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REVIEW ARTICLE

Impacts of Flooding and Flood Preparedness on Subjective Well-Being: A Monetisation of the Tangible and Intangible Impacts

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Abstract Flood disasters severely impact human subjective well-being (SWB). Nevertheless, few studies have examined the influence of flood events on individual well-being and how such impacts may be limited by flood protection measures. This study estimates the long term impacts on individual subjective well-being of flood experiences, individual subjective flood risk perceptions, and household flood preparedness decisions. These effects are monetised and placed in context through a comparison with impacts of other adverse events on well-being. We collected data from households in flood-prone areas in France. The results indicate that experiencing a flood has a large negative impact on subjective well-being that is incompletely attenuated over time. Moreover, individuals do not need to be directly affected by floods to suffer SWB losses since subjective well-being is lower for those who expect their flood risk to increase or who have seen a neighbour being flooded. Floodplain inhabitants who prepared for flooding by elevating their home have a higher subjective well-being. A monetisation of the aforementioned well-being impacts shows that a flood requires €150,000 in immediate compensation to attenuate SWB losses. The decomposition of the monetised impacts of flood experience into tangible losses and intangible effects on SWB shows that intangible effects are about twice as large as the tangible direct monetary flood losses. Investments in flood protection infrastructure may be under funded if the intangible SWB benefits of flood protection are not taken into account.

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1 Introduction

Natural hazards can have large societal impacts. As an illustration, it is estimated that natural hazards caused 7700 fatalities and $110 billion losses worldwide in 2014 (Munich Re 2015). Out of the set of natural hazards, flooding is often regarded as having the greatest effect on humanity (UNISDR 2011). Flood losses are expected to increase in frequency and severity in the future due to a combination of socio-economic development and climate change (IPCC 2012). It has been argued that in order to optimally manage changing risk, good estimates of flood risks are required which is often measured as direct property losses, an important input for cost–benefit analysis that guide investments in flood risk management strategies (Mechler 2016). However, a comprehensive societal cost–benefit analysis should also include intangible losses caused by floods, e.g. psychological damage or anxiety (Lamond et al. 2015) in addition the tangible or monetary losses. Intangible losses are often neglected in risk assessments compared to tangible flood losses (e.g. property losses), perhaps due to the perceived difficulty of converting intangible losses into monetary values (Prettenthaler et al. 2015). The inclusion of intangible losses in societal cost–benefit studies are required in order to move closer towards a fuller view of welfare.

Natural hazards can negatively affect the well-being of households that experience the hazard which results in non-monetary or intangible losses (Lamond et al. 2015). For example, the following could be considered as intangible or non-monetary losses: loss of life; the number of affected people; and the loss of biodiversity or damage to eco-systems (Prettenthaler et al. 2015). Moreover, there could be emotional impacts when peoples' homes and personal property are damaged, such as stress and inconvenience, which adversely influence human welfare (Lamond et al. 2015) in addition to the consequences emanating from serve monetary losses. Kunreuther and Pauly (2015) argue that these emotional effects can be important to determine how individuals respond to a flood. For instance, negative emotions, such as worry of flooding or regret of insufficient disaster preparedness, can encourage a person to buy flood insurance or to take other preparatory measures. These effects should be included in risk assessments and the resulting risk management strategies.

Researchers can directly investigate welfare by asking individuals about their happiness also referred to as subjective well-being, henceforth SWB (MacKerron 2011). SWB scales can be an accurate proxy of the individual's level of overall SWB (Kahneman and Krueger 2006; Krueger and Schkade 2008) and can, for example, be applied to valuing negative impacts on an individual's welfare (e.g. Frey et al. 2009). Dolan et al. (2008) provide an extensive review of this literature and discuss the variables found to have a robust relationship with SWB. Dolan et al. (2008) do not address the relationships between natural hazards and welfare (Dolan et al. 2008). Relatively few studies have examined the connection between the impacts of natural hazards, such as flooding, and SWB. An exception is the study of Luechinger and Raschky (2009), who investigate the consequences of droughts and floods, respectively, on SWB and find significant SWB losses. Luechinger and Raschky (2009) analyse data from surveys of American and European households and show that flood events have a negative effect on welfare. Moreover, they find tentative evidence that risk transfer mechanisms, such as insurance, can attenuate the welfare losses due to flooding (Luechinger and Raschky 2009). However, Luechinger and Raschky (2009) use aggregated survey data that cannot make a link between flood experiences and SWB at the individual level. Therefore, using more refined survey data is a useful next step in studying the welfare impacts of natural disasters at the household level.

This paper has several objectives. The first is to estimate the long term SWB impacts of experiencing a flood for households exposed to flooding, and to examine how these impacts can be offset by flood preparedness measures taken at the household level. The second is to monetise these effects, if found, in order to separate tangible (traditionally measured in monetary terms) and intangible welfare losses (not a direct monetary impact) in order to assess their relative magnitudes which can provide useful insights for flood risk assessments.

Data has been collected by a survey of about 900 flood-prone households in France. We estimate relations between flood experience, flood risk perceptions and flood preparedness with overall SWB. Several studies have found that household level flood preparedness measures are effective at reducing the damage suffered during a flood (e.g. Hudson et al. 2014; Poussin et al. 2015). In this study we investigate the relation with SWB and implementing the following measures: elevation, whereby households have elevated their building's ground floor above the likely flood water height; dry flood-proofing measures, whereby households employ small scale measures aimed at preventing water from entering the building; wet flood-proofing measures, whereby households employ measures aimed at limiting damage once water has entered a building, for example by using water-resistant construction materials for foundations or flooring.

