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Gravitational natural hazards: Valuing the protective function of Alpine forests

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ABSTRACT

Forests produce significant non-market benefits by protecting residential and commercial real estate as well as all kinds of infrastructure (e.g. rail tracks, highways, power lines) against gravitational natural hazards such as avalanches, mudslides, and rockfall. The Austrian Federal Forests (Österreichische Bundesforste – ÖBf) recently commissioned a research project on the valuation of this ecosystem service by means of the replacement cost method and the hedonic pricing approach.

Based on the international literature, this paper focuses on a careful and realistic design of the baseline scenario with which the "marginal change" in ecosystem services can be assessed and valued. While the (current) management scenario is rather clear and reflects the approach pursued by the ÖBf (reasonably labeled as multifunctional forestry), the design of the baseline scenario (intensified commercial forestry) assumes a reduced protective function of the forests which, however, would still have to be in line with strict legal frameworks such as the Austrian Forest Act or European nature conservation directives.

Given these strict frameworks, the potential leeway for commercial forestry is rather limited; still, the current multifunctional forest management secures ecosystem services worth up to EUR 14.7 m per year (valued at replacement costs of technical measures to substitute the protective function of forests), which corresponds to EUR 268 per hectare and year. The result of the hedonic pricing approach for property in hazard zones protected by forests is substantially lower: The ecosystem service is valued at EUR 2.9 m per year (which corresponds to an annual per-hectare value of EUR 53). The results in general underline the importance of multifunctional forestry and of the ecosystem services function sustained especially in state-owned forests.

1. Introduction and background

Forests and their function of protecting residential and commercial land as well as infrastructure from gravitational natural hazards (e.g. avalanches, mudslides, and rockfall) are of significant importance in Alpine regions. Especially in France, Italy, Switzerland, and Austria, large areas would not be suitable for economic activities without protective forests. In Austria, forests cover about 46% of the surface (another 10% of the land are high-alpine areas such as rocks and glaciers). Total forest land in Austria amounts to about 3.9 m hectares, of which protective forests have a share of about 25% (Perzl and Huber, 2014). Protective forests are defined under the Austrian Forest Law as forests that (potentially) protect residential and industrial areas, agricultural land and all kinds of infrastructure against gravitational natural hazards. In some Austrian regions (e.g. in the federal provinces [*Bundesländer*] of Tyrol, Vorarlberg, and Salzburg), up to 47% of forests are classified as protective forests (Perzl and Huber, 2014). In an international perspective, protective forests for avalanche control, of course, only make up a minor share of the total forest cover worldwide. Only few countries (including Switzerland and Austria) have large shares of their forests designated as avalanche control forests (Miura et al., 2015).

The high share of protective forests in specific regions thus points to their enormous importance for everyday human life in the Alps; in fact, they facilitate settlements, infrastructure, and productive economic activities in mountainous areas. The protective function of forests, and their future significance, is highlighted by the substantial damage caused by gravitational events such as avalanches, rock- and mudslides, and rockfall (e.g. Brang et al., 2001; Dorren et al., 2004; Teich and Bebi, 2009; see Dupire et al., 2016 for a recent study on indicators of such natural hazards). In general, the regulating function of mountain forests may even be the single largest value of all ecosystem services provided

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by Alpine forests (e.g., Häyhä et al., 2015). The Austrian Disaster Relief Fund (*Katastrophenfonds*) compensates losses of households, municipalities, and other owners of affected land, and invests in disaster prevention, such as technical measures against avalanches and floods; the fund has paid about EUR 400 m on average per year in compensation and for preventive technical measures (BMF, 2016). In some years with severe events (e.g. the floods in 2002), compensations are significantly higher.

Given this perspective on the function of forests, the ÖBf (Austrian Federal Forests [*Österreichische Bundesforste, ÖBf*]) commissioned a research program to value the ecosystem services provided by forests to the authors of this paper. Among other ecosystem services, such as drinking water provision and local climate regulation, the ÖBf asked the authors to value the protective function of forests on ÖBf land.

