2010).

These examples illustrate the fact that understanding the effect of different collective measures on individual adaptation to floods is crucial in order to anticipate and improve the effectiveness of flood management policies aimed at fostering private adaptation to floods.

We focused on France, where the mean annual damage generated by floods between 1980 and 2010 has been estimated at between 650 and 800 million Euros (MEDDE, 2012). We explored the relationship between individual adaptation and the three main flood management policies: the French national disaster compensation scheme, which applies to almost all inhabitants (CatNat system), zoning instruments called Flood Risk Prevention Plans (FRPP), and dikes. We studied simultaneously the influence of zoning instruments and dikes on individual adaptation to floods. We also took into account other prominent determinants of individual adaptation decisions (Grothmann and Reusswig, 2006, Scolobig et al., 2012), which are personal flood experience, economic factors (e.g. homeownership), socio demographic factors (e.g. educational level), geographic factors (e.g. being physically exposed) or political factors (e.g. living in a particular administrative area). To the best of our knowledge, this is the first multivariate analysis that investigates the levee effect. Our results show that living behind a dike has a negative impact on individual adaptation to floods. This effect is mitigated by the fact of also living in a FRPP area. Moreover, the CatNat system does not rule out individual adaptation.

In section 2, we describe the three main flood management policies used in France. Then, in section 3, we present the data and method used to study their effect on private adaptation to floods. In section 4, we present the underlying model. We expose our results in section 5 before discussing them in section 6. We conclude in section 7.

2 Flood management policies in France

2.1 National disaster compensation scheme

The high uncertainty regarding the expected losses due to natural hazards, adverse selection, and the fact that the potential losses can be very high can dissuade insurance companies from covering this kind of risks (Jaffee and Russell, 1997). Accordingly, in France, natural disasters are deemed uninsurable.[1]As a result, in 1982, a national disaster compensation scheme (the CatNat system) has been legally established to provide coverage against natural disasters to the majority of inhabitants (Grislain-Letrémy and Peinturier, 2010). The CatNat system relies on a private-public partnership. On the one hand, it is mandatory for private insurance companies to include a guarantee against natural disasters in all home or earth-bound motor vehicle insurance policies. On the other hand, a fixed percentage of every insurance premium is used to pay this guarantee,[2] no matter the level of exposure of the insured good. Note that the CatNat system provides coverage against natural disasters to a large majority of the inhabitants of metropolitan France, since 99% of them had their home insured in 2010 (Grislain-Letrémy and Peinturier, 2010). Moreover, the Caisse Centrale de

---

[1] According to the Insurance Law, Art. L125-1.

[2] 12% of the base contract of every home insurance policy and 6% of the guarantee against theft and fire hazard of every earth-bound motor vehicle insurance policy.

Réassurance (CCR), which is a reinsurance company owned at 100% by the French State, offers private insurance companies reinsurance contracts that pertain to natural disasters. In practice, after a natural event occurs, the impacted municipalities can ask the Prefect of the region to acknowledge that they were struck by a natural disaster. The Prefect builds a case that describes the nature and intensity of the event and presents it in front of a ministerial commission. If this latter decides that the event was indeed a natural disaster, the inhabitants of the concerned municipalities, if they are insured, can be compensated. In general, the level of compensation depends on the damage, which is assessed by an insurance expert, and not on the presence of individual adaptation measures (Caisse Centrale de Réassurance, 2011). In short, the CatNat system combines some characteristics of government relief (a large majority of the people affected by a natural hazard are compensated) and of a mandatory insurance (there is a deductible and people pay an insurance premium).

2.2 Natural Risk Prevention Plans

A zoning instrument was embedded into the legal framework in 1982 and simplified in 1995 to give rise to the Natural Risks Prevention Plans (NRPP). A NRPP is made up of two main parts: a map of the areas exposed to different levels of the natural hazard and a set of rules which specify the extent to which new constructions are allowed and the individual adaptation measures that are recommended or mandatory in each area. A Flood Risk Prevention Plan (FRPP) is a type of NRPP that deals with flood risks (Erdlenbruch et al., 2009). In principle, compensation can be denied to people whose dwellings do not conform to the relevant urban planning rules, including the NRPP rules. However, in practice, there is no systematic link between the compliance with the NRPP rules and the level of compensation (Grislain-Letrémy and Peinturier, 2010).

2.3 Dikes

In France, dikes are the main structural flood defences.They cover approximately 9 000 km and are protecting an area of about 20 000 km^2, i.e. 3% of the whole territory.[3] However, only 3 000 km

---

[3] See http://www.irstea.fr/nos-editions/dossiers/digues-barrages-risques-impacts/digues-protection.

were considered in good condition in 2010 (Centre Européen de Prévention du Risque d'Inondation, 2017).

The dikes are owned and maintained by public authorities, private companies, or individuals. However, private companies and individuals must ask public authorities for a permit before they can build a dike or any other work likely to change the water flow.[4]Ultimately, dikes can be regarded as collective measures since they generally modify the exposure to floods of several people and their construction depends on a public decision.

3 Data and method

In this section, we present our case study and the data and variables used in our analyses.

3.1 Case study

We focused on two departments of the South of France: the Aude and the Var departments. The former was affected by a major flash flood in November 1999, which killed 35 people and caused an estimated loss of 771 million Euros (Vinet, 2008). As for the latter, it was hit by the same type of phenomenon in June 2010. During this event, 26 people died, and the estimated damage was between 1 000 and 1 500 million Euros (Vinet et al., 2012).

We surveyed inhabitants in 8 municipalities of the Aude department and 4 of the Var department. Among these municipalities, 8 are partially covered by a Flood Risk Prevention Plan (FRPP) and 4 had not implemented such a plan at the time of the survey (2015). Furthermore, dikes with a height of at least 1 m are present in 4 of the selected municipalities and absent in the 8 other municipalities (cf. Table 1).

---

[4] See Law of the environment, Art. L214-3.

Table 1: Number of existing FRPPs, dikes, and respondents in the surveyed municipalities at the time of the survey

Municipality	FRPP (date of approval)	Dikes (date of construction)	Number of respondents
		AUDE	
Cascastel-Des-Corbières	0	0	15
Coursan	1 (2008)	12 (between before 1950 and 1992)	20
Lézignan-Corbières	1 (2004)	0	43
Narbonne	2 (2008)	1 (1986)	43
Peyriac-Minervois	1 (2007)	0	21
Raissac-d'Aude	1 (2004)	0	7
Villedaigne	1 (2010)	0	14
Villeneuve-Les-Corbières	0	0	4
		VAR	
Draguignan	1 (2014)	2 (unknown)	41
Fréjus	1 (2014)	5 (between before 1950 and 1961)	40
Le Cannet-Des-Maures	0	0	42
Villecroze	0	0	41

3.2 Data

3.2.1 Data sources and description

Primary data

In summer 2015, we surveyed 331 inhabitants of flood-prone areas in the 12 selected municipalities. The interviews were conducted in face-to-face settings (see Richert (2017)).

The respondents were selected so that approximately 80% of the sample had already experienced a flood in their municipality. The sample is representative of the French population in terms of gender. Its heterogeneity is sufficient to control for the effect of sociodemographic features on private adaptation to floods. Indeed, as shown in Table 2, all age classes are represented, the respondents are equally distributed between the two studied departments, and there is approximately as many people who have at least a high school diploma as people who have a lower level of education. We also observe that 65% of the respondents own their home, which corresponds about to the national average.

The survey was designed to evaluate the extent of private adaptation among the respondents and identify potential drivers or barriers to the adoption of individual adaptation measures.

We identified 11 individual adaptation measures. Some are mandatory in some areas of the FRPPs, some are recommended, and some are not mentioned. All measures were presented to the respondents. For each of them, the respondents were asked to tell whether it was present in their dwelling or not. Then, for each measure that existed in their dwelling, they had to indicate whether it had been taken by their household or by someone else.[5]

As indicated in Table 3, the most common measure is placing electrical wiring and systems or the boiler high up on walls, and the second most common measure is building the dwelling with a raised ground floor or crawl space. The measure that has been taken by the largest number of respondents is the fact of storing the valuables upstairs.

Table 2: Distribution of sociodemographic variables in the sample

Variable	Category	Proportion
Department	Aude	0.50
	Var	0.50
Gender	Male	0.47
	Female	0.53
Age	$<$ 30 years old	0.16
	30 - 44 years old	0.20
	45 - 59 years old	0.24
	60 - 74 years old	0.28
	$>$ 74 years old	0.12
Education level	Less than a high school diploma	0.52
	High school diploma or higher	0.48
Ownership of the home	Home owners	0.65
	Others	0.35

N = 331.