The results are then monetised to separate tangible and intangible losses, providing a novel contribution to the scarce literature on this topic. Monetisation of well-being impacts is the process of transforming non-monetary impacts of an experience, such as a flood, on SWB into an equivalent monetary value. That way SWB impacts are translated into a readily understood and comparable metric, like money. The monetisation process is conducted by measuring the ratio of the effect of an event on SWB to that of how SWB is related to an income increase. This ratio indicates the change in income required to compensate (equate) for SWB changes caused by experiencing the negative (positive) event. Once a monetary value has been associated to a SWB impact, it is decomposed into parts that correspond to tangible and intangible impacts. Tangible impacts are those with a pre-existing monetary value, such as flood damage suffered or damage prevented from flood preparedness measures. Intangible impacts are the remaining impacts without pre-existing monetary values, such as discomfort and psychological impacts from flooding.

The remainder of this paper is structured as follows. Section 2 presents the data and methodology. Section 3 gives the results which are discussed in Sect. 4. Section 5 concludes.

2 Data and Methodology

2.1 Survey and Data Description

A mail survey was conducted in France in 2011 to collect data from a random sample of households in 3 regions (the Var, West, and the Ardennes). These regions are at risk of flooding and differ with respect to: past experiences with floods (i.e. not all respondents have been personally flooded); the type of floods; the time passed since the last flood; the probabilities of flooding; flood related losses; and the local ‘flood cultures’.

The survey response rate was 10.5%, which resulted in 885 returned questionnaires, which is in line with other surveys (e.g. Joseph et al. 2015) regarding flood related topics. A comparison between official statistics of the sampled population and statistics of characteristics of our respondents shows that the sample is approximately representative of the French population as a whole (Poussin et al. 2013). More details regarding the survey can be found in Poussin et al. (2013) and in the Online Supplementary Information (SI), Section SI.A. The key variables used in our analysis are described in Table 1 and descriptive statistics that are relevant for this particular application are provided in Table 2.

Many of our respondents experienced flooding. About seventy percent of the sample has been flooded in their current home before and many respondents (41%) had experienced a flood within the previous 12 months of being surveyed. Moreover, just over half of the sample has been in a near miss situation in which the community surrounding their current home was flooded, but the respondent was not. For the purposes of our evaluation it is not required that all the individuals experienced the same flood, because we are interested in examining how SWB is related with flood experiences that occurred at different times in the past. For example, recent floods may have a larger impact on current SWB than floods that occurred a long time ago. In this respect, the large number of individuals that have been flooded within 12 months of the survey allows for detecting the more immediate impact of flood events on SWB. According to the availability heuristic, the more recent the flood event, the more focused it is in the minds of the respondents (Tversky and Kahneman 1973). This variable may also relate to the frequency of flooding since people who are frequently flooded are more likely to have been flooded in the recent past.

There is a heterogeneity in answers to the subjective flood risk perception questions which provides a basis for examining its influence on SWB. The question asked a respondent to rate their belief that damage will be high during a future flood and a similar question asked to rate a respondent’s belief that flood risk will increase or not. The proportion of respondents that believe that their flood risk will increase or that they will suffer a high degree of damage in the case of a flood event is approximately forty percent (40%). The proportion of people who worry about the current and (or) future flood probability is about sixty percent (60%). Thus, many respondents believe that they will face a worsening problem with flooding, which is in line with several studies (e.g. Dumas et al. 2013).

2.2 Methodology

A summary of our overall methodology is visualized in Fig. 1. The statistical analysis which is used the estimate the influence of flood experience, flood risk perceptions, and flood preparedness on SWB is explained in detail in Sect. 2.2.1 and the monetisation of these relations is explained in Sect. 2.2.2.

2.2.1 Regression Models

The literature offers two interpretations of SWB values: ordinal vales, which means that no importance is placed on the number itself, but rather on the position of the number in the scale (Ferrer-i-Carbonell 2005); cardinal values which means the number itself matters and the scores can be counted (van Praag et al. 2003). Both interpretations can deliver equally robust results (e.g. Frey et al. 2009). We will employ regressions consistent with