The ÖBf manages forests and other land (e.g., high-alpine areas, pastures, lakes) owned by the Republic of Austria; the company was set up by law, is organized as a public limited company (Bundesforstegesetz, 1996), and has to manage the land efficiently based on sound management principles, and to 'optimize the economic outcome' (i.e., provide profits to the central government's annual budget). However, in a day-to-day perspective, forestry is only one branch of activities, since the ÖBf focuses on 'multifunctional' forest management. Apart from timber production, large shares of the land are protected under national or international (especially EU) law (e.g., national parks [category II of IUCN management guidelines; cf. Dudley, 2008], nature conservation areas, Natura 2000 habitats, species, and bird habitats), while other parts of the land are high-alpine areas without any direct commercial use. In addition, the ÖBf has to conserve freshwater and groundwater resources and is increasingly engaged in the planning and managing of, and consulting for, nature conservation on its own land as well as in other areas.

The protective function of forests as such is included neither in the usual national accounting systems nor in specific forestry accounting, as the benefits accruing from this function are typical non-market goods and services for which no market prices, and thus no straightforward measures of scarcity, are available. Furthermore, the national forestry accounting systems in Europe are usually not easily comparable since the countries apply different measurement, statistical and valuation methods (Sekot, 2007).

Given the legal frameworks of forestry and nature conservation, and the aims and objectives of the ÖBf's multifunctional forestry approach, estimating the economic value of the protective function of Alpine forests is not straightforward but is embedded both in legal, economic, ecological, and institutional frameworks and contexts. Thus, this paper and the underlying study (Getzner et al., 2016) focus on the following research questions:

- Which economic value can be attributed to the protective function of forests on ÖBf land given the current management regime of multifunctional forestry?
- How can this value be ascertained by means of the replacement cost method as well as the hedonic price approach?

The first question relates to the definition of a baseline scenario in order to operationalize the marginal change of ecosystem services given by the protective function of forests. The "marginal change" in the current context of environmental valuation reflects the change of environmental quality brought about by a certain management (or environmental) program in comparison to a baseline scenario (Johansson, 1993). Therefore, a central part of this paper concentrates on a detailed description of this marginal change as the foundation of any economic valuation exercise. The purpose of this approach is to model the value of protective forests against the background of two plausible-realistic planning alternatives. Plausibility in the current context assumes logical and factual consistency between all defining parameters of a certain scenario, which is also realistic if the environmental program or management regime is within legal boundaries, and has been discussed as possible option and subject of debate by stakeholders such as policy makers. The second question refers to the valuation itself by means of two approaches; it will become clear that the two questions are linked insofar as the definition of the baseline scenario might also depend on the choice and operationalization of the respective valuation method.

The structure of the paper is as follows: Section 2 provides a brief overview of the literature on the assessment and valuation of the protective function of forests with a special emphasis on the Alpine region. Most of the studies presented are from Switzerland, Austria, and Italy. In Section 3, we discuss the baseline scenario for estimating the "marginal change" of the protective function. Section 4 presents the results of the economic valuation based on the replacement cost method, while Section 5 presents the (partially contrasting) results of the hedonic pricing approach. Finally, in Section 6, we summarize and discuss the results, and draw conclusions.

2. Valuing Alpine forests and their protective functions

As briefly outlined in the introduction, the protective function of forests is substantial in many parts of the Austrian Alps. Fig. 1 presents a map highlighting the total area managed and owned by the ÖBf as well as the protective forests on ÖBf land.

Many published papers on the value of the protective function of forests in Alpine regions concentrate on Geographic Information System (GIS) and risk-based planning (e.g., Teich and Bebi, 2009), on the replacement costs of and the willingness to pay for the conservation of protective forests (e.g. Notaro and Paletto, 2012; Olschewski et al., 2011), and on choice experiments for the valuation of different combinations of conservation scenarios (e.g. Olschewski et al., 2012). However, the range and spatial dimensions of these studies vary widely from small protective forests of 1 ha to large forests of many hundreds of hectares.

