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Valuing the Impacts of Landslides: A Choice Experiment Approach

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Abstract

This paper analyzes the preferences for reducing the negative impacts of landslides. Negative consequences of landslides include impacts on transport infrastructure, humans, the environment and important societal services. We apply a choice experiment. The analysis is based on 6048 observations from 504 participants in a web panel. The overall finding is that reducing the risk of landslides would have a positive impact on individuals' utility, and that individuals prioritize preventing negative consequences on human health and safety over maintaining societal services, environmental status, and preventing damages to transport infrastructure, which seems to be least pressing. Results indicate that prioritizations of citizens differ from the prioritizations of public authorities, whose risk assessment model for evaluating the consequences of landslides gives equal weight to the different impacts.

Keywords Impacts of natural hazards · Choice experiment · Landslide risks · Risk preferences

Background

Extreme weathers and impacts caused by landslides and floods are likely to become more frequent and severe in the future as a result of climate change (IPCC 2014). Natural disasters generate significant costs in the form of damaged property and infrastructure but may also have negative impacts on humans and the environment. This paper focuses on how different impacts of landslides are valued. The purpose is to elicit the preferences and willingness to pay for reductions in some of the consequences of landslides. Methodologically we apply a choice experiment approach.

Although the literature on the social costs of climate change is substantial, studies on the valuation of impacts caused by extreme weather, and in particular landslides, are scarcer. There are studies focusing on landslide effects and the willingness to re-settle from landslide prone areas in developing countries (Charoenphong 1991; Mertens et al. 2018; Vlaeminck et al. 2016). When Vlaeminck study the willingness to re-settle from landslide prone areas in Uganda, they find that people living in high risk areas (on steep slopes or

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in villages that have already been affected by landslides) are more willing to re-settle than people living in low-risk areas (Vlaeminck et al., 2016). It has also been found that wealthier households are more willing to re-settle than poorer households and that institutional factors such as trust in institutions are important for the willingness to re-settle in Cameroon (Baert et al. 2020).

In a European context, there are studies on the societal impacts of landslides focusing on e.g. Italy, Norway, Switzerland and the UK. To the best of our knowledge there is no previous study on the preferences for reducing landslide risk in Sweden. Flügel et al. (2015) apply a choice experiment to examine how car drivers in Norway value landslide risks compared to road accident risks. Vranken et al. (2013) use a restoration method approach to estimate (a lower bound for) landslide costs in Belgium. They find that reconstruction of roads and railroads damaged after landslides constitute an important part of these costs. Mattea et al. (2016) use a choice experiment to examine whether visual information affects preferences for different devices that can be used to reduce landslide risk in the Italian Alps. Their results show that visual information contribute to higher willingness-to-pay for the measure for which information was provided and they thus conclude that education may increase peoples' willingness to pay for measures to reduce landslide risk (Mattea et al. 2016). Franceschinis et al. (2020) use the same data as Mattea et al. (2016) but apply a Latent Class model to analyze preference heterogeneity across groups. They find women with higher education and income more likely to belong to the class with a higher willingness to pay for all devices. When Thiene et al. (2017) analyze how subjective perceptions about the probabilities (for instance that a landslide will occur, and that people will die as a result) differ from science-based probabilities, they find that respondents overestimate these probabilities also after receiving information about the science-based estimates (in particular their own chance of dying were hugely overestimated). In a second step, Thiene et al. (2017) use the subjective risk perceptions in a choice experiment in which participants could choose between different types and levels of risk reductions, results reveal that that larger risk reductions, compared to baseline, were significant in explaining choices.

Based on a review on the socio-economic consequences of natural disasters, Allaire (2018) argue that the evaluation of impacts is mainly focused to damages on infrastructure and property, while non-tangible impacts on health and public services are largely omitted. The aim of this study is to contribute with such knowledge in a Swedish context. Sweden has many relatively small municipalities (in number of citizens) and local decision structures; local authorities and decision makers often work simultaneously with different issues related to land and water use – sometimes with conflicting policy goals. Thus, the environmental values held by the citizens constitute important input for decision makers and public officials involved in climate change adaptation, such as undertaking measures aimed to reduce future landslide risk. This is where the present study contributes, by focusing on preferences closely linked to the same criteria used by the public authorities. These criteria – which are used as attributes in the choice experiment—include impacts on: human life, the environment, infrastructure, and on important societal services. Due to geological and hydrological characteristics, the Gothenburg region in the south-western part of the country is the most vulnerable to landslides and flooding. Most of previous landslides in the country have occurred in proximity to the Göta River and as a result of expected changes in precipitation in combination with continued urbanization this region is expected to be even more severely affected by landslides and flooding in the future (e.g. Kiilsgaard et al. 2015; Swedish Geotechnical Institute 2016; SOU, 2007:60). We use the Göta River area as our case study but will evaluate how different impacts are valued in a somewhat generic context, i.e. participants are asked to choose between alternatives describing different impacts