---

[5] Note that the respondents could add individual adaptation measures to the list if one that was not listed was present in their dwelling. In total, 21 measures were added but they could all be assimilated to one of the 11 measures proposed.

Table 3: List of adaptation measures and their characteristics

Measure	Status	Present (%)	Taken (%)
Raised ground floor, raised crawl space	M or R	44	9
Watertight doors and windows	NM	2	1
Opening on the roof to facilitate evacuation	NM	16	3
Water resistant materials (for the floors and/or walls)	M or R	5	4
Sewer non-return valves	R	4	3
Slot-in flood barrier(s)	R	9	8
Pump(s)	NM	19	11
Electrical wiring and systems and/or boiler high up on walls	M or R	45	14
All main rooms (kitchen, bedrooms, living-room) upstairs	NM	33	8
Measures to improve water flow	NM	23	10
Valuables stored upstairs	NM	26	18

M: Mandatory; R: Recommended; NM: not mentioned. The columns "present" and "taken" indicate the percentage of respondents in the sample (N = 331) for which the measure is present in their dwelling or has been taken by the household, respectively. Note that all measures that have been taken by the household are included in the measures that are present.

Data on flood risk perception, experience, exposure to such risks, and sociodemographic features were also collected and the geographic coordinates of each respondent's dwelling were recorded.

Secondary data

Secondary data relate to rivers, FRPPs, and dikes located in the 12 studied municipalities.

- Rivers spatial database:

  In order to locate the rivers that flow through the chosen municipalities, we used the 2014 version of a publicly available national spatial database named CARTHAGE.[6] We focused on rivers that are at least 5 km long.

- FRPPs spatial databases:

  Each FRPP of the studied area comprises a map that delineates several risk zones in which specific building rules and recommendations apply.[7] In some of these zones, new constructions are forbidden and inhabitants have to take some individual adaptation measures. We refer to

---

[6] See https://www.data.gouv.fr/fr/datasets/cours-deau-metropole-2014-bd-carthage/.

[7] The databases which concern the FRPPs that exist in the Var department are publicly available (see http://statique.sigvar.org). For the Aude department, they were provided by the departmental service in charge of territorial planning (DDTM Aude).

these zones as building ban areas. The rules and recommendations are quite similar across the FRPPs of the selected municipalities. The FRPPs of the selected municipalities in the Aude (Var) department and the location of the respondents' dwellings with respect to these FRPPs are presented in Figure 1 (Figure 2).

- Dikes spatial database:

  In France, hydraulic structures are listed and located in the national spatial database SIOUH (information system of hydraulic structures). The most recent observations in this database are from 2015 for the Aude department and 2017 for the Var department. We kept the observations which relate to dikes that are at least 1 m high, designed to protect at least 10 people, and located along a river that is at least 5 km long. Figure 3 indicates the location of the respondents' dwellings in relation to dikes for municipalities with a dike (Coursan, Narbonne, Draguignan, Fréjus).

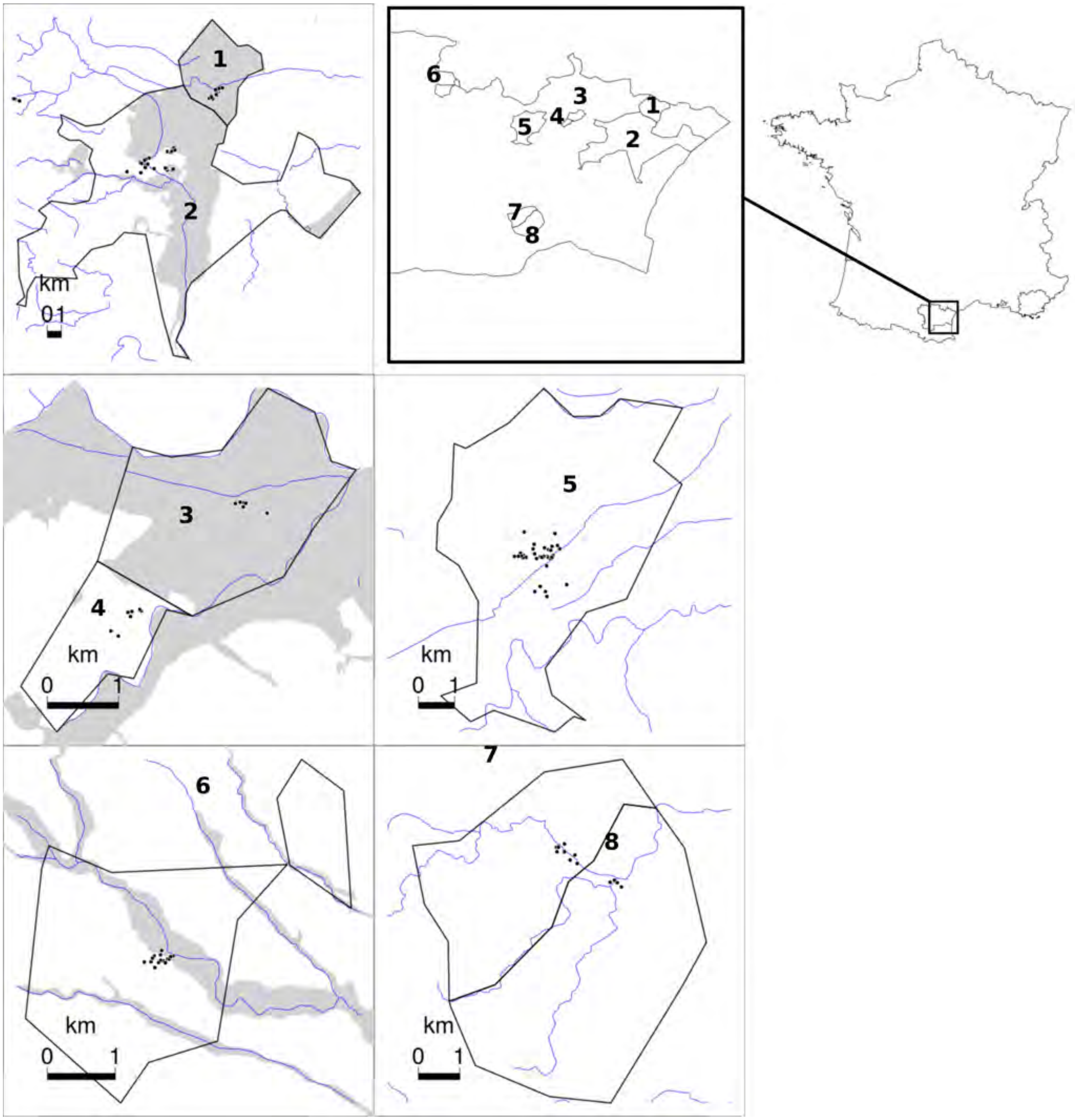


Figure 1: In grey: FRPPs in the surveyed municipalities of the Aude department. 1: Coursan; 2: Narbonne; 3: Raissac-d'Aude; 4: Villedaigne; 5: Lézignan-Corbières; 6: Peyriac-Minervois; 7: Cascastel-des-Corbières; 8: Villeneuve-les-Corbières. The blue lines represent the rivers, the dots represent the dwellings of the respondents.