Starting with a study of a smaller spatial dimension, Fuchs et al. (2007) present two alternatives for valuing avalanche hazard mitigation strategies at Davos (Switzerland); they conduct a cost-benefit analysis for a patch of around 7 ha in four different scenarios and compare the results to those of a cost-effectiveness analysis (cf. also Gamper et al., 2006). The four scenarios range from single technical measures (snow fences) to a combination of technical measures with organizational and spatial planning policies. The results indicate that technical measures are rather economical when compared to the opportunity costs (hedonic prices) of preventive land use planning (i.e. designation of red zones in natural hazard maps that lead to construction bans). The paper also shows that partial avalanche prevention structures are less efficient than measures for the total hazard zone. For our paper, the results of Fuchs et al. (2007) are important insofar as the technical measures to substitute the protective function of forests have to be constructed over a wide area in order to secure the full protection of residential areas or infrastructures (cf. Brang et al., 2006).

Grasser (2009) studies the cost-effectiveness of several options for the management of protective forests in the canton of Schwyz in Switzerland. She shows that among the several options available to substitute or complement the protective function of forests, including natural regeneration policies, the most economical form of protection is a sustainably managed protective forest that is able to secure infrastructures and residential areas. Technical measures such as wooden or steel snow bridges are more expensive.

Notaro and Paletto (2012) basically address the same topic as we do. They apply the replacement cost method to a small patch of protective forests in the Valdastico valley (Italy). The replacement cost method itself is rather widely used for valuing forest ecosystem services, especially with respect to erosion control and soil conservation, watershed protection, and carbon control (Ninan and Inoue, 2013). However, results vary widely across these studies – even though the replacement cost method is usually considered a robust method. In this context, Ninan and Inoue (2013) emphasize that the local context is especially important when discussing the value of forest ecosystem services and