of landslides in their municipality without specifying the context in detail for each municipality, instead the attributes and levels are selected to be considered reasonably realistic in each municipality in the region. This helps us to empirically challenge whether the different impacts are equally weighed as (implicitly) assumed in the assessments of the public authorities. Since policy makers and officials involved in mitigating or adapting society to the consequences of climate change often need to prioritize between different policies and measures, knowledge about how different types of impacts are valued in relative terms is highly relevant for the implementation of resource efficient risk reducing policies. If citizens do not consider different types of consequences equally important, decisions based on such (implicit) assumptions will lead to inefficient use of societal resources.

The Survey

The Göta River Area

The casualties after heavy rains, floods and earthquakes, are often a result of the landslides caused by these events. With regard to loss of lives, developing countries in Asia are most severely affected by landslides, while material damage generally dominates in industrialized countries (e.g. Kirschbaum et al 2010). The choice experiment in this study is implemented in five municipalities (Ale, Gothenburg, Kungälv, Lilla Edet, Vänersborg and Trollhättan) located close to the Göta River in the southwestern part of Sweden. In Sweden, landslides covering more than one hectare occur on average every two to three years (Swedish Civil Contingencies Agency, 2021) and this area, in the southwest of the country, is the region most vulnerable to landslides and flooding in Sweden. The most severe landslide in the country occurred here in 1977, when 9 persons were killed, 62 more were injured and 62 houses were destroyed (Swedish Civil Contingencies Agency 2017). Due to climate change and continued urbanization, the Gothenburg region is expected to be increasingly affected by landslides and flooding in the future. Mitigation measures and adapting policies are therefore high on the political agenda (e.g. Kiilsgaard et al. 2015; Swedish Geotechnical Institute, 2012; Swedish Geotechnical Institute 2016; SOU, 2007:60).

Survey development

The survey consisted of three parts. The first part included questions about previous experience, knowledge and concern regarding landslides, together with questions about attitudes towards different societal and environmental hazards. The second part included the choice experiment. The choice tasks were preceded with information about possible impacts on society from landslides. The last part of the questionnaire collected socio-demographic information. Experts from the Swedish Geotechnical Institute, which is the national authority responsible for preventing landslide risk in Sweden, supported the development of the survey. The survey development was also supported by a number of smaller pre-tests; 6 local residents living close to the Göta River participated in individual pre-tests, and one pilot was conducted with a group of eight Ph.D. students. The number of levels of the attributes was reduced after the pre-tests, and some minor clarifications and changes in formulations were also made after these pre-tests. The main lesson from the pre-tests was

however that after the number of levels had been reduced the choice task seemed to be understandable and manageable for participants.

The choice experiment

Defining the attributes to be included in the choice experiment and their corresponding levels is clearly important; selected attributes must be relevant from a policy perspective and understandable from the individual participant's perspective. In this study the attributes are based on the same criteria as used by the Swedish Geotechnical Institute (SGI) in their assessment of landslide risks (see e.g., Kiilsgaard et al. 2015). The criteria are landslide impacts on: human life (number of people affected), the environment (e.g. water pollution), transport infrastructure (e.g., type of road/railway affected), and on important societal services (e.g. hospitals, drinking water production). Each criterion in the risk assessment made by the Swedish Geotechnical Institute ranges from 1 to 5, where 1 corresponds to no or very small consequences, 2 to large consequences, 3 to very large consequences, 4 to extremely large consequences, and 5 corresponds to what is called catastrophic consequences. Table 1 shows the definitions of the levels of damage used by the SGI (Kiilsgaard et al., 2015, our translation).

The definitions as presented in Table 1 were not considered specific enough to be used as they are as levels in a choice experiment. In order to make the choice task comprehensive and feasible for participants, the description of the attributes and their corresponding levels were modified and somewhat simplified compared to the criteria used by public officials. The impact "number of people injured or killed" was called "impacts on human life" in the choice experiment. There are however not large railway stations or schools in all municipalities and no large sports arena in any of the municipalities, and it would thus not be meaningful to include the extremely large or catastrophic outcomes. Levels four and five were therefore omitted and the number of levels was reduced from five to three, in order for participants to consider the outcome as understandable and reasonable. The remaining levels, one, two and three, were presented similarly as in the risk assessment made by the public authority, yet with specific numbers of people injured or killed (0, 10, 50).