Table 1 List of variable definitions

Variable name	Definition
Panel A: Subjective well-being (domains)	
Overall SWB	A categorical variable on a scale of 0–10 describing the respondent's degree of overall SWB.
SWB with health	A dummy variable taking the value 1 if a respondent is satisfied with their health and 0 otherwise.
SWB with home	A dummy variable taking the value 1 if a respondent is satisfied with their home and 0 otherwise.
SWB with living environment	A dummy variable taking the value 1 if a respondent is satisfied with their general living environment and 0 otherwise.
SWB with financial situation	A dummy variable taking the value 1 if a respondent is satisfied with their general financial situation and 0 otherwise.
SWB with the amount and use of their free time	A dummy variable taking the value 1 if a respondent is satisfied with their free time and 0 otherwise.
SWB with family life	A dummy variable taking the value 1 if a respondent is satisfied with their family life and 0 otherwise.
SWB with social life	A dummy variable taking the value 1 if a respondent is satisfied with their social and 0 otherwise.
Panel B: Flood risk perceptions	
Worries about current and/or future flood probabilities	A dummy variable taking the value 1 if a respondent is worried over their flood probabilities and 0 otherwise.
Expects high damage if flooded	A dummy variable taking the value 1 if a respondent thinks that it is likely high damage will be suffered during a flood and 0 otherwise.
Expects future flood risk to increase	A dummy variable taking the value 1 if a respondent believes it is likely that their person flood risk will increase and 0 otherwise.
Panel C: Flood experiences	
Flooded before	A dummy variable taking the value 1 if a respondent has been flooded in the past either in their current or previous home and 0 otherwise.
Flooded within the last year	A dummy variable taking the value 1 if a respondent has been flooded in the past either in their current or previous home within the 12 months previous to completing the survey and 0 otherwise.
Neighbour has been flooded when respondent was not	A dummy variable taking the value 1 if a respondent has had a neighbour flooded while themselves were not and 0 otherwise.
Panel D: Individual flood protection measures	
Has undertaken dry flood-proofing.	A dummy variable taking the value 1 if a respondent owns sandbags or other water barriers or anti-backflow valves are installed on pipes to stop flood-waters from entering the home through the pipes and 0 otherwise.
Has elevated their building	A dummy variable taking the value 1 if the level of the ground floor is elevated above the most likely flood level and 0 otherwise.
Wet flood-proofing	A dummy variable taking the value 1 if the foundations/materials have been strengthened to resist water and 0 otherwise.

the cardinal interpretation in order produce regression coefficients that are intuitive to interpret.[1]

[1] Ordered logit models that are consistent with the ordinal interpretation were also estimated (results reported in SI.D), which provided similar results.

Table 2 Summary of descriptive statistics of key variables

Variable name	Average value	Standard deviation	Range
Panel A: Subjective well-being (domains)			
Overall SWB	7.32	1.79	{0,1,2,3,4,5,6,7,8,9,10}
Happy with health	0.79	0.41	{0,1}
Happy with home	0.85	0.36	{0,1}
Happy with living environment	0.81	0.39	{0,1}
Happy with financial situation	0.68	0.47	{0,1}
Happy with the amount and use of their free time	0.67	0.47	{0,1}
Happy with family life	0.89	0.32	{0,1}
Happy with social life	0.83	0.38	{0,1}
Panel B: Flood risk perceptions			
Worries about current and/or future flood probabilities	0.60	0.49	{0,1}
Expects high damage if flooded	0.43	0.50	{0,1}
Expects future flood risk to increase	0.45	0.50	{0,1}
Panel C: Flood experiences			
Flooded before	0.71	0.46	{0,1}
Flooded within the last year	0.41	0.49	{0,1}
Neighbour has been flooded when respondent was not	0.56	0.5	{0,1}
Panel D: Individual flood protection measures			
Has undertaken dry flood-proofing.	0.12	0.33	{0,1}
Has elevated their building	0.47	0.50	{0,1}
Wet flood-proofing	0.20	0.50	{0,1}
Number of observations	422		

The framework that assumes that overall SWB can be decomposed into several subjective well-being domains (SWBDs) results in Eq. (1), with possible interactions between the SWBDs (van Praag et al. 2003). To examine the possibility of interactions between the SWBDs, a mediation style analysis is conducted. For example, a flood can affect SWB directly or indirectly through the SWBDs.

Various styles of mediation can occur based whether there is a complementary or competitive effect (both a direct effect and indirect through the mediating variable act in either the same or opposing direction), indirect-only (only effects through the mediator), direct-only (no indirect effect) (Zhao et al. 2010).

We apply a mediation analysis which estimates a set of regression models simultaneously via seemingly unrelated regressions. Seemingly unrelated regressions are used in order to model the set of equations with correlated error terms. Accounting for this correlation is relevant since a shock in a single SWBD may be transferred to other SWBDs, because each observation of the SWBD variables is from the same individual.

This is show in Eq. (1), whereby, $\in_i$ is the random error and $FR(.)$ represents the flood risk SWBD that is of particular interest. The parameter to be estimated for the impact of a $SWBD_{i,j}$ on overall $SWBD_i$ is β_j, while $\boldsymbol{\gamma}$ is a vector of parameters; $\overline{\gamma_{0,j}}$ and $\overline{\gamma_j}$ are parameters for the jth $SWBD_{i,j}$ for individual i and ε_j is the individual SWBD error term which can be correlated:

