Avalanche Protection by Forests – A choice experiment in the Swiss Alps

1 INTRODUCTION

1.1 Background

Forest ecosystems generate a wide range of ecosystem goods and services (ES) to human society (MA 2005). One of the main ES of forests in mountainous regions is the protection of people and infrastructure against natural hazards, such as snow avalanches (Brang et al. 2006). In Switzerland, about 43% of the forests have a protective function (Brändli 2010). Since this service is a typical public good, it is seldom marketed and, thus, information about its economic value is lacking.

Planning and maintaining avalanche protection by forests often requires decisions concerning different technical and silvicultural measures, even more, since catastrophic storm events have increased in recent decades (Usbeck et al. 2010). In order to provide a comprehensive basis for decision-making in landscape planning and cost-efficient forest management, alternative evaluation techniques can be applied (Grêt-Regamey et al. 2008; Olschewski et al. 2008).

Recent studies have shown that Choice Experiments (CE) are feasible instruments to value hazard-mitigating services of forests. While some authors focus e.g. on the determination of the value of statistical life (Rheinberger 2009), others concentrate on particularities such as the impact of small risk changes on the valuation results (Leiter & Pruckner 2009). As a novelty, we combine a choice experiment determining the willingness to pay for avalanche protection with a risk-based evaluation techniques, virtual reality visualizations, and alternative cost estimations in a comprehensive interdisciplinary analysis.

1.2 Study area

The Swiss municipality Andermatt, Canton Uri, has about 1,250 inhabitants with additional overnight accommodation for 1,500 tourists, and lies at an altitude of about 1,450 m.a.s.l. Our study area comprises the north facing slope of ‘Gurschen’ reaching an altitude of about 2,000 m.a.s.l. with a gradient continuously above 30°. The annual average temperature is 2.7°C, with a margin of -6.7°C in January and 11.8°C in July. The annual average precipitation is 1,280 mm and snow height is 1.7 meter on average with extremes of more than 3.0 meters (Olschewski et al. 2011).

The protection forest is highly important for preventing avalanche hazards. This has been officially recognized by putting a ban on access and harvesting since 1397. Lining and reforestation projects starting from 1874 on led to an expansion of the protection forest from 4 ha to about 24 ha nowadays, which is dominated by Norway spruce (*Picea abies*) mixed with individuals of European larch (*Larix decidua*) and Swiss stone pine (*Pinus cembra*). The core area consists of an about 300-year-old spruce forest surrounded by younger afforested areas. The protection forest has partly been destroyed by the storm ‘Vivian’ in 1990; this area has been reforested with Norway spruce. In the area above the protection forest additional technical linings have been installed since the 1950s (Olschewski et al. 2011).

2 METHODOLOGY

2.1 Damage potential and risk analysis

Risk analyses allow for a transformation of the protective function into economic values. To evaluate this function in our study region, we determined the damage potential of an avalanche event with a reoccurrence period of 300 years. The risk of this extreme event has been calculated following the recommended uniform procedure for risk analyses (Bründl et al. 2009, Borter 1999), where risk is defined as the product of the probability of a damaging event and its consequences

$$R_j = \sum p_j \cdot A_j \qquad (1)$$

where R_j is the risk depending on scenario *j*, p_j is the probability that scenario *j* occurs, and A_j is the damage potential as the sum of damages to objects and people affected in scenario *j*.

The methodology for valuing the impact of the assumed wind-throw area as well as of different forest structures on the annual collective risk of the municipality Andermatt is based on the methodical framework presented in Teich & Bebi (2009). In addition to the classical risk analysis, this procedure of a GIS-based risk evaluation contains a classification of forest structures based on aerial photographs, the calculation of potential avalanche release areas within the forest and the prediction of avalanche run-out distances using the two-dimensional numerical avalanche dynamics program RAMMS (Christen et al. 2008).