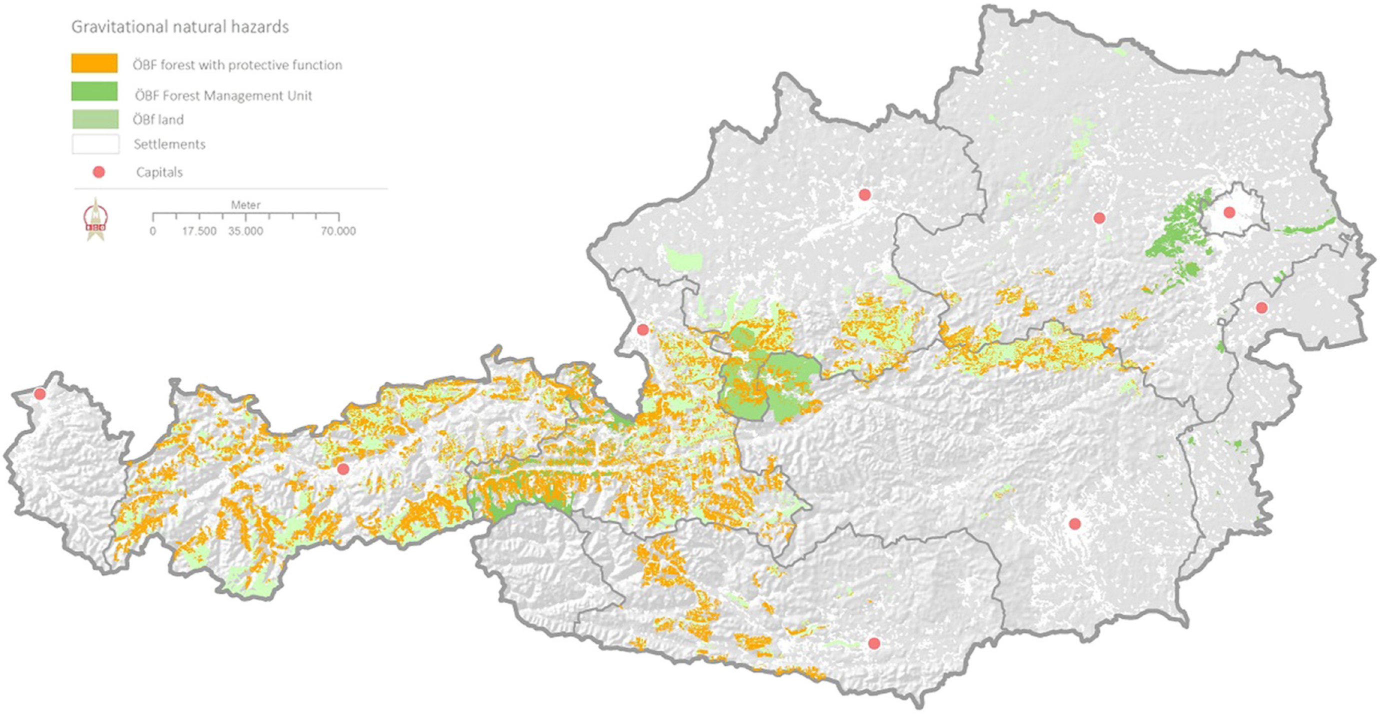

Fig. 1. Mapping the protective function of forests in Alpine regions in Austria (GIS model).
Source: Authors' GIS model (for details, see Getzner et al., 2016).

designing conservation policies. Notaro and Paletto (2012) present their paper along this line of argumentation by carefully valuing a range of scenarios of the management of a certain plot of protective forest with respect to the local specifics of the area. They evaluate several bio-engineering and technical measures in terms of precisely valuing of ecosystem services of protection from gravitational natural hazards on about 270 ha of protective forest (cf. also Notaro and Paletto, 2004; Goio et al., 2008).

In the context of climate change, Olschewski et al. (2008) discuss the replacement cost method as specifically suitable for valuing the protection against avalanches and other gravitational natural hazards. They also stress a caveat of this method, which is that it focuses on the cost side alone while leaving out any possibility to account for the benefits of protective forests. To overcome this problematic focus, Olschewski et al., (2011, 2012) present the results of willingness-to-pay and choice experiment studies for a small protective forest. Summing up, the replacement cost method only shows the potential lower bound of environmental values;[1] hedonic pricing will potentially result in higher benefit values if the protective function of forests is adequately represented on the real estate market and perceived as such by real estate owners.

This short literature review shows a lack of pertinent studies that

- go beyond single (small) patches of protective forests and try to value the protective function of forests for large areas;
- try to estimate the value of the current management regime as compared to a hypothetical reference scenario which assumes the legal maximum of commercialization of forestry; and
- discuss the differences between the replacement cost method and hedonic pricing of real estate in the Alpine region.

Therefore we now turn to the design of scenarios as a basis for assessing the marginal changes in the quantity and quality of ecosystem services as one of the key elements of valuing ecosystem services in the next section.

3. Defining marginal economic value: baseline and management scenarios

The economic value of a certain ecosystem service is usually defined on the basis of marginal change in environmental quality (e.g. Johansson, 1993; Ninan, 2009; Markussen et al., 2003). Environmental economists are generally hesitant to establish the 'absolute' value of an ecosystem service as a stock value but, rather modestly, limit their analyses to the marginal change in ecosystem services in terms of flow data, which, in turn, of course rest on the stock of natural capital and its changes over time (Haines-Young et al., 2012).

While this general concept is widely accepted, some studies in the context of national accounting of biodiversity propose to calculate some absolute values of ecosystem services if, for any reason, marginal changes are not defined or management scenarios are not clear (von Grünigen et al., 2013). Some studies clearly try to arrive at comparable economic values collected in meta-analyses for certain types of ecosystem services. For instance, Jónsson and Davíðsdóttir (2016) only recently presented a range of values taken from several studies on soil ecosystem services. They compare these values and come up with a wide range of estimates for several specific types of ecosystem services; however, as is also the case with Kumar (2010), only sketchy information is provided on the specifics of the underlying studies, nor is there any indication of the marginal change and the scenarios and assumptions underlying the respective valuations.