In the pre-tests, participants found it difficult to comprehend the differences in the levels of the attributes "impacts on the environment" and "impacts on societal services". After some iterations, these attribute were given two levels instead of five. Respondents were informed that a landslide could – but must not—have a negative impact on the environment (due to e.g. hazardous substances contaminating water and soil) and on societal services (participants were told that societal services were either affected for about a month or unaffected). Finally, the attribute "impact on transport infrastructure" had three levels since also in this case, some of the initial levels as defined in the risk assessment were fairly similar and hard to distinguish from each other.

Each choice set comprised three alternatives (A, B and C). Alternative C was the business as usual alternative (BAU), with no measures implemented to reduce landslide risk (see Table 2). Alternative C did not imply any cost. It should be noted that the non-monetary attribute levels in alternative C are also hypothetical as they correspond to the more severe consequences, scoring relatively high in the risk assessments made by the SGI. The outcome in alternative C is however considered realistic in the future by the authorities, due to climate change (e.g. Kiilsgaard et al. 2015; Swedish Geotechnical Institute 2016).

Table 1 Different levels of landslide damages, as defined by the SGI

Severity of conse-quence	Impacts on *life*. Number of people injured or killed	Impacts on the *environment*	Loss of societal function	Impacts on transport infrastructure
1	None	No environmentally hazardous activities affected, small environmental risk	Very small societal significance	Other than public road (tractor road, footpath)
2	A few	No environmentally hazardous activities affected, medium-sized environmental risk	Small societal significance	Public road (width <5 m)
3	Corresponding to the number of people in a detached house with several dwellings	Environmentally hazardous activities affected, major consequences for the environment	Moderate societal function	Public road (width 5–7 m)
4	Corresponding to the number of people at a larger school, apartment building or larger railway station	Damage on environmentally hazardous activities, extremely large consequences for the environment	Important societal function	Public road (width <7 m)
5	Corresponding to the number of people in a multi-arena (thousands)	Damage on environmentally hazardous activities, catastrophic consequences for the environment	Very important societal function	Railway, motorway

Table 2 Attributes and levels

Attribute Impacts on…	Definition	Attribute levels	
		Alternative A and B	Alternative C (BAU)
life	Number of people injured/diseased	0, 10, 50	50
the environment	Harmful substances spreading to the environment via the water, air and/or soil	Pollution/ no pollution	Pollution of the environment
societal services	Damages to societal services such as hospitals, schools or public drinking water systems	Loss of societal services for 30 days/ no loss of societal services	Loss of societal services for 30 days
infrastructure	Damages to infrastructure that imply that traffic is rerouted and new roads/railways need to be constructed	Motorway/highway/railroad disabled for 30 days/ Public road/avenue disabled for 30 days No damage to infrastructure	Motorway/highway/railroad disabled for 30 days
Fee	Municipal fee in SEK to be paid each year for ten years	250; 600; 1,000; 1,500 SEK	0 SEK

Alternatives A and B correspond to scenarios where measures towards reducing the risk of landslides have been undertaken. Respondents were told that these alternatives could be financed through an annual *fee* that, if implemented, would be paid by all households in their municipality for the coming ten years. It would take considerable time and financial resources (about 5–6 billion SEK) to implement measures aimed at reducing the risk of landslides in the Göta River valley as it stretches alongside 186 km of riversides (Swedish Geotechnical Institute 2012). A timeframe of ten years was therefore considered long enough to be perceived as reasonable realistic.

Results from previous research about the impact of uncertainty and risk on environmental preferences are somewhat ambiguous; Veronesi et al. (2014) did not find preferences to be sensitive to the level of probability of occurrence, but there are other studies, such as Drake et al. (2013), Bartczak and Meyerhoff (2013) and Rolfe and Windle (2015) reporting that preferences over changes in environmental quality are sensitive to probabilities. We analyze the impact of changes in probabilities on preferences by varying the probabilities in the choice experiment scenarios. In the first choice set, the respondent was asked to make a choice between the three alternatives A, B or C given that the probability that a landslide would occur during the coming period of ten years was 10 percent. After choosing the preferred alternative in the initial choice set the respondent faced a follow-up question, in which she/he was asked whether she/he would change the choice in the previous question if the probability of a landslide would either increase to 50 percent or decrease to 1 percent. Communicating probabilities in a way that is comprehensive for citizens in general is not trivial, it can be done by using probabilities or by using verbal expressions, and these can be combined as well (both the IPCC and the Swedish authorities use mainly verbal expressions such as unlikely, likely, very likely etc.). Verbal risk communication can however also be problematic (Harris and Corner 2011). Probabilities were used in the choice experiment and the follow-up question, as they were considered to be more distinct. In the follow-up questions, the changes in probabilities were quite large, and although the results of the pre-tests did not indicate that they were considered unrealistic, these pre-tests were quite limited in size and it is possible that this was the case, not least for the increase from 10 to 50 percent.