The damage assessment includes identifying endangered objects located in the run-out areas of the simulated avalanches. Thus, the damage potential consists of expected damages to exposed buildings and the expected loss of lives in these buildings (Bründl et al. 2009).

2.2 Choice experiment

We determined the willingness to pay (WTP) for avalanche protection by applying a choice experiment, where all households in Andermatt were invited by letter to participate in an online survey. The stated preference method aims at determining, which factors or attributes are most important for the choice decision (Train 2003). It is assumed that the choice decision depends on the utility derived from the different attribute levels: the higher a positive attribute level, the higher the utility, and consequently, the higher the probability to be chosen. The approach is based on random utility theory, where the utility of individual *n* from alternative *i* can be expressed as

$$U_{ni} = V_{ni} + \varepsilon_{ni} \qquad (2)$$

with *U* being the utility function, *V* the observable component given by the attributes, and *ε* the unobserved random component (Louviere 2001). We assumed this component to be independently and identically 'extreme value' distributed, which allows to apply a multinomial logit model for data analysis (Train 2003).

Special emphasis has been put on a clear and concise wording of the questionnaire. As questions related to the valuation of natural hazards might lead to misunderstanding and distorted answering, we conducted expert interviews, focus groups and pre-tests to clarify possible ambiguities.

In our basic scenario we assume that a wind throw has damaged about 1 ha of the protection forest. This scenario is particularly appropriate for our study region, because most of the population in Andermatt is still familiar with the consequences of the storm Vivian in 1990. Furthermore, it enables us to determine, which aspects or attributes of avalanche protection are actually important to the population. To do this, alternative measures to restore avalanche protection were introduced and described by five different attributes: type of measure, starting time, duration, damage avoidance and costs (compare table 1).

Table 1. Attributes and levels of protection alternatives.

Attributes	**Levels**			
Type (TY)	Logs	Grills	Bridges	Nets
Damage avoidance (DA, in %)	50/60/70	60/70/80	70/80/90	70/80/90
Duration (T, in years)	15/20/25	20/25/30	60/70/80	60/70/80
Starting time (ST, in years)	1 / 3 / 5	1 / 3 / 5	1 / 3 / 5	1 / 3 / 5
Costs (CO, in USD)[1]	100/150/200	200/250/300	400/500/600	400/500/600

1) All calculations have been made in CHF. For publication purposes, CHF values has been transformed into USD based on a 1:1 exchange rate (CHF/USD), which approximately reflects the average exchange rate throughout 2010.

Different level labels have been assigned to the same attribute in order to reflect particularities of the respective technical measures. According to Hensher et al. (2005) this does not cause any problems, as long as the labels for quantitative attributes are equally spaced within each attribute. In our example the costs of logs but also their potential to avoid damages is supposed to be lower than that of grills, bridges and nets. Additionally, life time differs due to earlier natural decomposition of wooden materials. Note that the attribute ‘Type’ has four different level labels, which are held constant. Different combinations of attribute levels are combined in choice sets consisting of three options. Following the ‘short-cut design’, each option within a choice set is built by choosing attribute levels used least frequently in previous options for a specific respondent with the aim to minimize overlap, i.e., to keep the options in any task as different from one another as possible (Sawtooth 2008). Each respondent was asked to choose one out of three options from 10 subsequent choice sets.

We further specified the observable component *V* given in Eq. 2 as depending on the discounted risk reduction (*DR*), the costs per household (*CO*) and the type of protection measure (*TY*) (compare Eq. 3):

$$V_{ni} = \alpha \cdot DR_{ni} + \beta \cdot CO_{ni} + \gamma \cdot TY_{ni} \qquad (3)$$

Equation 4 shows in detail how the discounted risk reduction *DR* (in USD) is determined: the first component considers the time *ST* (in years) it takes to establish protection measures and includes the discount rate δ (in percent). The second term sums up the discounted annual risk reduction *R* during the project duration *T* (in years) (compare Alberini et al. 2007).