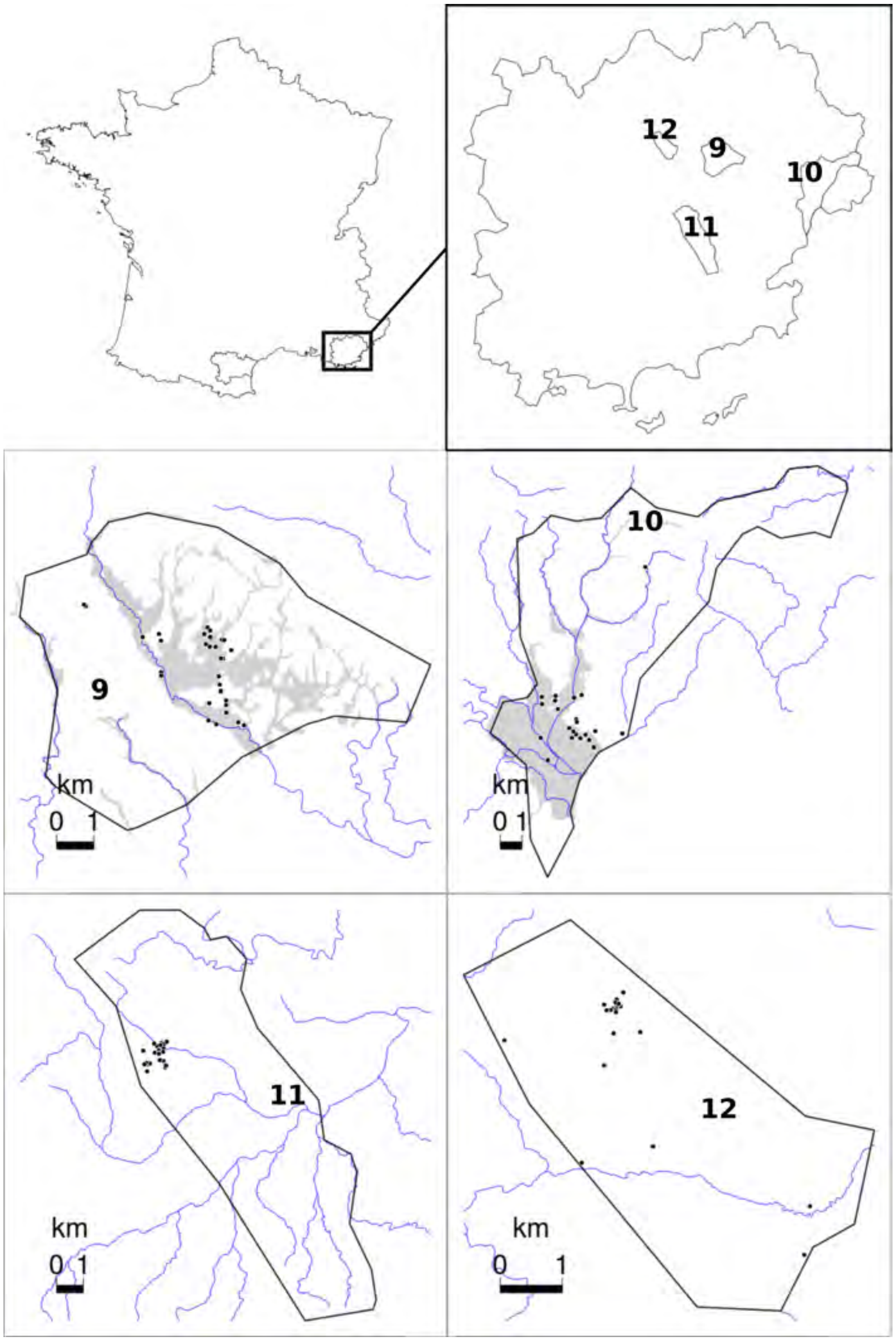


Figure 2: In grey: FRPPs in the surveyed municipalities of the Var department. 9: Draguignan; 10: Fréjus; 11: Le Cannet-des-Maures; 12: Villecroze. The blue lines represent the rivers, the dots represent the dwellings of the respondents.

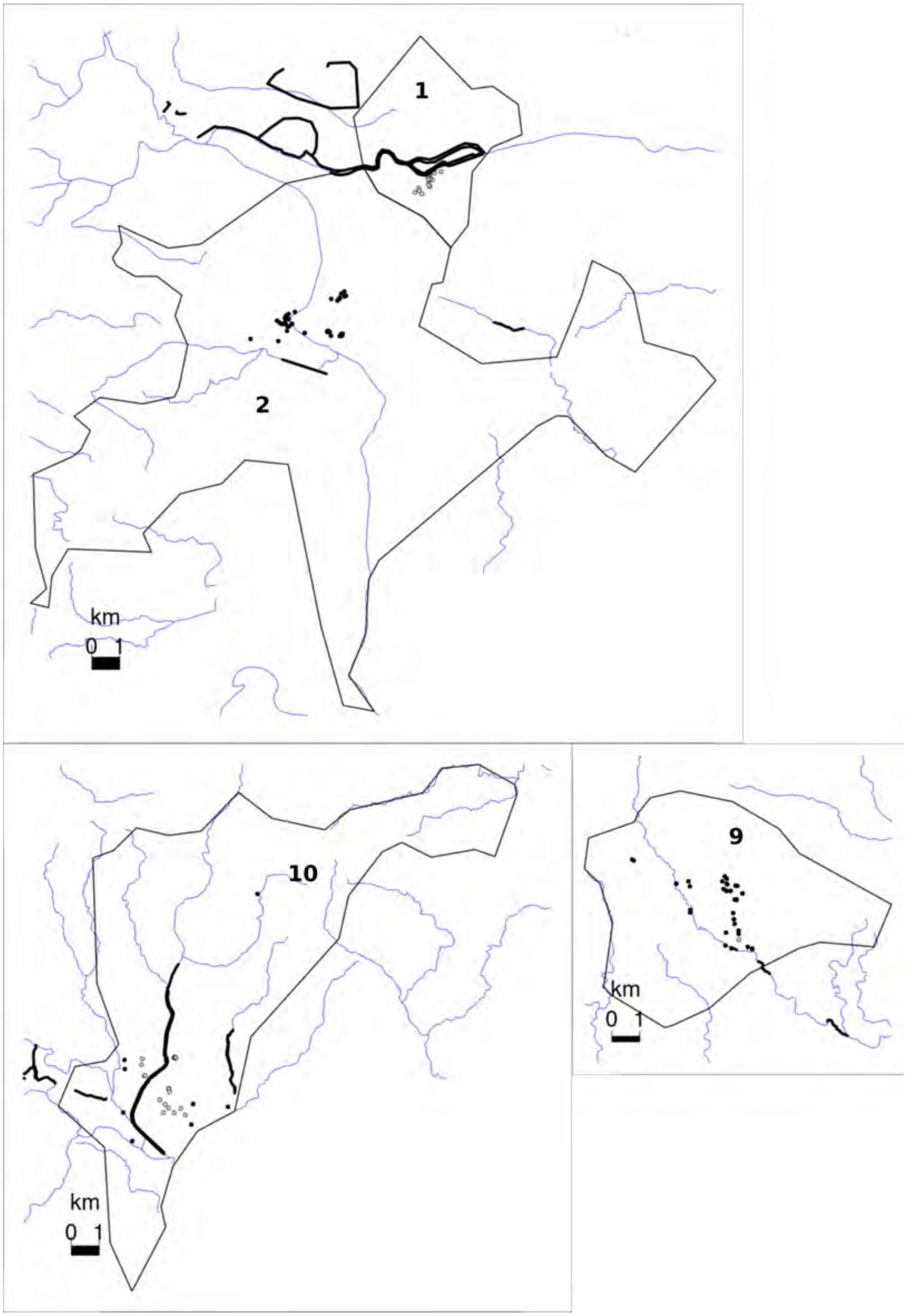


Figure 3: Location of the respondents' dwellings in relation to dikes in Coursan (1), Narbonne (2), Draguignan (9), and Fréjus (10). The thick black lines represent dikes and the thin blue lines represent rivers. The gray dots represent the dwellings of the respondents which are behind the nearest dike. The black dots represent the dwellings of the respondents which are not behind the nearest dike.

3.2.2 Variables included in the models

In all models, the dependent variable is an indicator of private adaptation to floods and the independent variables are 1) variables that describe the location of the respondents' dwellings in relation to dikes and FRPPs, and 2) control variables.

Dependent variables

We constructed 2 binary indicators of private adaptation to floods: 1) **present**, which takes the value 1 if at least one individual adaptation measure is present in the respondent's dwelling, and 2) **taken**, which takes the value 1 if at least one individual adaptation measure that is present in the respondent's dwelling has been taken by his/her household. The variable **present** is used to focus on the relationship between the location of a dwelling and its adaptation status. The variable **taken** focuses on the household's decision in this context.

Independent variables describing the situation in relation to FRPPs and dikes

Two binary variables indicate the situation of each respondent in relation to FRPPs: 1) **in FRPP**, which takes the value 1 if the respondent lives in an area delineated by a FRPP, and 2) **in building ban area**, which takes the value 1 if the respondent lives in the building ban area of a FRPP.

In order to describe the situation of the respondents in relation to dikes, we constructed a binary variable named **behind dike**. It takes the value 1 if there is a dike between the respondent's dwelling and the nearest river. The process followed to construct this variable is explained in appendix A.

Control variables

Potential drivers of private adaptation to floods were chosen as control variables. Three variables aim to control the exposure of the respondents to floods. The first one, **distance to the nearest river**, indicates the distance (as the crow flies) in kilometres between the respondent's dwelling and the nearest river. Richert (2017) found a positive relationship between this variable and the perception of the threat posed by the risk of flooding, and a positive relationship between this latter and the willingness to adopt individual adaptation measures. The second variable, **exposure**, is binary and takes the value 1 if the respondent lives in a single-storey house, in an apartment located on the ground floor or below or in a house where the main rooms are on the ground floor or below. We took this variable into account because some adaptation measures are mostly relevant to protect the ground floor (for example: slot-in flood barriers, watertight doors and windows). The third variable, **experience**, is binary and takes the value 1 if the respondent had already experienced at least one flood at the time of the survey. In our survey, experiencing a flood means that at least the municipality of residence was flooded.[8] Grothmann and Reusswig (2006), Poussin et al. (2014) and Richert et al. (2017) for example found a positive relationship between flood experience and individual adaptation to these risks.