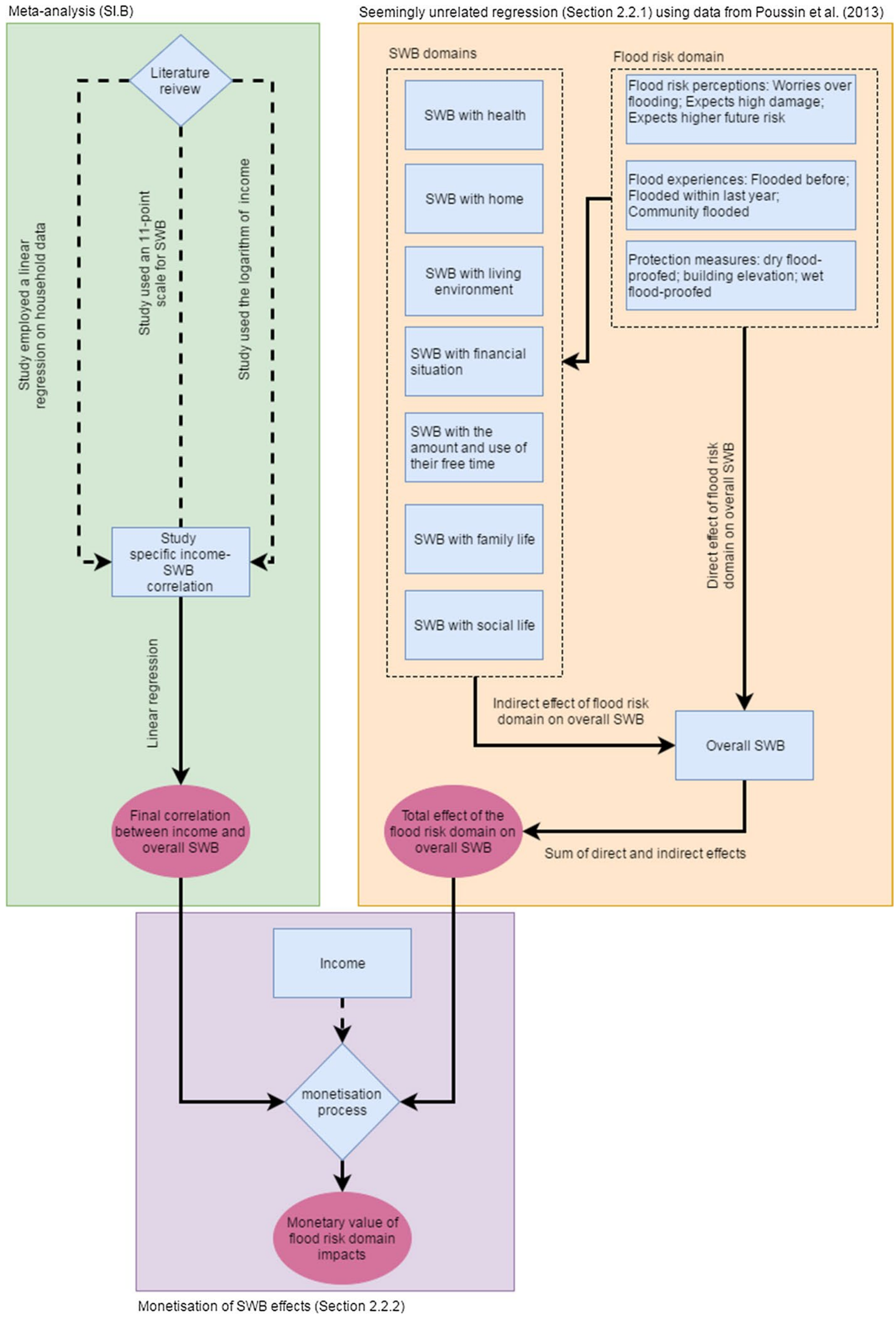

Fig. 1 Visualization of the methodology. *Notes*: *Dashed lines* represent data flows. *Solid lines* represent modelling flows. *Pink ovals* represent objectives. *Blue rectangles* represent data input variables. A *blue diamond* represents data input processes. (Color figure online)

$$\begin{cases} SWB_i = \beta_0 + \sum_1^7 \beta_j SWBD_{i,j} + FR\left(Experience_i, Perceptions_i, Flood\,preparedness_i\right)\boldsymbol{\gamma} + \in_i \\ SWBD_{i,1} = \overline{\gamma_{0,1}} + FR\left(Experience_i, Perceptions_i, Flood\,preparedness_i\right)\overline{\gamma_7} + \varepsilon_i \\ \vdots \\ SWBD_{i,7} = \overline{\gamma_{0,7}} + FR\left(Experience_i, Perceptions_i, Flood\,preparedness_i\right)\overline{\gamma_7} + \varepsilon_7 \end{cases} \tag{1}$$

In Eq. (1) *FR*(.) consists of three elements: previous flood experiences; subjective perceptions of current and future flood risk; household level flood risk management strategies. These variables are included in this SWBD for three reasons. First, flood events are negative events in an individual's life. Second, the flood risk perception and worry variables are likely to have an effect on SWB because flooding is an endemic risk in the sampled areas. Subjective beliefs regarding the probability and magnitude of flood events are likely to reduce the degree of life satisfaction. Third, the flood preparedness decision variables are included because better preparation for a flood may make an individual less unhappy with living in a flood-prone area, since the risk of living there is lower.

The first element of Eq. (1) replicates a standard linear regression; however, the standard errors may be different due to an altered structure of the covariance-variance matrix to account for cross-correlations. Mediation analysis via seemingly unrelated regressions allows for calculating the direct effect of *FR(.)* on SWB and indirect effects through the SWBDs following Eq. (2). The experience element of *FR(.)* is used as an example, but it should be realized that the formula is similar for the other elements. In Eq. (2) $\gamma^{Experience}$ represents the direct effect of the variable on SWB, while $\sum_1^7 \beta_j \overline{\gamma_1^{Experience}}$ is the total indirect effect of the flood risk SWBD as it acts through the different other SWBDs.

$$Total\,effect_{Experience} = \boldsymbol{\gamma}^{\boldsymbol{Experience}} + \sum_1^7 \beta_j \overline{\gamma_1^{Experience}}. \tag{2}$$

2.2.2 Monetisation of SWB Impacts

Monetisation of the effects of *FR(.)* on SWB is based on the trade-off between income and SWB. The resulting value is called the compensating value (CV). CVs are calculated via the ratio of the marginal effect of the variable of interest to the marginal effect of income on SWB. This results in the amount of money that equates SWB before and after an event (Clark and Oswald 2002). For instance, the CV of the effect of flood experience on SWB estimates the amount of money someone would need as compensation for this experience to arrive at the same SWB level before the flood happened.