$$DR = e^{-\delta \cdot ST} \cdot \int_0^T R \cdot e^{-\delta \cdot t} dt \quad (4)$$

By assuming that utility depends on different attributes, we can (i) determine whether there is a significant positive or negative impact, and (ii) analyze trade-offs between specific attributes by building the ratio of any two coefficients. The reason can easily be seen in Eq. 5 and 6, where the total derivative of the utility function *U* (e.g. with respect to risk reduction and costs) is set to zero:

$$dU = \frac{\partial U}{\partial DR} \cdot dDR + \frac{\partial U}{\partial CO} \cdot dCO = \alpha \cdot dDR + \beta \cdot dCO \overset{!}{=} 0 \quad (5)$$

$$-\frac{\alpha}{\beta} = \frac{dCO}{dDR} \quad (6)$$

The marginal value or implicit price of an attribute can thus be calculated as the negative of its coefficient divided by the coefficient of the cost variable, and reflects people's WTP to achieve more of the respective attribute (Bennett & Adamowicz 2001). Note that in our particular case the ratio of α and β reflects the increase in costs that keeps the household at a constant utility level given a reduction in avalanche risk.

$$WTP = -\frac{\hat{\alpha}}{\hat{\beta}} \cdot DR \quad (7)$$

2.3 Visualization

In order to avoid anomalies within non-market valuation studies the evaluability of attribute levels is crucial. Particularly for communicating attribute levels of primarily visual environmental goods, such as land-cover change, visual stimuli have proved to be very effective (Bateman et al. 2009). The use of visual stimuli is not new in preference studies and techniques, such as photomontages, photo manipulations or GIS-based 3D landscape visualizations, have been used for representing the landscape view corresponding to scenarios of land-cover change (Lafortezza 2008; Grêt-Regamey et al. 2007; Tress and Tress 2003; Ode et al. 2009). Recent findings show that integrating virtual reality visualizations into choice experiments reduces the variability of preferences and significantly reduces the asymmetry between willingness to pay (WTP) for gains and willingness to accept (WTA) for corresponding losses (Bateman et al. 2009). For these reasons we applied 3D landscape visualization techniques to increase respondents' familiarity with the basic scenario and the alternative protection measures.

In contrast to the manipulation of two dimensional photos, 3D landscape visualization offers powerful means to reproduce the conditions given in the study region rather realistically using data of an Geographical Information System (GIS) as a basis and provide views from any perspective. A digital elevation model with 2 m resolution, orthophotos as well as land-cover data such as building footprints, forest areas and existing steel bridges for avalanche protection were used as input data to the software package 'Visual Nature Studio' (VNS 3; www.3dnature.com). Following a general visualisation workflow, further objects were added to the basic 3D landscape model (Wissen Hayek et al. 2010). Trees were represented by billboards based on photos and buildings as simple house models with generic facade textures based on photos taken in the study area. 3D models of technical constructions for avalanche protection were generated with 'Google SketchUp Pro' (http://sketchup.google.com). Iterative consultation of experts for the evaluation of intermediate results and adaptation of the visualizations according to their feedback, ensured a precise representation of protection measures and vegetation. In this way, we developed a virtual 3D landscape model of relative high visual realism (compare Figure 1).