The respondent could answer *yes*, and change to another alternative (the alternatives then appeared again), *no*, or *I don't know*.[1] The motive for varying the level of risk in the scenarios rather than including risk as one of the attributes, like in Veronesi et al. (2014), Drake et al. (2013), and Cadavid and Ando (2013), was to facilitate the choice tasks. Choosing between alternatives that includes probabilities can be mentally cumbersome for respondents (Logar and Brouwer 2016; Corso et al. 2001). By altering the probability of an event between the choice sets, rather than between the alternatives within a choice set, the participant is given time to reflect on the differences of the impacts of a landslide and the probability of an event separately.

The final design of the choice experiment was constructed using Ngene software. We apply an efficient design. By using prior information achieved from the two pilot tests, the efficient design avoids dominant alternatives and minimizes the correlation between attributes levels. By doing so, the efficient design can generate model estimates with small standard errors (Ferrini and Scarpa 2007; Rose and Bliemer 2013; Sándor and Wedel

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[1] The second choice task introduced two possible choices to the respondents; i.e. to reflect over whether they would like to change their choice when the level of risk changed and, if so, to evaluate the attributes and levels once again. As probabilities may be considered an abstract concept, we introduced the "*I don´t know*" alternative in the follow-up question to allow uncertain respondents to "opt out" from the choice whether to change their preferred alternative or not.

2001; Scarpa and Rose 2008). Because information (priors) is available with some degree of uncertainty, a Bayesian D-error approach, assuming normally distributed priors, was used. The final experimental design consisted of 12 choice sets, divided in two blocks. Each individual answered 12 choice sets, 6 "initial" choice sets (with a 10 percent probability of a landslide) and 6 "follow-up" choice sets (with either a 1 percent or a 50 percent probability of a landslide). Hence, only the probability of a landslide changed between the initial choice questions and the follow-ups, while all attributes and levels were equal. The increase/decrease of probabilities in the follow up questions was randomly assigned; there were two versions of each block, where the first version of each block contained the randomized assignment of probabilities to the follow-up questions, and in the second version the assignment of probabilities was inverted. Table 3 gives an example of a choice set and follow-up question, in this example the respondent chose alternative A in question 1, and alternative B in the follow-up question. With regard to Alternative C, is should be noted that the BAU is somewhat different from a traditional status-quo alternative in most choice experiments. If no measures to prevent the impacts of landslides are undertaken, the expected consequences are increasing, due to climate change. Therefore, Alternative C represents a hypothetical, yet likely, outcome during the coming 10 years if no measures are undertaken.

Results

Data Collection and Descriptive Statistics

Data was collected in June 2017, via a web panel, administered by the company Norstat. The panel contains approximately 90,000 members, who are randomly recruited by telephone. There are possible issues stemming from any differences in characteristics of those who choose to be a part of the panel and the rest of the population (Bethlehem 2009). Such potential problems include professional survey-takers, self-selection bias and under-coverage of individuals without Internet access. The latter may however be a limited problem in Sweden as most individuals have since long had access to Internet and use the Internet frequently. The sample consists of panel members residing in the municipalities around the Göta River (namely Ale, Gothenburg, Kungälv, Lilla Edet, Trollhättan and Vänersborg). In total 1894 panel members were invited to answer the survey, out of which 504 responded (126 respondents per block), corresponding to a response rate of 27 percent, which is comparable with other surveys using web panels (Elgan and Leifman 2013; Svensson 2013).

The socio-demographic characteristics of the sample presented in Table 4 show that the gender and age distributions in the sample are similar to the corresponding regional averages (Statistics Sweden 2016). The respondents are however, on average, more educated then the regional population in general. Although the statistics for income levels are not entirely comparable (as the sample household incomes are given as ranges rather than as specific numbers), the households in the sample seem to have somewhat higher incomes than the regional averages. The regional population average lies however within one standard deviation of the mean for the respondent sample.