It would be preferable to generate a relationship between income and SWB from our own dataset. However, the model already includes the financial SWBD which means that it is inappropriate to include an income variable.[2] An alternative approach is to model the impact of income on SWB through the indirect effect that income has on the financial SWBD using a mediation analysis. The survey elicited household income via categorical

[2] Other control variables may suffer from similar problems due to the SWBDs acting aggregation sources of SWB.

income classes. This variable can be converted to a continuous variable by assuming that each observation takes the value equal to the mid-point value in the income class boundaries.[3] The logarithm of income is used which results in a semi-elasticity of 0.22 with a standard error of 0.23, suggesting a highly uncertain value for monetisation. To overcome this limitation we employ a meta-analysis, which is a commonly applied method for value transfer (Wilson and Hoehn 2006). The meta-analysis (described in SI.B) estimates a value of 0.21, which is very close to our within sample estimate of 0.22. The meta-analysis value will be used for our final monetisation.

The CV is calculated following Eq. (3) where the term '$Variable_x$' stands for the explanatory variable of which its effect on SWB will be monetised, which has the regression coefficient β_x. β_{income} is the regression coefficient for the relationship between income and overall SWB. Equation (3) takes its form due to the use of the logarithm of income resulting in a semi-elasticity value.[4] In effect, it estimates the percentage change in income required to compensate for negative life events.

$$CV = -\frac{\beta_x}{\beta_{income}} Income \tag{3}$$

A 90% confidence interval of CV is constructed that takes the uncertainty into account regarding both the correlation between income and overall SWB as well as between the flood risk SWBD components and overall SWB.

The monetary value of an intangible effect, such as experiencing a flood or flood preparedness, is estimated following Eq. (4). The value of intangible impacts is estimated by subtracting the tangible impacts from the monetised value of SWB impacts. For estimating the intangible impacts of flood experience or flood risk perceptions the experienced flood damage is used as tangible flood impact in Eq. (4), while flood damage avoided is used to estimate intangible impacts of flood preparedness. For instance in the latter case, the intangible benefits of flood preparedness are estimated by subtracting the tangible benefits of prevented flood damage from the total monetised SWB benefits of flood preparedness. We use the average tangible impacts from Poussin et al. (2015) who have estimated these already for our sample. As an illustration, suppose that the CV of the total SWB impact for being affected by a flood is equal to €100, while the tangible damage suffered during a flood was €25, then the intangible loss would be estimated as €75.

$$\begin{gathered} Intangible\,Impact = |CV| - Tangible\,Flood\,Impact, \\ Tangible\,Flood\,Impact = \begin{cases} Experienced\,flood\,damage \\ Flood\,damage\,avoided \end{cases}. \end{gathered} \tag{4}$$

3 Results

Table 3 displays the results of the main statistical models. The estimated SWBD parameters indicate that being happy with their financial situation, health or family are the most powerful explanatory variables to determine overall SWB and are of roughly equal strength

[3] A drawback of this approach is that, the results are quite sensitive to how the income categories are converted into continuous values.

[4] As Eq. (4) can also be written as $\frac{\partial \ln(income)}{\partial SWB_x}$, this is approximately equal to the percentage change in income given a one unit change in x.

Table 3 Estimated parameters of the regression models

	Direct effect	Indirect effect	Total effect
Constant	4.50*** (0.44)		
Happy with health	0.77*** (0.24)		
Happy with home	0.76*** (0.27)		
Happy with living environment	0.59*** (0.22)		
Happy with financial situation	0.73*** (0.18)		
Happy with the amount and use of their free time	0.25 (0.17)		
Happy with family life	0.85*** (0.30)		
Happy with social life	0.53** (0.26)		
Worries about current and/or future flood probabilities	−0.15 (0.16)	−0.34** (−0.14)	−0.49** (0.19)
Expects high damage if flooded	−0.16 (0.16)	0.01 (0.14)	−0.16 (0.21)
Expects future flood risk to increase	−0.26* (0.13)	−0.40*** (0.12)	−0.66*** (0.17)
Flooded before	−0.51** (0.23)	−0.01 (0.21)	−0.51* (0.31)
Flooded within the last year	−0.48** (0.23)	−0.27 (0.20)	−0.74** (0.31)
Neighbour has been flooded when respondent was not	−0.26** (0.13)	−0.14 (0.11)	−0.40** (0.17)
Has elevated their building	0.2 (0.13)	0.13 (0.12)	0.33* (0.17)
Has undertaken dry flood-proofing.	0.44** (0.22)	−0.08 (0.16)	0.36 (0.25)
There is a household plan on how to cope with a flood	0.26 (0.20)	−0.10 (0.16)	0.15 (0.26)
Wet flood-proofing	−0.018 (0.170)	0.173 (0.131)	0.155 (0.224)
N	422		
R^2	0.477		

Values within parentheses are standard errors, which are heteroscedasticity corrected. *, **, *** stand for statistical significance at the 10.5 and 1% level respectively; R^2 is for direct effects

(coefficient ~0.8, SE = 0.3, $p < 0.01$). The variables 'satisfaction with the living environment' or 'social life' are the next most powerful SWBDs, (with coefficients of 0.6 and 0.5, $p < 0.05$). The SWBDs act in the expected manner since satisfaction with a single area of life results in a higher overall level of SWB.