The variable **present before arrival** is binary and indicates whether at least one adaptation measure was already present in the dwelling before the household moved in. This variable was included in models that explain the variable **taken** because we assumed that the presence of a measure in the dwelling can affect the potential benefit of taking another one.

The department of the respondent is taken into account in order to control for the effects of the local socio-economic and political environment. The variable **department** is binary and takes the value 1 if the respondent lives in the Var department.

Two other control variables relate to the sociodemographic characteristics of the respondents: **education level** is a binary variable that takes the value 1 if the respondent has at least a high school diploma, and **ownership** takes the value 1 if the respondent owns his home. These variables are taken into account because they were significant in a previous study based on the same primary data to explain the willingness to adopt individual adaptation measures (Richert et al., 2017).

Note that we did not include flood risk perception as a control variable because it may not explain actions taken in the past due to potential feedback effects (Richert et al., 2017).

Tables 4 and 5 indicate the distribution of each variable among the sample.

---

[8] Thus, this variable encompasses several situations: among the respondents who experienced at least one flood, 40% had water only in the street of their municipality, 10% had their workplace flooded, and 51% also had their dwelling, cave, or garage flooded.

Table 4: Summary of the binary variables

Variable	Modality coded as 1	Proportion of 1
present	at least one measure present	0.77
taken	at least one measure taken	0.44
in FRPP	dwelling in FRPP area	0.42
in building ban area	dwelling in building ban area	0.21
present before arrival	at least one measure present before arrival	0.53
behind dike	dwelling behind a dike	0.16
exposure	dwelling exposed to floods	0.61
education level	high school diploma or higher	0.48
experience	experience of at least one flood	0.82
ownership	owner of the dwelling	0.65
department	Var department	0.50

N = 331

Table 5: Distribution of the quantitative variable (distance in km)

Variable	Minimum	Mean	Maximum	Standard deviation
distance to the nearest river	0.002	0.585	2.250	0.606

N = 331

4 Econometric model

4.1 Underlying models

We used random utility models to explain the adaptation decisions (McFadden, 1974, Train, 2002). Utility, U derived by individual n from choosing alternative i can be decomposed into two parts:

$$U_{ni} = V_{ni} + \epsilon_{ni} \tag{1}$$

where V_{ni} is the part that is explained by observed factors and ϵ_{ni}, the error term, depends on unobserved factors. Here, U_{ni} represents individual's taste for individual adaptation measures. It is assumed that individuals choose the option that provide them the highest level of utility.

We used binary choice models in which adaptation decisions are coded 1 and non-adaptation decisions are coded 0. Since only differences in utility matter, the utility related to the option coded

0 is set to zero. Given the relatively low number of observations available for our study (331), we used logit models. The error term is an independently and identically distributed extreme value (Train, 2002). The utility function is specified to be linear: note X_{ni} the vector of observed values explaining V_{ni} for each option and β, the vector of corresponding parameters, we have:

$$V_{ni} = \beta' * X_{ni}. \tag{2}$$

It can be shown (McFadden, 1974, Train, 2002) that the probability for individual n to choose the option i rather than option j is:

$$P_{ni} = \frac{e^{\beta' X_{ni}}}{\sum_j e^{\beta' X_{nj}}}. \tag{3}$$

When heteroskedasticity is present we have:

$$P_{ni} = \frac{e^{\frac{\beta' X_{ni}}{\sigma_n}}}{\sum_j e^{\frac{\beta' X_{nj}}{\sigma_n}}}. \tag{4}$$

where σ_n is the scale parameter, which is related to the variance of the errors as follows: $Var(\epsilon_n) = \sigma_n^2 * \frac{\pi^2}{6}$. Since σ_n is not observed, we can only estimate the parameters that enter the utility function divided by the scale parameter. In heteroskedastic logit models, the scale parameter is a function of the observed variables.

For our study, an important limitation of the logit model is that it cannot represent heterogeneity of taste.

4.2 Estimation strategy

First, we estimated homoskedastic logit models to explain each dependent variable. Then, we estimated heteroskedastic logit models for each dependent variable. Here, the scale parameter depends on the non-significant control variables of the homoskedastic logit models. We tested the relevance of the heteroskedastic models using log-likelihood ratio tests.

In all models, we always included the variable **behind dike** and one of the two variables that describe the location in relation to FRPPs: **in FRPP** or **in building ban area**. We did not include these latter variables together in the same model because they are highly correlated by construction. Moreover, we studied the combined effect of the FRPP location variables and the variable **behind dike** by adding an interaction term. In all models, we always included the variable **department** and an interaction term between this variable and the one that describes the location relative to FRPPs. Indeed, since the FRPPs of the Aude department are older than those of the Var department (see Table 1), the effect of these adaptation tools can differ depending on the department.

The other control variables included depend on the explained variable. On the one hand, for models that explain the variable **present**, we did not take into account the control variables that relate to the respondent (**education level**, **experience**, **ownership**) because the measures that are present in a respondent's dwelling can have been taken by someone else. On the other hand, for models that explain the variable **taken**, we included all the control variables.

Finally, as recommended by Bryman and Cramer (2005), we limited the risk of multicollinearity by checking that no correlation between the independent variables exceeds 0.8 (see appendix B).

4.3 Endogeneity issues

Let us discuss the status of three variables for which the exogenous character might not be immediately visible.

Concerning the variable **behind dike**, it seems unrealistic to suppose that dikes are constructed because of lacking individual adaptation for two main reasons. First, most of the dikes considered in the study are at least 50 years old (see Table 1). Since more than 90% of the respondents had lived in their dwelling for less than 50 years at the time of the survey, their adaptation level could not have been taken into account in the decision to build these dikes. Second, it is unusual to conduct thorough analyses of individual adaptation before deciding to build a dike in France. Since 2011, cost-benefit analyses are mandatory to get funding from the French State for some dike projects.

However, the only adaptation measure they take into account is the fact that the first floor can be elevated. In our data, only 2 dikes considered were possibly built after 2011[9] and only 1 respondent lives behind these dikes. Hence, we do not think that the variable **behind dike** can be endogenous.

Likewise, FRPPs are decided on the basis of hydrological hazard and population density maps which are independent from individual adaptation status. The other way round, FRPPs do sometimes prescribe adaptation measures for the most risky areas. Again, we do not think that the variables **in FRPP** or **in building ban area** can be endogenous.

Finally, even the variable **experience** is exogenous from adaptation decisions. Indeed a respondent is said to have experienced a flood if at least his/her municipality was flooded. The variable does not depend on the degree of flooding of the dwelling itself.

5 Results

5.1 Models of the presence of at least one measure

The two homoskedastic logit models that explain the variable **present** are called A1 and A2. Their estimates are reported in Table 6. They show that dwellings located behind a dike are less likely to contain at least one individual adaptation measure than the others. The negative relationship between the variable **behind dike** and the variable **present** is mitigated by the fact of also being in a FRPP or a building ban area. According to model A2, the respondents of the Var are generally more likely than the others to have at least one adaptation measure in their dwelling. However, the fact of living in the Var department reduces the probability to have at least one measure for the respondents who live in a building ban area.

Table 7 indicates the means and standard deviations of the individual marginal effects of the independent variables included in A1 and A2. The variable **behind dike** has the greatest mean marginal effect in absolute value: on average, the fact of being located behind a dike reduces the probability that a dwelling has at least one individual adaptation measure by approximately 0.45.

---

[9] We do not know their date of construction (see Table 1).

We also tested whether the error term was heteroskedastic. To do so, we used the control variables that are not significant in models A1 and A2 to explain the scale parameter in heteroskedastic logit models. The estimates of these models are not reported here because the p-values of the likelihood ratio tests between them and their homoskedastic equivalents are greater than 0.1, indicating that we cannot reject the hypothesis that the error term is homoskedastic.