The survey also included questions about previous experiences of and knowledge about landslides. 18 percent of the respondents report that they, or someone they know, have been affected by landslides. When asked whether they had received any information about the risk of landslides by the municipality, six percent had received such information. The

Table 3 Choice set example

Question 1

Imagine a **10 percent risk** of a landslide occurring in your municipality sometime over the next 10 years. Which of the following alternatives, A, B or C do you prefer?

	Alternative A	**Alternative B**	**Alternative C – no measures taken**
Impact on **societal services**, e.g.: a hospital, water facility, or a school becoming unusable for 30 days	**Loss** of societal services for 30 days	**No loss** of societal services for 30 days	**Loss** of societal services for 30 days
Impacts on the **environment**, e.g. spreading of contaminants	**No pollution** of the environment	**Pollution** of the environment	**Pollution** of the environment
Impacts on **humans**, the number of people injured or, in the worst case, killed	**50** people	**0** people	**50** people
Impacts on **infrastructure**, kind of road being unusable for 30 days	**Motorway/highway/railroad**	**No damage** to infrastructure	**Motorway/highway/railroad**
Annual fee SEK a year to be paid for ten years	**250** SEK	**1500** SEK	**0** SEK
MY CHOICE	[X]	[]	[]

Question 2

In the previous question, we asked you to imagine a 10 percent risk of a landslide occurring

If the risk increased to 50 percent, would you like to change your choice?

[X] Yes, I want to change my choice to alternative B

[] Yes, I want to change my choice to alternative C

[] No

[] I don´t know

The entries in boldface are presented as they were in the choice experiment. Attribute names, levels and changes in probabilities were in bold to make them easy to detect for respondents

Table 4 Socio-economic and demographic characteristics of the sample

Descriptive statistics	Sample		Regional population
Variable	*Mean*	*Standard deviation*	*Mean*
Female	52%	0.499	50%
University education	52%	0.498	43%
Age	53 years	17	50 years
Monthly income per household	40,000–60,000 SEK	10,000–20,000	38,000 SEK

respondents were also asked whether they perceived themselves as having more knowledge about landslides and their consequences than people in general. 12 percent of the respondents claimed that this was the case. Hence, although about one fifth of the respondents report that they, or someone they know, have some experience of landslides the majority of the participants do not have any personal experience or much knowledge about landslide risks.

How landslide risks are valued may not only be affected by the expected impacts of such events, but also by the probability of an event, and by attitudes towards uncertain outcomes. In the survey, the risk introduced to participants varied between the scenarios, where the probability of the occurrence of a landslide was alternated to either increase or decrease every other question. The respondents were further asked about their self-perceived willingness to take risks in general, and in different domains (health, the environment, finances and safety). The results indicate that respondents are more willing to take risks in general than in relation to a specific area. Furthermore, the responses indicate that participants are less willing to accept risks affecting the health and safety of others than themselves.

Estimation Results and Discussion

The data set contains 6048 observations, each of the 504 respondents answered 12 choice sets. In half of the choice sets, in the follow-up questions, only the probability of a landslide changed, while attributes and levels were identical as in the preceding choice set. When respondents were asked whether they would like to change their choice from the previous question, most participants chose to stick with their original choice although the changes in probabilities were substantial, from ten to either one or fifty percent probability that a landslide would occur during the coming ten years. In about 20 percent of the follow-up questions, respondents changed their choice while in about 70 percent they did not, and in about 10 percent respondents reported that they did not know.

The business as usual alternative was chosen in 13 percent of the choice sets. The probability that the business-as-usual alternative was chosen was, to some extent, related to the stated probability of a landslide. When the probability of a landslide was increased to 50 percent the probability that the business-as-usual alternative was chosen remained the same as in the first choice set (10 percent). When the presented probability of a landslide instead was reduced to one percent the proportion of the respondents that chose the business-as-usual doubled however to 22 percent.

In the econometric analysis we apply a Random Parameter Logit (RPL) model. This model specification is preferred (over the Multinomial Logit model) since the dataset displays heterogeneity in taste, indicated by the statistically significant standard deviations of the estimated parameters, see Table 5. The results from estimating the RPL model

Table 5 Results from estimating the RPL model

RPL Model		
Variable	Coefficient (s.e.)	Standard deviation
Fee	-0.0002 (0.000)***	Fixed
No impact on infrastructure	0.153 (0.054)***	0.557***
Limited impact on infrastructure (public roads)	0.100 (0.154)	0.867
No impact on human life	1.864 (0.119)***	3.207***
Limited impact on human life (10 individuals affected)	0.796 (0.146)***	0.183
No impact on the environment	0.866 (0.070)***	1.927***
No impact on societal services	0.870 (0.068)***	1.571***
Business as usual	-1.994 (0.295)***	5.819***
Probability of occurrence low *business as usual	1.930(0.140)***	Fixed
Probability of occurrence high *business as usual	-0.201(0.141)	Fixed
Simulated Log-likelihood value	-4153.174	
Number of Halton draws	2000	
Pseudo R^2	0.375	
BIC	8340.3	
Number of parameters	17	
Number of observations	6048	