The effect of the memory of being flooded and being flooded within the last 12 months are each correlated with a fall in overall SWB (total effect = 1.3, $p < 0.05$). These overall SWB impacts imply a compensation equivalent to €150,000 for the mean household income or €130,000 for median household income ($p < 0.05$) as shown in Table 4. The majority of this impact is driven by the immediate impacts of a flood because after a year the SWB impact is just under half (at €61,000, $p < 0.1$). The indirect effects are negative across all the SWBDs; although small in size they have a large combined effect.

Living in a flooded community also reduces the SWB of a respondent even when they themselves have not been flooded. The (direct and total) effect is smaller than when an individual is flooded themselves, perhaps because of the relief from being spared tangible damage. Out of the set of risk perception variables there are two variables with negative statistically significant total effects ($p < 0.05$): worrying about flooding and expecting flood risk to increase. Overall, these subjective perceptions may place a larger downward pressure on SWB as compared to flood experiences when they are not attenuated over time.

Table 4 The estimated compensating value required to compensate for changes in subjective well-being due to flood experiences, risk perceptions, or preparedness decisions

	Expected Value	90% confidence interval lower bound	90% confidence interval upper bound
Correlation between ln(Income) and SWB	0.21	0.17	0.25
	Mean CV	90% confidence interval upper bound	90% confidence interval lower bound
Immediate aftermath of a flood			
Median income	€126,000	€23,000	€235,000
Mean income	€150,000	€27,000	€280,000
12 months after being flooded			
Median income	€51,000	€900	€104,000
Mean income	€61,000	€1100	€124,000
A neighbour was flooded, while you were not			
Median income	€40,000	€30,000	€53,000
Mean income	€48,000	€36,000	€63,000
An individual expects their flood risk to grow			
Median income	€66,000	€53,000	€81,000
Mean income	€79,000	€63,000	€97,000
Elevation			
Median income	−€33,000	−€23,000	−€45,000
Mean income	−€39,000	−€27,000	−€53,000

Positive values represent compensation for SWB losses, while negative values represent in effect SWB gains

The self-protection measure that is robustly correlated with overall SWB is elevation, which is associated with an increase in overall SWB of a third of a SWB level worth about €39,000. This is a plausible effect because by elevating their ground floor the household has a greater sense of security and protection from flooding. This is confirmed by the total indirect effects which are positive across the SWBDs and the total effect is statistically significant. The dry and wet flood-proofing measures did not have a robust impact on SWB, even though they may reduce tangible losses indirectly.

The estimated CVs of floods in Table 4 are next decomposed into intangible and tangible effects of floods on well-being. The observed reduction in SWB due to a neighbour being flooded or a perception of increasing flood risk can be considered fully intangible impacts, because neither variable implies a direct costs for the respondent in question. The average damage to household contents and buildings suffered during the most recent flood event by the survey respondents is estimated to be approximately €50,000. Tangible losses of €50,000 result in an estimate of the intangible losses suffered at the time of a flood at the equivalent of €100,000, which is nearly twice as large as the tangible losses.

From the flood preparedness variables, wet flood-proofing did not display significant correlations with overall SWB. Nevertheless, Poussin et al. (2015) estimated that wet flood-proofing may be cost-effective. One reason why cost-effective damage mitigation measures can be uncorrelated with changes in overall SWB is that although they may limit damage, water still enters the building during floods. Poussin et al. (2015) find that dry flood-proofing did not significantly reduce flood damage, which is consistent with the insignificant impact of this measure on overall SWB in Table 3. In contrast, elevation was estimated to reduce flood damage by an average of €8000 (Poussin et al. 2015), which means that intangible benefits of elevation are €31,000.

4 Discussion

4.1 Comparison with Existing Studies

The direct effects model in Table 3 explains about fifty percent (48%) of the variation in overall SWB which is mainly due to the SWBDs. The overall fit is quite good since MacKerron (2011) finds that empirical studies of SWB normally explain far less than fifty of the variation in SWB through observed variables, such as socio-economic factors. Our results suggest that using the SWBDs as independent variables captures much of the variation within the data due to their aggregated nature.

The estimated effects of our flood risk and preparedness variables on overall SWB are difficult to interpret without being placed in context. Table 5 provides a summary of studies which are similar in that they estimated the CV or SWB impacts of flooding or other major life events. Luechinger and Raschky (2009) estimate a CV value for experiencing flooding in an area for people who may, or may not, have been personally flooded. This value is not directly comparable with our CV for people who were personally flooded. Luechinger and Raschky (2009) used a US sample that consists of a wider cross-section of society at a higher spatial scale, while our French sample focuses on individuals exposed to flooding which can provide more relevant insights for flood risk management policies for the population threatened by floods. Our CV values are higher, which is not surprising given these sample differences. Another basis for the comparison are the studies by Bockarjova et al. (2009) and Brouwer and Schaafsma (2013) who estimate CV values between €2500 and €120,000 for various flood impacts in the Netherlands. Our estimated CV of flood experience of €130,000 is close to the estimates found by these two Dutch studies, despite differences in applied methods, kind of floods, and geographical focus. A third base for comparison are the SWB effects of other major life events than floods. Our estimated CVs displayed in Table 4 vary within the range of estimates found in the literature regarding major life events or problems. Furthermore, the finding that a flood will have lasting SWB impacts is consistent with other findings that individuals do not fully adapt to major life events. For instance, Oswald and Powdthavee (2008) find an adaptation of SWB to developing disabilities which is similar to the adaptation of SWB we find for flood impacts. Overall our results appear plausible when placed in context with other life events.