Table 6: Models A1 and A2: logit models of the presence of at least one individual adaptation measure (explained variable: **present**)

Variable	**MODEL A1**		**MODEL A2**	
	Estimate	s.e	Estimate	s.e
(Intercept)	1.464 ***	0.391	1.529 ***	0.350
behind dyke	-3.400 ***	0.683	-2.713 ***	0.459
in FRPP	-0.432	0.403	-	-
in building ban area	-	-	-0.570	0.408
behind dyke*in FRPP	2.475 ***	0.795	-	-
behind dyke*in building ban area	-	-	2.787 ***	0.764
in FRPP*department	-0.497	0.651	-	-
in building ban area*department	-	-	-1.809 **	0.785
department	0.829	0.515	1.021 **	0.436
exposure	0.081	0.301	-0.019	0.305
distance to the nearest river	-0.046	0.321	-0.228	0.346
LR test statistic (full vs. null)	**42.97*****		**48.53*****	
McFadden adjusted R^2	**0.08**		**0.09**	
AIC	**327.28**		**321.72**	
Predicted (vs real) present	**315(256)**		**296(256)**	

N = 331. *: p-value < 0.1; **: p-value < 0.05; ***: p-value < 0.01. LR test (full vs. null): likelihood ratio test between the model and a model with the same dependent variable and only an intercept.

Table 7: Marginal effects of each independent variable included in models A1 and A2: mean and standard deviation

Variable	**MODEL A1**	**MODEL A2**
	Mean (sd)	Mean (sd)
behind dike	-0.473 (0.230)	-0.425 (0.230)
in FRPP	-0.016 (0.173)	-
in building ban area	-	-0.173 (0.250)
department	0.083 (0.019)	0.067 (0.130)
exposure	0.012 (0.004)	-0.003 (0.001)
distance to the nearest river	0.063 (0.013)	-0.015 (0.03)

N = 331

5.2 Models of the presence of at least one measure taken by the household

The models B1 and B2 were estimated to explain the variable **taken** (see Table 8). They suggest that the respondents who live behind a dike are less likely to have taken at least one measure than the others. This relationship is mitigated by the fact of living in a FRPP or a building ban area. Owners and respondents who experienced at least one flood are more likely than the others to have taken at least one measure. On the opposite, households who live in dwellings where at least one measure was already present when they arrived are less likely than the others to have taken at least one measure by themselves.

The means and standard deviations of the individual marginal effects of the independent variables included in B1 and B2 are presented in Table 9. The variable **ownership** has the greatest mean marginal effect: owning one's home increases the probability of having taken at least one measure by approximately 0.25 on average. In absolute value, the mean marginal effect of the variable **behind dike** is three times smaller in models B1 and B2 than in models A1 and A2.

We also estimated two heteroskedastic logit models with the scale parameter explained by all the control variables used in B1 and B2 that are not significant to explain the dependent variable in these models. The estimates of these models are not reported here because the p-values of the likelihood ratio tests between them and their homoskedastic equivalents are greater than 0.1. Thus, we cannot reject the hypothesis that the error term is homoskedastic.

Table 8: Models B1 and B2: homoskedastic logit models of the fact that at least one individual adaptation measure has been taken by the household (explained variable: **taken**)

Variable	**MODEL B1**		**MODEL B2**	
(Intercept)	-0.908 *	0.467	-0.677	0.437
behind dyke	-1.830 **	0.718	-1.035 **	0.459
in FRPP	0.005	0.349	-	-
in building ban area	-	-	-0.183	0.382
behind dyke*in FRPP	2.057 **	0.827	-	-
behind dyke*in building ban area	-	-	1.884 **	0.781
in FRPP*department	-0.333	0.545	-	-
in building ban area*department	-	-	-0.844	0.748
distance to the nearest river	-0.342	0.241	-0.361	0.249
exposure	-0.141	0.272	-0.238	0.271
experience	0.822 **	0.331	0.724 **	0.332
department	0.055	0.376	-0.011	0.321
ownership	1.044 ***	0.276	1.110 ***	0.279
education	-0.006	0.252	-0.002	0.251
present before arrival	-0.742 ***	0.259	-0.842 ***	0.269
LR test statistic (full vs. null)	**42.98*** **		**42.06*** **	
Mc Fadden adjusted R^2	**0.04**		**0.04**	
AIC	**434.28**		**435.20**	
Predicted (vs real) taken	**129(144)**		**112(144)**	

N = 331. *: p-value < 0.1; **: p-value < 0.05; ***: p-value < 0.01. LR test (full vs. null): likelihood ratio test between the model and a model with the same dependent variable and only an intercept.

Table 9: Marginal effects of each independent variable included in models B1 and B2: mean and standard deviation

Variable	**MODEL B1**	**MODEL B2**
	Mean (sd)	Mean (sd)
behind dike	-0.158 (0.193)	-0.122 (0.164)
in FRPP	0.029 (0.149)	-
in building ban area	-	-0.056 (0.159)
distance to the nearest river	0.002 (0.001)	-0.08 (0.031)
exposure	-0.030 (0.006)	-0.051 (0.010)
experience	0.172 (0.035)	0.153 (0.030)
department	-0.019 (0.036)	-0.04 (0.075)
ownership	0.228 (0.036)	0.241 (0.034)
education level	-0.001 (0.000)	0.000 (0.000)
present before arrival	-0.163 (0.027)	-0.184 (0.030)

N = 331

Note that the models A1, A2, B1, and B2 conform to the rule of thumb outlined by Peduzzi et al. (1996), according to which we need a minimum of 10 outcome events per independent variable. In the context of discrete choice models, the number of outcome events to take into account is the number of observations in the least chosen category. Table 10 compares the maximum number of parameters that can be estimated depending on the explained variable and the number of parameters that we estimated in practice.

Table 10: Maximum number of parameters depending on the independent variable

Independent variable	Least chosen category	Number of observations in the least chosen category	Maximum number of parameters	Number of estimated parameters
present	0	75	7	7
taken	1	144	14	11

Following Peduzzi et al. (1996), the intercept is not counted.

5.3 Descriptive statistics to explore the influence of the CatNat system

In the following, we analyse the influence of the CatNat system on individual adaptation.

Among the 331 respondents, 270 have experienced at least one flood. 81 of them stated that they suffered significant material damage due to a flood. Figure 4 shows the distribution of material damage among these respondents.

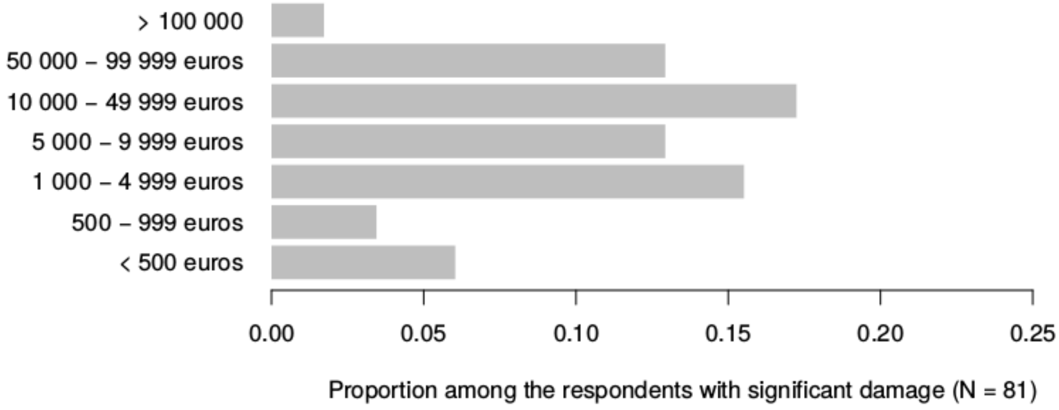


Figure 4: Distribution of material damage due to a flood (in euros)

Among the 81 respondents who stated that they suffered significant damage, 64 were compensated, at least partially.[10] In spite of this compensation, 27% of them took at least one individual adaptation measure after the flood they experienced. In comparison, 24% of the respondents who suffered significant damage but were not compensated took at least one measure after this event. Moreover, 14% of those who experienced a flood but did not suffer significant damage also took at least one measure after this event. Figure 5 summarizes these statistics. According to these results, some people who were aware that they could be compensated after a flood still decided to take action to reduce the vulnerability of their dwelling to floods. Hence, individuals' willingness to adapt to floods by themselves was not completely crowded out by the CatNat system.

---

[10] Among the 17 respondents who claimed they were not compensated, 7 stated that they had less than 500 Euros of damage, 4 said that their damage was between 1 000 and 5 000 Euros, 2 that it was between 5 000 and 10 000 Euros, 3 claimed it was between 10 000 and 50 000 Euros, and 1 that it was over 100 000 Euros.