***, **, * statistical significance levels at 1%, 5%, and 10%, respectively

presented in Table 5 were estimated using Nlogit 5 software and 2000 Halton draws. For more details about the RPL model, see Train (2003) and Hensher and Greene (2003).[2]

The utility coefficients for the attributes – impacts on *human life*, *the environment, societal services,* and *infrastructure* – are random coefficients (for variable definitions, see appendix A, Table 7). The model was estimated under different distributional assumptions, including the normal, uniform and triangular distribution. By comparing the simulated log-likelihood values, Mc Fadden pseudo R-square and the Akaike information criteria, the model assuming that all these utility coefficients follow a uniform distribution seemed to fit the data best (although differences were quite small). The cost coefficient *Fee* and the constant (equal to one for Alternative C, *Business As Usual*) are assumed to be non-random.

We are aware that the assumption of a non-random cost coefficient is restrictive. One way to overcome problems associated with deriving WTP from random preference-space coefficient attributes is to estimate the model in WTP space instead (Greene and Hensher 2009; Scarpa et al. 2008; Train and Weeks, 2005). However, the model estimated in WTP-space (using Nlogit as well as Stata) did not converge (Balcombe et al. 2009).[3] Therefore, all WTPs presented here are estimated in utility space (still assuming the cost parameter to be fixed).

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[2] The Generalised Mixed Logit model was also considered as it can also account for scale heterogeneity (Train and Weeks 2005; Louviere and Eagle 2006; Greene and Hensher 2010). If variance (i.e. scale) heterogeneity exists it can produce bias in welfare measures if not accounted for (Adamowicz et al. 2008). No scale heterogeneity was however identified, implying that the model reverts back to the RPL model.

[3] Unfortunately, we failed to achieve convergence due to problems with flat likelihood function also after trying the following recommendations suggested by our reviewer: scaling the cost variable (fee) by 1000, use of both random and Halton draws, allowing for correlation of random coefficients, and by varying the order of variables (Palma et al. 2020).

The results reveal that overall the respondents' valuation of reducing the risk of negative impacts from landslides are positive and statistically significant. All attribute coefficients except for *limited impact on infrastructure (public roads)* are statistically significant at the one percent level. All random coefficients have positive signs, indicating that the probability of choosing an alternative is increased when the attribute appears in the alternative, compared to the business-as-usual alternative. The reference levels of the attributes are: large impacts on *infrastructure* (damages to a motorway, highway and/or railway for 30 days), large impacts on *human life* (50 individuals affected by landslides), negative impact on the *environment* and on *societal services* (reduced for 30 days). The interpretation of a positive sign for the attributes is that respondents prefer *no damages to infrastructure*, *no impact on human life* or *limited impact on human life* (only ten individuals affected), over 50 individuals affected by a landslide. The respondents also prefer the *environment* not to be polluted by a landslide. In addition, maintaining important *societal services* is preferred over having important societal services reduced for 30 days. Finally, the cost coefficient estimate *fee* is negative implying that the respondents of course prefer low fees over high. The results also indicate that the respondents have tendencies to avoid choosing the business-as-usual alternative of doing nothing to reduce the risk of landslides.

To examine whether the probability of a landslide seem to have any impact on the willingness to contribute to reducing the expected damage from a landslide, the probability parameters were interacted with the business-as-usual alternative. The estimated low-risk coefficient is positive and statistically significant, indicating that the probability of choosing the business-as-usual alternative increases as the stated probability of landslides decreases. There is no statistically significant evidence that a higher risk would increase the willingness to pay to avoid the negative impacts of landslides. This somewhat surprising lack of statistical significance should be interpreted with care. One possible explanation for this lack of statistical significance is that the respondents did not consider the presented increase of 50 percent realistic.

The statistically significant standard deviations for pertaining *infrastructure* (except for no damages to public roads), impacts on *human life* (except for limited impact on human life), the *environment* and *societal services*, imply preference heterogeneity.