4.2 Sensitivity Analysis

When evaluating the robustness of our results, potential endogeneity of the flood risk SWBD variables must be considered. Endogeneity occurs when an important excluded variable is correlated with one of the included explanatory variables and the dependent variable. The excluded variable causes the estimated model to provide inaccurate parameter estimates. Dolan et al. (2008) note several robust relationships between socio-economic variables and SWB that should be controlled for in a regression model of SWB, which include: (relative) income; health; personal and community relationships; family background and employment status. For the most part, these variables are key components of

Table 5 Characteristics and results of other studies which examined the impacts on SWB or CV of floods or other major life events

Study	Research objective	Sample	Method	Result
Luechinger and Raschky (2009)	Evaluate the utility impacts of flooding in monetary terms	Cross-section and time series data from 1973 to 1998 for Europe Cross-section and time series data for the United States from 1993 to 1998	Regression models of aggregated SWB	CV is 24% of average annual household income to have a 0% chance of flooding
Bockarjova et al. (2009)	To estimate the compensation required for being injured, evacuated, or die during a flood	530 respondents from areas at risk of flooding in the Netherlands (annual probability of 1 in 4000)	Choice experiments	CV is €100,000, €2500, €7000,000 respectively
Brouwer and Schaafsma (2013)	To estimate the willingness to accept compensation for controlled floods with an occurrence probability of 0.8%	800 households in the Netherlands across different areas of flood risk. Respondents have experienced either a flood or a near miss within 20 years of the survey.	Choice experiments	CV is €120,000
Blanchflower and Oswald (2004)	To determine the monetary value of a lasting marriage	General Social Surveys of the United States years from 1972 to 1998	A natural experiment of SWB between widows and married women	CV is €108,000
Powdthavee (2008)	To estimate the SWB effects of regularly talking with friends or family	British Household Panel Survey between 1997 and 2003	Panel data regression models of SWB	CV is €61,000
Powdthavee and van den Berg (2011)	To estimate the SWB effects of medical problems ranging from skin conditions to mental illnesses	British Household Panel Survey between 1997 and 2009 for Wales	Random effects models of SWB	CV is €4000–€330,000
Oswald and Powdthavee (2008)	To determine the rate of adaptation of SWB to (varying degrees of) disability	British Household Panel Survey between 1997 and 2005.	Fixed effects models of SWB	30–50% of the SWB loss is attenuated over time depending on the severity of the disability

Table 5 (continued)

Study	Research objective	Sample	Method	Result
Lucas (2007)	To estimate the degree of adaptation of SWB to major life events such as divorce or the death of a spouse.	German Socio-economic Panel Study and the British Household Panel Study	Estimated trajectories of SWB before and after major life events	There is an overall process of adaptation to major life events, although the degree to which adaptation occurs varies over events and across individuals.

The estimates presented here have been converted in 2014 euro values for the purpose of comparability with our estimates

our SWBDs, meaning that they are controlled for in our regression models.[5] Dolan et al. (2008) states several further important unobservable variables that may play a role in determining SWB, which include: motivation; and intelligence. We added an explanatory variable reflecting individual motivation to reduce flood risk, which did not affect our results. Intelligence may not be such a relevant factor for the flood risk SWBD, because the thought processes related with flood preparedness decisions are often determined by simple behavioral heuristics (Kunreuther and Pauly 2004). Nevertheless, we checked whether our results were affected by including education as a proxy for intelligence, which was not the case.

Even though effects of socio-economic variables, like marital status, age etc., on overall SWB is in principle already captured by our SWBD variables, they may have effects over and beyond their link with SWBDs. To this end, we test the sensitivity of our main results to including variables for: age, age squared, gender, income, and marital status. There is little change in the overall patterns of the magnitude and significance of the regression coefficients, while for the most part these socio-economic variables are statistically insignificant. The inclusion of only statistically significant socio-economic variables (which differ per SWBD) does not substantially affect our main results about the flood risk and flood preparedness variables.

Furthermore, we test how sensitive our results are to accounting for individual pessimism by including a variable for sadness of the respondent (detailed results not reported here). Including a variable for the overall sadness of the respondent results in small changes in coefficient values of the SWBDs, but does not affect the statistical significance of explanatory variables. Most importantly, including the sadness variable does not affect the main results of the flood risk domain variables.[6]

[5] Moreover, there may be a connection between flood preparedness decisions and personality. Several studies find that protection motivation theory (PMT) can explain household flood preparedness decisions (e.g. Poussin et al., 2014). Personality is a factor that determines a household's PMT evaluation (Maddux and Rogers, 1983). Heller et al. (2005) argue that the most appropriate aspect of an individual's personality in this regard is their tendency to worry about natural hazards. We controlled for worry in our regression models by including a series of dummy variables of how concerned the respondent is with current and future flood risk.

[6] An additional sensitivity test is conducted by including a binary variable that indicates if the individual is motivated to further reduce or manage their risk. The rationale is that an individual who is motivated to further manage and control the external issue of flood risk may not be as pessimistic as others who are not as motivated. Including this variable did not affect our main results.