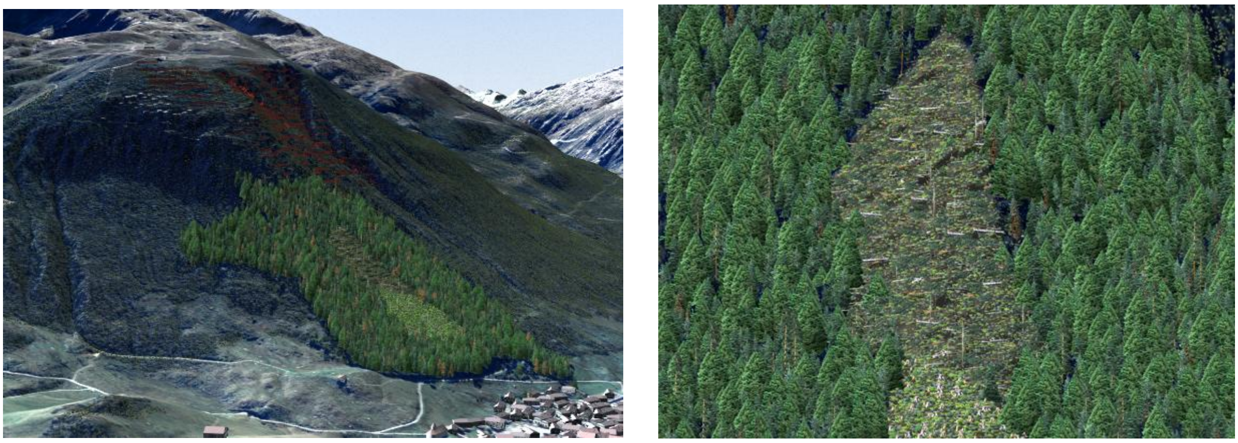

Figure 1. Visualization of the protection forest and the wind throw area (left: distant view, right: close-up view).

3 RESULTS

3.1 Damage assessment and risk analysis

Under current conditions –without wind throw- the damage potential in our study region adds up to approx. 20.5 million USD for an avalanche event with a 300-years reoccurrence period. This corresponds to an annual collective risk of approx. 68,500 USD for the municipality of Andermatt. The respective avalanche release areas and run out zones are shown in Figure 2 (left and right side).

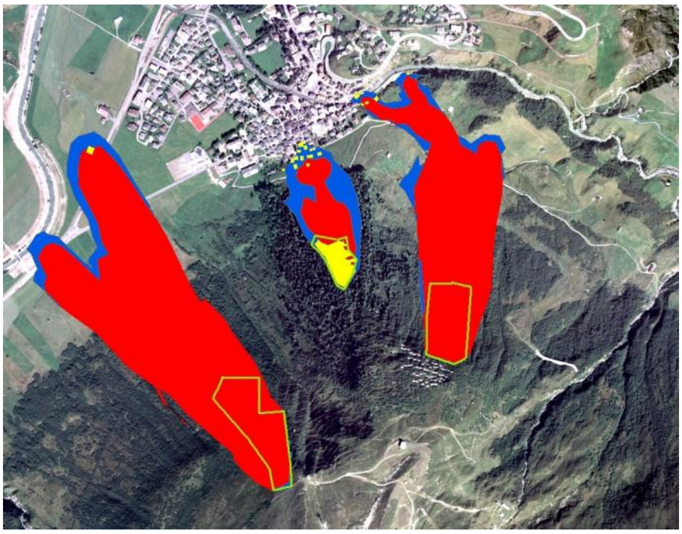

Figure 2. Calculated avalanche run-out distances for a 300-year avalanche event (Olschewski et al. 2011). (Blue and red: avalanche danger zones; yellow border: potential avalanche release areas; yellow filled: assumed wind throw area)

Assuming that a wind throw has damaged about 1 ha of the protection forest (yellow filled area in the middle of Fig. 2), the damage potential would increase up to approx. 29.5 million USD, resulting in an annual collective risk of approx. 98,500 USD. Thus, the additional risk generated by the wind throw area is about 30,000 USD per year. Referring to a project duration of 80 years, which is the highest level of our attribute 'duration', the discounted risk sums up to 470 USD per household.

3.2 Choice experiment

From a total of 488 households, 129 completed the survey, which means a respondents rate of about 26%. The statistical analysis has been conducted by using the 'BIOGEME'-software (Bierlaire 2003, 2008). All selected attributes have a significant influence on the result (compare Table 1). The coefficients have the expected sign: discounted risk reduction (DR) is positively related to utility, while increasing costs (CO) have a negative impact on the derived utility. The discount rate δ has been estimated simultaneously and results in 14.5 %.