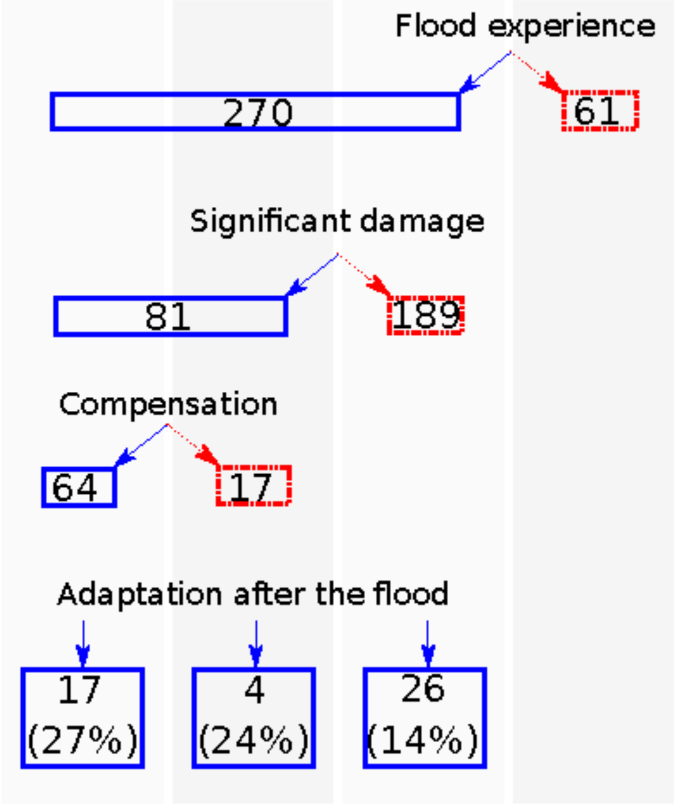


Figure 5: Number of respondents who experienced a flood, suffered significant material damage, were compensated, and took an individual adaptation measure after a flood. Solid lines: "yes"; dashed lines: "no". Each panel represents the following category of respondents, from left to right: 1) experienced a flood, suffered significant material damage, were compensated, 2) experienced a flood, suffered significant material damage, were not compensated, 3) experienced a flood, did not suffer significant material damage, 4) did not experience a flood. The percentages are computed by dividing the number in the same box by the total number of respondents in the category.

6 Discussion

Our study provides three main results. First, we found a negative relationship between the fact of living behind a dike and individual adaptation to floods. Second, this effect could be mitigated by the fact of also living in a FRPP. Finally, the CatNat system does not rule out individual adaptation. In the following, we discuss each of these results, identify their limitations, and consequently provide ideas for future research.

6.1 Negative effect of dike protection on individual adaptation

The negative effect of dike protection on individual adaptation to floods is in line with the levee effect hypothesis, according to which being protected by a dike could provide a feeling of safety and thus foster housing development in areas protected by dikes and reduce the willingness to take adaptation measures (Tobin, 1995).

Few studies have explored the levee effect empirically (Bradford et al., 2012, Ludy and Kondolf, 2012, Scolobig et al., 2012). To our knowledge, our study is the first to provide multivariate analyses that support the levee effect. Therefore, it enables us to weigh its role on individual adaptation against the influence of other factors. According to our results, the negative effect of living behind a dike on individual adaptation decisions is smaller (on average and in absolute value) than the effect of having experienced a flood, being the owner of one's home, and living in a home where adaptation measures are already present.

Further research could examine more precisely the effect of dikes on individual adaptation: on the one hand, hydrological models could be used in order to identify individuals effectively protected by dikes. On the other hand, the heterogeneity of dikes could also be taken into account. According to Brouwer and Van Ek (2004) and Vis et al. (2003), the height of a dike, for example, could affect the perception of the risk of flooding of the inhabitants it protects, and thus the willingness to take adaptation measures. Finally, examining the relationship between the effectiveness of the different adaptation measures and the level of exposure to floods could help identify the measures that are worth taking for people who live behind a dike.

Hence, as policy implication of our results, we can state that the levee effect should be considered when directing information on adaptation measures to the population. Moreover, according to our results, it may be useful to design incentives targeted at people who are not homeowners or have not experienced any flood in order to increase the percentage of people protected by individual adaptation measures.

6.2 Mitigation of the effect of dike protection by the FRPPs

In our models, the negative effect of living behind a dike on individual adaptation is mitigated by the fact of also living in a FRPP. Two possible explanations can be given to this result: first, FRPPs may play as a signal and increase people's awareness of living in a risky area, despite the dike; second, the guidelines of the FRPPs in terms of adaptation measures could have been followed by some respondents in areas protected by dikes.

Although FRPPs in some areas are relatively recent, (see Table 1), implementing such regulation takes years, involving public meetings and discussions, which supports the assumption that the population is aware of the plans. The fact that the relationship between the variable **in building ban area** and individual adaptation is greater in the Aude department than in the Var department supports the assumption that FRPPs influence individual adaptation and that this effect could increase with their age.

Given the fact that zoning has a significant impact, more research could be directed towards the design of the most appropriate risk communication tools. As shown by Dransch et al. (2010) maps have to depict information in a vivid manner and in suitable complexity. Moreover, interactivity is important as it allows people to choose a particular area of interest. The general application of such principles could even re-inforce the role of zoning instruments.

6.3 The CatNat system does not rule out individual adaptation

The third result, our finding that the CatNat system does not rule out individual adaptation, is not in line with the assumption that national compensation schemes completely crowd out individual protection and that there is no incentive for individual action when insurance premiums do not depend on the level of exposure (Latruffe and Picard, 2005, Picard, 2008).

One explanation for the high rate of individual adaptation could be the relative uncertainty about the implementation of the national compensation scheme, which hinges on a ministerial decision about the "natural disaster" character of the event. Indeed, Raschky et al. (2013) found in a comparative study in Austria and Germany that the crowding out effect was stronger when governmental relief was more certain. However, this explanation does not seem to be plausible in France, since the probability of obtaining a favourable decision when asking for the acknowledgement of a natural disaster is very high. Indeed, according to a report from the Caisse Centrale de Réassurance (2011), the state of natural disaster was declared for more than 85% of the municipalities that requested it between 1982 and 2011.

Another explanation is the fact that natural disasters do not generate only material losses. Inhabitants exposed to such risks may indeed want to protect themselves against psychological and other health related damage, which are difficult to compensate. This would also explain why individual action would not depend on the design of the insurance premium. This explanation does not only hold in France but also in other countries and could explain some of the mixed results obtained in the crowding-out literature.

Our results are robust to two potential critiques: first, individuals may not be informed about the compensation scheme, second, they may have incentives from insurers to adopt individual adaptation measures. In our study, more than one quarter of the respondents who experienced the functioning of the national compensation scheme after a flood took at least one adaptation measure after this event. Moreover, as also shown in Poussin et al. (2013), insurers in France do not generally give incentives to take individual adaptation measures.

The compulsory nature of the CatNat system in France did not allow us to finely analyse its influence on the adoption of individual adaptation measures. To further explore the relationship between compensation schemes and adaptation measures, it could be interesting to collect data from inhabitants of flood-prone areas living on both sides of the French-German border in order to compare the tendency to take adaptation measures between people who benefit from the CatNat system, people covered by a market insurance against floods, and people who do not have any insurance.

6.4 A broader perspective

A broader perspective can be gained from the insights of the socio-hydrology literature, which studies the interactions and feedback effects between hydrological and societal phenomena. As discussed by Di Baldassarre et al. (2013), Grames et al. (2016), Viglione et al. (2014), people have always settled close to rivers because of the numerous advantages they provide (rivers are transport corridors, they provide water for industry and agriculture, they constitute valuable natural environments and they generate fertile floodplains). However, floods affect negatively people living in floodplains and may reduce economic growth in the area. "Human adjustments" (White, 1942), or risk management policies can be set up with the aim to reduce the negative effects of floods. Such adjustments influence floods as well as human reactions to floods. For example, building levees generally leads to a shift from frequent flooding to rare, but potentially catastrophic flooding. Moreover, levees induce a decrease in risk awareness among people, as people have less experience of extreme events. Finally, levees may exacerbate high water levels downstream (Di Baldassarre et al., 2013).

Our study could help refine the interactions that are described in socio-hydrological frameworks. We contribute to a better understanding of the interactions between levees and society's protection decisions by studying their effect on individual adaptation measures, which is one dimension of flood preparedness. In some socio-hydrological models, the influence of dikes on protection decisions is mediated by their effect on risk awareness (Di Baldassarre et al., 2013). Because the relation between awareness and preparedness has been found to be weak in the literature (Scolobig et al., 2012)[11], we focus directly on the link between dikes and flood preparedness. This link could be integrated in aggregated models. Our study could also help better define the decision variables considered in socio-hydrological models: social-planners may not only choose the height of dikes and the distance to the river, but also design zoning policies; households may not only decide to move, they can also decide to stay and to adapt. Our study also disentangles possible interactions between different decision variables, revealing the trade-offs between protection from dikes and individual adaptation, and the effect of other explanatory factors such as flood risk experience, exposure and socio-economic factors. In particular, in our case study, the relation between public policies and individual actions

---

[11] One explanation for this is that once individual measures have been taken, individual perception of risk changes (Bubeck et al., 2012, Richert et al., 2017).

is not trivial. Indeed, the presence of levees decreases the probability of individual adaptation but this effect is mitigated by another public policy: the FRPP zoning tool. Such effects could be included in integrated models on hydrological systems and society.