Additional model specifications have been tested for; attribute parameters have been interacted with the business-as-usual parameter and with income, university education, age, gender, previous experience and knowledge of landslides. None of these proved however to be statistically significant and they are therefore omitted from the results presented here. The lack of statistical significance of the income and education interaction coefficients implies that the preferences of those with higher income levels and/or education levels are not different from those with lower income and/or education levels. Remembering the overrepresentation of individuals with higher incomes and education in the sample, there is thus no evidence that the problems caused by this selection is severe. The attribute levels were also interacted with the level of risk presented in the follow up choice-set but since the statistical significance of these interactions was limited they are omitted from the model presented here. The attribute coefficient estimates proved to be stable and did not change substantially with respect to signs, sizes or statistical significance across model specifications.

Table 6 Mean WTP estimates (Euros in parenthesis)

Marginal willingness to pay in SEK (Euros in parenthesis)

Attributes	1% probability			10% probability		
	Mean WTP	s.e	95% confidence interval	Mean WTP	s.e	95% confidence interval
No impact on infra-structure	87 (9)	195	-295,2 469,2	695** (70)	276	154,04 1235,96
Limited impact on infrastructure (public roads)	-268 (27)	411	-537,56 1073,56	701 (70)	648	-569,08 1971,08
No impact on human life	2245*** (225)	469	1325,76 3164,24	4694*** (469)	1197	2347,88 7040,12
Limited impact on human life	1197*** (120)	454	307,16 2086,84	1763** (176)	751	291,04 3234,96
No impact on the environment	1676*** (168)	352	986,08 2365,92	2437*** (244)	607	1247,28 3626,72
No impact on soci-etal services	1607*** (161)	325	970 2244	2451*** (245)	595	1284,8 3617,2

***, **, * indicate statistical significance levels at 1%, 5%, and 10%, respectively

Marginal Willingness to Pay

The willingness to trade-off between any two attributes is the ratio of their respective coefficients, and the marginal willingness to pay (WTP) for each attribute is computed as the negative of the coefficient of that attribute, divided by the *fee* coefficient. The WTPs are estimated in Swedish crowns (SEK), while corresponding WTPs in Euros are presented in parentheses in Table 6.[4] The marginal WTPs are calculated for one and ten percent probability. The RPL model estimations on which these WTP calculations are based are presented in full in the appendix (Tables 8, 9 and 10). Since we did not find any statistically significant support for the notion that cost affects choice for the 50 percent probability model, we did not estimate marginal WTPs for this model.

The WTPs of all attributes except *infrastructure* are statistically significant at one percent in both models. Although the mean WTPs are higher for the ten than for the one percent probability model, all confidence intervals except for *no infrastructure* (which is only statistically significant for 10 percent) are overlapping and no conclusions about any differences in WTPs can thus be drawn. There are considerable differences in marginal WTPs for the different attributes. Acting to reduce risk of landslide *impacts on human life* is considered the most important for our respondents, while there is limited support for any willingness to accepts costs to reduce *impacts on infrastructure*. Flügel et al. (2015) who studied the valuation of land slide risk reductions in the setting of car accidents also found that human risks are considered important, although they reported a somewhat lower WTP of €98[5] (909 NOK/SEK). Our participants are also willing to pay substantial amounts for reducing the risk that

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[4] The WTPs in Euros were calculated using an exchange rate of 10 SEK/€
[5] The value of NOK corresponds to the value of SEK.

a landslide would cause harmful substances to be spread to the *environment* via the water, air and soil and to avoid negative impacts on *societal services*. Damages on infrastructure is thus considered the least important, which is consistent with the findings of Spegel (2017), who analyze the preferences for the impacts of floods in the same region.

Concluding Remarks

This paper has applied a choice experiment to analyze the preferences for the consequences of landslides, including impacts on infrastructure, but also on less studied impacts such as on human life and safety, the environment and important societal services. Data was retrieved from a web panel implemented in the landslide prone valley surrounding the Göta River in southwest of Sweden. The overall finding is that reducing the risk of landslides would have a positive impact on individuals' utility; responses indicate that respondents are willing to pay an additional annual fee to reduce the consequences of landslides. Participants prioritize preventing negative impacts on humans over maintaining important societal services and environmental status, which is consistent with previous studies (Birol et al. 2009; Veronesi et al. 2014). Although these studies are not entirely comparable since the attributes and settings differ, the general indication from the economics literature estimating the value of fatal risks (Wang and Mullahy 2006; Alberini and Chiabai 2007) and from the literature on environmental valuation (Roberts et al. 2008; Lew et al. 2010) is that fatal risks are usually valued higher than environmental risks. Preventing damages to infrastructure is the least concerning area, according to our results.