Table 2. Estimated coefficients and log-likelihood function.

Attributes	Coefficient	Std err	t-test
Risk reduction (DR)	0.00104	0.000144	7.18
Costs (CO)	-0.00484	0.000458	-10.58
Type (TY)	0.341	0.0664	5.14
Discount rate (δ)	0.145	0.0270	5.39
Log L	-1301.21		
Number observations	1290		
Number respondents	129		
LL-Ratio-Test	232.0		

The willingness to pay (WTP) for avalanche risk reduction can be determined, as described above, by building the ratio of the respective coefficients (compare Eq. 8):

$$WTP = -\frac{\hat{\alpha}}{\hat{\beta}} \cdot DR = -\frac{0.00104}{-0.00484} \cdot DR = 0.215 \cdot DR \qquad (8)$$

According to Eq. 4, the discounted risk reduction depends on project duration, starting time, damage avoidance, and the discount rate. Table 3 shows some possible combinations of these attributes. Note that for the statistical routine *DR* has been multiplied by 0.01 and coded accordingly in order to avoid conditioning problems due to different parameter magnitudes. Thus, the ratio α / β in Eq. 8 has to be multiplied by the same figure to properly reflect the correct dimension of WTP.

Table 3: Willingness to pay (WTP) based on different attribute levels

Scenario	Project duration (T)	Starting time (ST)	Damage avoidance (DA)	Annual risk reduction (R)	Discounted risk reduction (DR)	Lump sum payment (WTP)	Annuity (WTP)
	(years)	(years)	(%)	(USD)	(USD)	(USD)	(USD)
A	15	5	50	16‘700	50‘750	110	18
B	60	3	70	23‘300	107‘150	230	33
C	80	1	90	30.000	180‘700	390	56

The estimated willingness to pay (expressed as a onetime (lump sum) payment at the beginning of the protection project) varies between 110 USD for Scenario A (starting after 5 years with a duration of 15 years and a damage avoidance of 50%) and 390 USD for Scenario C depending on the combination of attributes. The respective annuities as constant payments throughout project life time are given in the last column of Table 3. Note that these results relate to avalanche protection in general, i.e., irrespective of the type of measure. Consequently, they can also be interpreted as willingness to pay for protection by forests, under the condition that the forest has a similar effectiveness as technical measures in preventing avalanches.

3.3 Costs of avalanche protection

Efficiency requires the comparison of benefits and costs. While benefits have already been estimated as risk reduction and WTP, we additionally calculated the costs of alternative protection measures. These are, on the one hand, alternative costs of constructing and maintaining technical protection, completed by reforestation with the aim that growing trees can take over the protection function in the future. On the other hand, there are avoidance costs of silvicultural measures taken to maintain the existing forest and to reduce vulnerability to storm events right from the start. For all measures current investment costs and future maintenance costs are determined and discounted to the present. Then we assigned these values to all households assuming that the municipality has to bear 25% of the overall costs (compare Table 3).

Table 3. Comparing results of the valuation approaches (in USD per household).

Valuation Approach	Assumption/ Alternative	Lump sum (USD)	Annuity (USD)
Collective Risk	300-years event	470	69
Willingness to pay	risk reduction	390	56
Avoidance costs	forest management	20	3
Alternative costs	wooden logs	60	6
	wooden grills	195	28
	steel bridges/nets	600	87

4 DISCUSSION AND CONCLUSIONS

A comparison of the different valuation approaches shows that the willingness to pay for risk reduction is about the same as the collective risk related to a 300-years avalanche event. Note that WTP for risk reduction has not directly been asked for, but has been determined indirectly by combining several attributes. This procedure proved to be advantageous because it reduces probable cognitive difficulties of the respondents to understand the risk concept, especially when taking the different time horizons of the alternative measures into account.