7 Conclusion

Climate change is expected to increase the cost of natural hazards (OECD, 2015). Consequently, designing effective protection policies becomes more important. Promoting integrated flood risk management implies that the interplay between policies be better understood.

The present study examines the relationships between three flood management policies and individual adaptation to floods in France. It suggests that dike protection is a barrier to individual adaptation. On the other hand, adopting zoning policies can be effective to counteract the negative influence of dikes on individual adaptation. Moreover, homeownership is an important determinant for taking adaptation decisions, next to the experience of flood events. The present study also provides elements that temper the assumption that individual adaptation is prevented by national compensation schemes. Maybe the possibility of non-material damage due to floods brings people to act, despite good insurance coverage.

In terms of general recommendations, our results highlight the need for thorough empirical examination of the interactions between policies at different scales, but also across themes. Indeed, while our study reveals that there could be both competitive and complementary effects between policies in the context of flood risk management, the relationships between these policies and others that affect land use and housing should also be examined to better anticipate potential adverse effects.

Acknowledgements

We acknowledge financial support from the RDT research program of the French Ministry of Environment within the frame of the Retina project 13-MRES-RDT-2-CVS-023.

References

Blanco, E., Dutcher, E.G., Haller, T., 2017. To mitigate or to adapt? Collective action under asymmetries in vulnerability to losses. WP from the Faculty of Economics and Statistics, University of Innsbruck 2014-27, 1–35.

Botzen, W.J., Aerts, J.C., van den Bergh, J.C., 2009. Willingness of homeowners to mitigate climate risk through insurance. Ecological Economics 68, 2265–2277. URL: `http://dx.doi.org/10.1016/j.ecolecon.2009.02.019`, doi:`10.1016/j.ecolecon.2009.02.019`.

Bradford, R.A., O'Sullivan, J.J., Van Der Craats, I.M., Krywkow, J., Rotko, P., Aaltonen, J., Bonaiuto, M., De Dominicis, S., Waylen, K., Schelfaut, K., 2012. Risk perception - Issues for flood management in Europe. Natural Hazards and Earth System Science 12, 2299–2309. doi:`10.5194/nhess-12-2299-2012`.

Brouwer, R., Van Ek, R., 2004. Integrated ecological, economic and social impact assessment of alternative flood control policies in the Netherlands. Ecological Economics 50, 1–21. doi:`10.1016/j.ecolecon.2004.01.020`.

Bryman, A., Cramer, D., 2005. Quantitative Data Analysis With SPSS 12 and 13 - A Guide for Social Scientists.

Bubeck, P., Botzen, W.J.W., Aerts, J.C.J.H., 2012. A Review of Risk Perceptions and Other Factors that Influence Flood Mitigation Behavior. Risk Analysis 32, 1481–1495. URL: `http://doi.wiley.com/10.1111/j.1539-6924.2011.01783.x`, doi:`10.1111/j.1539-6924.2011.01783.x`.

Bubeck, P., Botzen, W.J.W., Kreibich, H., Aerts, J.C.J.H., 2013. Detailed insights into the influence of flood-coping appraisals on mitigation behaviour. Global Environmental Change 23, 1327–1338. URL: `http://dx.doi.org/10.1016/j.gloenvcha.2013.05.009`, doi:`10.1016/j.gloenvcha.2013.05.009`.

Burby, R.J., 2001. Flood insurance and floodplain management: the US experience. Global Environmental Change Part B: Environmental Hazards 3, 111–122.

Burby, R.J., 2006. Hurricane Katrina and the Paradoxes of Government Disaster Policy: Bringing

About Wise Governmental Decisions for Hazardous Areas. The Annals of the American Academy of Political and Social Science 604, 171–191. doi:`10.1177/0002716205284676`.

Caisse Centrale de Réassurance, 2011. Le régime d'indemnisation des catastrophes naturelles. Technical Report.

Centre Européen de Prévention du Risque d'Inondation, 2017. Les ouvrages de protection contre les inondations. Technical Report.

Di Baldassarre, G., Viglione, A., Carr, G., Kuil, L., Salinas, J.L., Blöschl, G., 2013. Socio-hydrology: Conceptualising human-flood interactions. Hydrology and Earth System Sciences 17, 3295–3303. doi:`10.5194/hess-17-3295-2013`.

Dransch, D., Rotzoll, H., Poser, K., 2010. The contribution of maps to the challenges of risk communication to the public. International Journal of Digital Earth 3, 292–311. URL: `http://www.tandfonline.com/doi/abs/10.1080/17538941003774668`, doi:`10.1080/17538941003774668`.

Ehrlich, I., Becker, G.S., 1972. Market Insurance, Self-Insurance, and Self-Protection. Journal of political Economy 80, 623–648.

Erdlenbruch, K., Bonté, B., 2018. Simulating the dynamics of individual adaptation to floods. Environmental Science & Policy 84, 134–148.

Erdlenbruch, K., Thoyer, S., Grelot, F., Kast, R., Enjolras, G., 2009. Risk-sharing policies in the context of the French Flood Prevention Action Programmes. Journal of Environmental Management 91, 363–369. URL: `http://dx.doi.org/10.1016/j.jenvman.2009.09.002`, doi:`10.1016/j.jenvman.2009.09.002`.

Filatova, T., 2014. Market-based instruments for flood risk management: A review of theory, practice and perspectives for climate adaptation policy. Environmental Science & Policy 37, 227–242. doi:`10.1016/j.envsci.2013.09.005`.

Grames, J., Prskawetz, A., Grass, D., Viglione, A., Blöschl, G., 2016. Modeling the interaction between flooding events and economic growth. Ecological Economics 129, 193–209. URL: `https://www.sciencedirect.com/science/article/pii/S0921800915303980`, doi:`10.1016/J.ECOLECON.2016.06.014`.

Grislain-Letrémy, C., Peinturier, C., 2010. Le régime d'assurance des catastrophes naturelles en France métropolitaine entre 1995 et 2006. Technical Report. Commissariat Général au Développement Durable.

Grothmann, T., Reusswig, F., 2006. People at Risk of Flooding: Why Some Residents Take Precautionary Action While Others Do Not. Natural Hazards 38, 101–120. URL: `http://link.springer.com/10.1007/s11069-005-8604-6`, doi:`10.1007/s11069-005-8604-6`.

Hudson, P., Botzen, W.J.W., Czajkowski, J., Kreibich, H., 2017. Moral hazard in natural disaster insurance markets: Empirical evidence from germany and the united states. Land Economics 93, 179–208. doi:`10.3368/le.93.2.179`.

Jaffee, D.M., Russell, T., 1997. Catastrophe Insurance, Capital Markets, and Uninsurable Risks. The Journal of Risk and Insurance 64, 205–230.

Kelly, M., Kleffner, A.E., 2003. Optimal Loss Mitigation and Contract Design. Journal of Risk & Insurance 70, 53–72. URL: `http://doi.wiley.com/10.1111/1539-6975.00047`, doi:`10.1111/1539-6975.00047`.

Kousky, C., Michel-Kerjan, E.O., y, P.A., 2018. Does federal disaster assistance crowd out flood insurance? Journal of Environmental Economics and Management 87, 150–164. URL: `http://dx.doi.org/10.1016/j.jeem.2017.05.010`, doi:`10.1016/j.jeem.2017.05.010`.

Kunreuther, H., Novemsky, N., Kahneman, D., 2001. Making Low Probabilities Useful. The Journal of Risk and Uncertainty 23, 103–120.

Latruffe, L., Picard, P., 2005. Assurance des catastrophes naturelles : Faut-il choisir entre prévention et solidarité ? Annales d'Economie et de Statistique 78, 33–56.

Lewis, T., Nickerson, D., 1989. Self-insurance against natural disasters. Journal of Environmental Economics and Management 16, 209–223. doi:`10.1016/0095-0696(89)90010-7`.

Ludy, J., Kondolf, G.M., 2012. Flood risk perception in lands "protected" by 100-year levees. Natural Hazards 61, 829–842. doi:`10.1007/s11069-011-0072-6`.

McFadden, 1974. "Frontiers in Econometrics". NY Academic Press. chapter 4: Conditi. pp. 105–142.

MEDDE, 2012. Mieux savoir pour mieux agir : principaux enseignements de la première évaluation des risques d'inondation sur le territoire français. Technical Report. Ministère de l'écologie, du développement durable, et de l'énergie. Paris.