The differences between how different impacts are valued suggest that there are differences between the relative valuations of impacts expressed by the citizens and in the model for risk assessment applied by the national authority. These results indicate that instead of giving all impacts equal weight, impacts on human life should be prioritized over impacts on transport infrastructure.

The valuation of different impacts from natural disasters is however highly case dependent, policymakers need to make decisions in an uncertain world with scarce resources and to make a case study for each and every decision would be very time consuming and costly. The analysis in this paper should be seen as an attempt to estimate the relative importance of the different impacts of landslides in general. By complementing these results with more site-specific case studies it would be possible to study to what extent and under which circumstances the relative ordering of impacts found in this study may hold also for specific cases. This is thus an arena for important further research.

Appendix

Table 7 Definition of variables

Variable	Definition	Min	Max
Fee	Municipal fee in SEK to be paid each year for ten years	0	1500
No impact on infrastructure	No damage to infrastructure Reference level: Damages to infrastructure that disables Motorway/highway/railroad disabled for 30 days	0	1
Limited impact on infrastructure	Public road/avenue disabled for 30 days Reference level: Damages to infrastructure that disables Motorway/highway/railroad disabled for 30 days	0	1
No impact on life	No individuals injured or diseased Reference level: 50 individuals injured or diseased	0	1
Limited impact on humans (10 individuals affected)	Ten individuals injured or diseased Reference level: 50 individuals injured or diseased	0	1
No impact on the environment	No pollution of the environment Reference level: Pollution of the environment by harmful substances spreading to the environment via the water, air and/or soil	0	1
No impact on societal services	No loss of societal services Reference level: Loss of societal services including hospital, fire station/police station/school, which reduces the society´s ability to function for 30 days	0	1
Business as usual	Refers to alternative C	0	1

Table 8 RPL model estimation –1 percent probability of occurrence

RPL Model		
Variable	*Coefficient (s.e.)*	*Standard deviation*
Fee	-0.0005 (0.000)***	Fixed
No impact on infrastructure	-0.002 (0.089)	0.001
Limited impact on infrastructure (public roads)	-0.277 (0.289)	0.121
No impact on humans	1.099 (0.143)***	2.347***
Limited impact on humans (10 individuals affected)	0.870 (0.265)***	0.032
No impact on the environment	0.707 (0.097)***	0.789
No impact on societal services	0.723 (0.102)***	0.667
Business as usual	-2.599 (0.591)***	8.084***
Model fit		
Log-likelihood value	-1296.955	
Pseudo R^2	0.219	
BIC	2623.9	
Number of parameters	15	
Number of observation	1512	

***, **, * statistical significance levels at 1%, 5%, and 10%, respectively

Table 9 RPL model estimation –10 percent probability of occurrence

RPL Model		
Variable	Coefficient	Standard deviation
Fee	-0.0003 (0.000)***	Fixed
No impact on infrastructure	0.187 (0.054)***	0.029
Limited impact on infrastructure (public roads)	0.189 (0.165)	0.249
No impact on humans	1.262 (0.081)***	1.433***
Limited impact on humans (10 individuals affected)	0.474 (0.165)***	0.325
No impact on the environment	0.655 (0.056)***	0.545***
No impact on societal services	0.659 (0.056)***	0.032
Business as usual	-1.763 (0.285)***	4.515***
Model fit		
Log-likelihood value	-2337.093	
Pseudo R^2	0.297	
BIC	4704.2	
Number of parameters	15	
Number of observation	3024	

***, **, * statistical significance levels at 1%, 5%, and 10%, respectively

Table 10 RPL model estimation – Subsample 50 percent probability of occurrence

RPL Model		
Variable	Coefficient	Standard deviation
Fee	-0.0001 (0.000)	Fixed
No impact on infrastructure	0.228 (0.084)***	0.163
Limited impact on infrastructure (public roads)	0.248 (0.264)	0.008
No impact on humans	1.094 (0.086)***	0.042
Limited impact on humans (10 individuals affected)	0.474 (0.394)	0.005
No impact on the environment	0.570 (0.081)***	0.011
No impact on societal services	0.603 (0.086)***	0.436*
Business as usual	-0.018 (0.201)	0.364
Model fit		
Log-likelihood value	-1259.440	
Pseudo R^2	0.242	
BIC	2548.9	
Number of parameters	15	
Number of observation	1512	

***, **, * statistical significance levels at 1%, 5%, and 10%, respectively

Data Availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Code Availability Not applicable

Declarations

Conflicts of Interest Not applicable

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