The estimated interest rate of 14.5% is slightly higher compared to other studies related to natural hazards and mortality risks. Rheinberger (2009) found that people discount mortality risks by about 12%, whereas Alberini et al. (2006) estimated that people discount future risk by 7.4 to 9.1% depending on the model specification. Moore & Viscusi (1999) determined a margin from 1 to 14 % for people discounting fatality risks. One possible explanation for the relatively high discount rate might be seen in the age structure of the respondents in our study region: The average age was 53; 65.4% of all respondents belonged to the class aged 40-64, which is a substantially higher proportion than the respective figure (35.5%) for the average population in Switzerland (Swiss Statistics 2010). Therefore, we re-estimated the model for different age classes separately. We found that, the estimated discount rate drops to 13.6%, when just considering respondents aged 50 or younger. This indicates that the age structure of the participants had influence on the results.

Concerning the collective risk estimates, it has to be considered that the expected loss of human lives have been valued by an amount of approx. 5 million USD each (Bründl et al. 2009). As a consequence, the expected mortalities contribute about 90% to overall risk and have overwhelming impact compared to damages of buildings. Thus, reducing the assumed average number and presence of people in exposed buildings, would lead to a substantial reduction in annual collective risk. However, our approach would allows for including such changes by adapting the respective lower discounted risk reduction in Eq. 8. Recently, other authors have applied probabilistic approaches to the uncertainty related to input parameters when estimating avalanche risks (Grêt-Regamey & Straub 2006).

Related to the cost estimates, we assumed that the households' contribution sums up to 25% of the overall costs, which represents a realistic cost sharing between municipality, canton and federal state in Switzerland. When comparing the costs of the alternative measures with the estimated willingness to pay, we found that WTP for risk reduction is substantially higher than the costs of wooden measures against avalanches (logs and grills), whereas costs of steel bridges and nets would not be covered by WTP. This indicates that the population of Andermatt seems to be well acquainted with the situation on the spot: the combination of wooden constructions and reforestation measures is regarded as an adequate solution, when disturbances create new avalanche release areas within forested terrain. However, the economically preferable solution is the maintenance of the existing forest, because protection is provided at lowest costs. This result crucially depends on, whether avalanche protection can actually be ensured in the long run. Therefore, maintenance and silvicultural management should focus on both increasing effectiveness against avalanches as well as reducing vulnerability to heavy storm events. Furthermore, the early and steady regeneration of the forest is crucial for a fast re-establishing of the protection function, once a wind throw has taken place.

Interestingly, WTP for risk reduction is well below the costs of steel constructions. Here, aesthetical aspects could play a role. We took this point into account by asking how important landscape aesthetics has been when making choice decision between the options. 75% of the respondents answered that this aspect was 'important' or 'rather important', whereas only 10% said it was unimportant. This result stresses the role of visualizations for the perception of the different options but also for the understanding of the questionnaire as a whole. As one of the advantages of an online survey, respondents had the opportunity to enlarge the visualizations on the screen, thereby getting a better impression of the wind throw area and the visual impact of the technical measures. The same holds for provided info-buttons related to, e.g., risk calculations for avalanche events with different reoccurrence periods. As a result, only 5% of the respondents found the questionnaire 'incomprehensible' or 'partially incomprehensible', and just 2% said the selected scenarios to be unrealistic.

Summing up, the present study provides important decision support for landscape planning and silvicultural management related to the protection function of forests. Combining a choice experiment with a risk-based evaluation techniques, GIS-based 3D landscape visualization, and alternative cost estimations based on engineering and silvicultural knowledge, turned out to be a complex procedure. As mentioned by Hoyos (2010), conducting such studies needs strong interdisciplinary collaboration. However, it turned out to be an adequate approach to value different attributes of avalanche protection services. The comparison of WTP, alternative costs and avoidance costs provides guidance towards efficient solutions for avalanche protection in mountainous regions.

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