Munich RE, 2018. NatCatSERVICE - Natural catastrophe know-how for risk management and research. URL: `https://natcatservice.munichre.com/`.

OECD, 2015. The Economic Consequences of Climate Change. Technical Report.

Peduzzi, P., Concato, J., Kemper, E., Holford, T.R., Feinstem, A.R., 1996. A simulation study of the number of events per variable in logistic regression analysis. Journal of Clinical Epidemiology 49, 1373–1379. doi:`10.1016/S0895-4356(96)00236-3`.

Picard, P., 2008. Natural Disaster Insurance and the Equity-Efficiency Trade-Off. The Journal of Risk and Insurance 75, 17–38.

Pielke, R.A., 1999. Nine fallacies of floods. Climatic Change 42, 413–438.

Pinter, N., 2005. One Step Forward, Two Steps Back on U.S. Floodplains. Science 308, 207–208. URL: `http://www.sciencemag.org/content/306/5701/1482.short`, doi:`10.1126/science.1103788`.

Poussin, J.K., Botzen, W.J.W., Aerts, J.C.J.H., 2013. Stimulating flood damage mitigation through insurance: an assessment of the french catnat system. Environmental Hazards 12, 258–277. doi:`10.1080/17477891.2013.832650`, `arXiv:http://www.tandfonline.com/doi/pdf/10.1080/17477891.2013.832650`.

Poussin, J.K., Botzen, W.W., Aerts, J.C., 2014. Factors of influence on flood damage mitigation behaviour by households. Environmental Science & Policy 40, 69–77. URL: `http://linkinghub.elsevier.com/retrieve/pii/S1462901114000264`, doi:`10.1016/j.envsci.2014.01.013`.

Raschky, P.A., Schwarze, R., Schwindt, M., Zahn, F., 2013. Uncertainty of Governmental Relief and the Crowding out of Flood Insurance. Environmental and Resource Economics 54, 179–200. URL: `http://link.springer.com/10.1007/s10640-012-9586-y`, doi:`10.1007/s10640-012-9586-y`.

Reynaud, A., Aubert, C., Nguyen, M.H., 2013. Living with Floods: Protective Behaviours and Risk Perception of Vietnamese Households. The Geneva Papers on Risk and Insurance Issues and Practice 38, 547–579. URL: `http://www.palgrave-journals.com/doifinder/10.1057/gpp.2013.16`, doi:`10.1057/gpp.2013.16`.

Richert, C., 2017. Les décisions individuelles d'adaptation aux inondations : le cas de résidents en zones inondables dans le Sud de la France. Ph.D. thesis. Université de Montpellier.

Richert, C., Erdlenbruch, K., Figuières, C., 2017. The determinants of households' flood mitigation decisions in France - on the possibility of feedback effects from past investments. Ecological Economics 131. doi:`10.1016/j.ecolecon.2016.09.014`.

Samuels, P., Klijn, F., Dijkman, J., 2006. An analysis of the current practice of policies on river flood risk management in different countries. Irrigation and Drainage 55, 141–150.

Scolobig, A., De Marchi, B., Borga, M., 2012. The missing link between flood risk awareness and preparedness: Findings from case studies in an Alpine Region. Natural Hazards 63, 499–520. doi:`10.1007/s11069-012-0161-1`.

Tobin, G.A., 1995. The levee love affaire: a stormy relationship? Journal of the American Water Resources Association 31, 359–367.

Train, K.E., 2002. Discrete Choice Methods with Simulation. Cambridge University Press.

Viglione, A., Di Baldassarre, G., Brandimarte, L., Kuil, L., Carr, G., Salinas, J.L., Scolobig, A., Blöschl, G., 2014. Insights from socio-hydrology modelling on dealing with flood risk – Roles of collective memory, risk-taking attitude and trust. Journal of Hydrology 518, 71–82. doi:`10.1016/J.JHYDROL.2014.01.018`.

Vinet, F., 2008. Geographical analysis of damage due to flash floods in southern France: The cases of 12 – 13 November 1999 and 8 – 9 September 2002. Applied Geography 28, 323–336. doi:`10.1016/j.apgeog.2008.02.007`.

Vinet, F., Lumbroso, D., Defossez, S., Boissier, L., 2012. A comparative analysis of the loss of life during two recent floods in France: the sea surge caused by the storm Xynthia and the flash flood in Var. Natural Hazards 61, 1179–1201. doi:`10.1007/s11069-011-9975-5`.

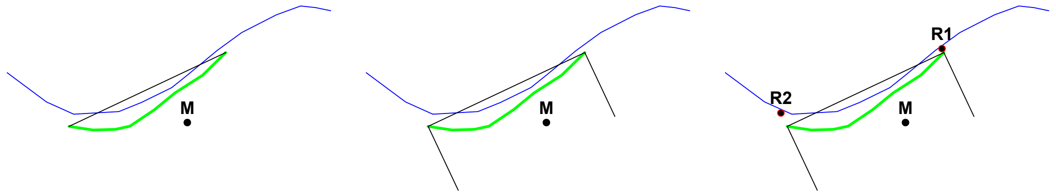
Vis, M., Klijn, F., Bruijn, K.M., Buuren, M.V., 2003. Resilience strategies for flood risk management in the Netherlands. International Journal of River Basin Management 1, 33–40. doi:`10.1080/15715124.2003.9635190`.

Wachinger, G., Renn, O., Begg, C., Kuhlicke, C., 2013. The Risk Perception Paradox — Implications for Governance and Communication of Natural Hazards. Risk Analysis 33, 1049–1065. doi:`10.1111/j.1539-6924.2012.01942.x`.

White, G.F., 1942. Human Adjustment to floods. Ph.D. thesis. University of Chicago. Chicago.

A Construction of the variable behind dike

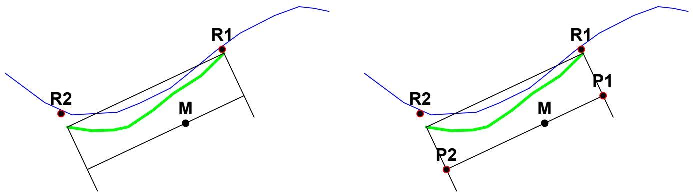
For each respondent, in order to determine whether his/her dwelling is behind a dike or not, we first found the closest river. If this latter is not protected by the dike which is the closest to the respondent, we assumed that the respondent is not behind a dike. Otherwise, we followed the process explained in figure 6: the dike is assumed to be located between a respondent's dwelling M and a river if the point M is located between the points P1 and P2 and if the dike's ends are respectively between R1 and P1 or R2 and P2.



(a) We approximated the dike which is the closest to the respondent's dwelling M by the straight line that goes through both of its ends.

(b) We found the two straight lines that are orthogonal to the one defined at stage (a) and that go through each end of the dike.

(c) We call R1 and R2 the intersections between the two lines defined at stage (b) and the river.



(d) We found the straight line that is orthogonal to the ones defined at stage (b) and that goes through M.

(e) We call P1 and P2 the intersections between the line defined at stage (d) and each of the lines defined at stage (b).

Figure 6: Stages followed to define whether each respondent's dwelling is located behind a dike. The dike is in green and the river in blue.

B Correlation between the independent variables

Table 11 indicates the Spearman correlation coefficients computed for all pairs of independent variables used in the study.

Table 11: Spearman correlation coefficients between the independent variables

	Variables of interest			Control variables						
	1	2	3	4	5	6	7	8	9	10
1	1	0.60 ***	0.25 ***	-0.18 ***	-0.09 *	-0.03	-0.05	0.02	-0.38 ***	-0.19 ***
2	-	1	0.14 **	-0.37 ***	0.06	-0.12 **	-0.01	0.08	-0.32 ***	-0.21 ***
3	-	-	1	0.05	-0.15 ***	-0.02	-0.03	-0.01	0.11 **	-0.25 ***
4	-	-	-	1	-0.19 ***	0.14 **	-0.03	-0.01	0.45 ***	0.10 *
5	-	-	-	-	1	0.09 *	-0.05	0.32 ***	-0.06	-0.04
6	-	-	-	-	-	1	0.05	0.09 *	0.26 ***	0.13 **
7	-	-	-	-	-	-	1	0.08	0.10 *	0.09
8	-	-	-	-	-	-	-	1	0.09	-0.04
9	-	-	-	-	-	-	-	-	1	0.03
10	-	-	-	-	-	-	-	-	-	1

N = 331. *: $p<0.1$; **: $p<0.05$; ***: $p<0.01$. 1: in FRPP; 2: in building ban area; 3: behind dike; 4: distance to the nearest river; 5: exposure; 6: education level; 7: experience; 8: ownership; 9: department; 10: present before arrival