4.3 Policy Implications

There are two main policy implications that emerge from the results of the current paper.

The first is that our results of the monetisation of the tangible and intangible SWB impacts of flooding are relevant for the design of risk management policies that concern flood-prone areas. The introduction noted that intangible benefits and costs are often excluded from the decision making process of risk managers. If intangible impacts from flooding would be negligible, then flood risk management decisions based on cost–benefit analysis that only include tangible impacts would be close to the socially optimal decisions. However, the results of this study indicate that the intangible costs of flooding may be between a quarter and twice the size of the tangible impacts. It is clear that intangible impacts are not negligible and should not be excluded from decision-making about flood risk reduction, because otherwise investments in flood risk management strategies are socially sub-optimal.

The second lesson is we find that even though the combined tangible and intangible losses due to a flood event or worries over future flood events are large, households can adapt to this loss in SWB over time and through taking adequate flood preparedness measures. However, the current adoption of flood damage mitigation measures is rather low and as such better incentives may be required to promote the uptake of such measures. For example this could be done by rewarding individuals who take such measures with discounts on their insurance premium (e.g. Hudson et al. 2016) since the vast majority of French households are insured against flooding and currently receive no financial reward from their insurance for reducing risk (Poussin et al. 2013).

4.4 Limitations

One limitation is that our study focuses a specific sub-set of the overall French population and as such the results may not be fully transferable to other regions that are not flood-prone. However, while the results of our study may not be readily generalizable to households outside of flood-prone areas, research about impacts of floods on SWB is not as relevant for households who do not face flood risk. Additionally, cultural aspects of French households may limit the transferability to areas outside of France. This is a limitation that we cannot assess without more studies linking flood experiences and perceptions to SWB. We have attempted to lessen this limitation by placing our results in context with other major life events (see Table 5). Moreover, even though our overall sample is representative of the French population, this may not be the case for the final set of observations used for our analysis due to missing observations for specific variables. This is why we checked whether the final dataset used for our analysis is similar to the total dataset, which turned out to be the case.

The second limitation relates to the process by which the data was collected. The data was collected by a backwards looking survey as is common when studying household level responses to floods or flood risk more generally. This backward looking nature could be hampered by a respondent's memory of their previous flood experiences and the accurateness of their responses to questions. Our approach tries to limit these potential inaccuracies by focusing on the most recent flood that a respondent has experienced and is more likely to be remembered than other past flood events.

4.5 Future Studies

This study has provided a starting point for monetising tangible and intangible impacts of floods on subjective well-being on which future research can develop. There is a large degree of uncertainty regarding the monetary equivalent values for the effects of flood risk on overall SWB, which highlights the need for future research in other regions. Future research could focus on the development of longitudinal data of flood experience, flood preparedness measures, and SWB in various regions prone to flooding. Such research would allow for obtaining improved insights into how SWB adapts to different kinds of flood events over time as well as the kind of flood risk management policies that are effective in ameliorating SWB losses. Furthermore, the purpose of our study was to value the SWB effects of flooding and preparedness for the average individual in order to be applicable for risk management decisions. The study of who is most affected by flooding is a question that may require a different approach, but can provide relevant insights for more tailored policy responses.

5 Conclusion

Flooding can cause large direct economic impacts, like property damage, which has been extensively researched. However, the consequences of floods or other natural hazards go beyond direct repair costs or production losses, because there are also intangible impacts, such as psychological consequences for individuals or reputational impacts for businesses. These impacts have hardly been studied, which may be due to the perceived difficulty of modelling or converting these intangible impacts in monetary terms for use in cost–benefit analysis. We build upon this literature in our study, by estimating both the SWB implications of floods and how these can be limited by flood preparedness. Moreover, we disaggregate these SWB impacts into tangible and intangible impacts on SWB. This is done by analysing data collected from a survey of about 900 households in flood-prone areas in France. We estimate relationships between SWB and explanatory variables of flood experiences, perceptions and preparedness decisions. Using these relationships we calculate the monetary value of the intangible impacts of these variables on overall SWB. This provided insight into the relative size of tangible and intangible impacts of experiencing flooding and flood preparedness.

Four main conclusions can be drawn from our results. First, the immediate impacts of a flood have a large negative effect on overall SWB that is larger than the effects of other individual SWBDs. Moreover, there is a degree of adaptation to flood events since the reduction in overall SWB is nearly halved 12 months after the flood event. The second conclusion is that flood events can have consequences for an individual's overall SWB, even if they themselves are not flooded. Such effects are relatively small; namely about one-third of that associated with the immediate effects of being personally flooded. Third, for communities that are prone to flooding the employment of individual flood protection measures can increase the SWB of these households. Elevation of homes increases SWB of flood-prone households. The fourth conclusion is that the intangible benefits or costs of the flood risk SWBD on overall SWB tend to be larger than the tangible damage suffered or the damage prevented. The average total tangible damage suffered during a respondent's previous flood was €50,000, while the implicit intangible loss was an average of €100,000.

We can draw two important lessons for flood risk management policies in areas outside the case study area from our study. This first is that the exclusion of intangible losses from flood risk assessments can result in a substantial underestimation of the welfare impacts and sub-optimal levels of protection investments. The second is that household level risk management strategies can not only lower flood impacts in a monetary sense, but also offer an improvement in welfare due to a greater sense of safety.

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