In our study, both valuation methods applied take the current management practice (tentatively labeled "multifunctional sustainable forestry") as a starting point. Regarding the replacement cost assessment,

[1] As the replacement cost method does not deal with the value of benefits as welfare measure, such costs are typically lower than gross benefits (cf. e.g. Hanley and Spash, 1993; Bockstael et al., 2000). However, whether the replacement cost approach underestimates environmental benefits certainly depends on the quantity and quality of ecosystem services already produced with respect to the marginal replacement costs which might follow a convex (increasing) function. Hedonic pricing aims to value benefits against natural hazards as perceived by real estate owners and might therefore lead to higher values. The basic assumption with this method is that owners perceive and value hazard risks accordingly, and that these individual assessments are expressed on the real estate markets. Therefore, the possible differences in values between these two methods have to be assessed in case-by-case empirical studies.

simply multiplying the area of protective forests times the costs of technical measures to establish the value of the protective function of forests might be highly misleading. Such approaches assume a baseline situation in which no protective forests would exist at all. While this might be considered completely unrealistic – protective forests have always existed in the Alps to different extents – settlements and infrastructures would have been built differently in Alpine areas without protective forests. In addition, population density in Alpine valleys would have been much smaller. A simplified assumption about the replacement costs on the whole area of protective forests may thus not lead to robust results with respect to marginal changes and opportunity costs, since this approach would lead to a result in which the total value of the protective function of forests would be no less than the welfare stemming from living and working in Alpine regions (which would not be feasible without that ecosystem service). In addition, the assumption of marginal change and the theoretical framework of the environmental valuation of ecosystem services are all based on a fixed system of relative prices. Environmental valuation, e.g. by means of replacement costs, therefore does not account for general equilibrium effects. Rather, we implicitly assume that the marginal changes that accrue do not have a major impact on other prices and consequently leave relative prices unchanged (Brent, 2006; Marggraf and Streb, 1997).

The definition of a baseline scenario is thus of paramount importance. Our description of (plausible) real or hypothetical future developments of the status quo has both to comply with the existing legal frameworks and reasonably take into account information about the possible economic, social, and environmental development with respect to forestry, and environmental conservation. For instance, Grêt-Regamey et al. (2008) are very careful in modeling the land use changes accruing after the expansion of a tourism resort in the Swiss Alps by means of GIS analysis including elements such as a digital elevation model, a land-cover map, and information on the local micro-climate as a basis for the economic valuation of altered ecosystem services – our GIS model basically includes the same features, and adds results of the GRAVIMOD/GRAVIRPOFOR projects specifically modeling avalanche tracks (Perzl and Huber, 2014). For the purpose of this study, a robust baseline scenario (as the foundation of describing and assessing marginal change) should especially meet the following requirements: (i) it should not include the alternative resettlement of residents or relocation of businesses from Alpine regions, (ii) it should not include intensive forestry on all land given the existing legal restrictions, and (iii) it should be in compliance with the EU and national legal frameworks, e.g. the Austrian Forest Act, or Natura 2000 sites according to the EU Birds and Habitats Directives. Describing marginal change in the protective function of Alpine forests is thus not straightforward, as the establishment, assignment, and management of protective forests is strictly regulated in Austria based on the Federal Forest Act (Forstgesetz, 1975), among others. In light of these considerations, the land owner, in our case the ÖBf, has only little leeway for different management scenarios.

The baseline scenario for forestry on land with protective forests may therefore rest on the following assumptions:

- Any intensification of forestry must be within the legal limits.
- Conservation efforts and the designation of protected areas are reduced to the legal minimum.
- The forest management approach is changed in that the multifunctionality approach is abandoned in favor of profit maximization (e.g. monocultures, shorter cycles from planting to harvesting, larger areas of clear cutting, and additional infrastructure for harvesting).

Our research question presented in Section 1 concentrates on the value of ecosystem services guaranteed by the current management practice; thus we assume the maximum legally feasible commercialization of forestry and describe the change in the extent of the protective function in this hypothetical reference scenario as compared with the current management practice. The most important input data for modeling the current as well as the hypothetical state of protection forests is a combination of data on land use and the management and conservation of all ÖBf land (see also Fig. 2).

As Table 1 shows, the ÖBf manages over 844,000 ha of land with a share of forests of about 61%. In the status quo, i.e. the current management system and practice of multifunctional forestry, about 50% of all land is covered by some regulation, including strict (e.g. core zones of national parks, wilderness areas or Natura 2000 sites), strong (e.g., nature conservation areas), and weak conservation requirements (e.g. landscape conservation zones). The intensity of commercial forestry in ÖBf forests is comparatively high on about 40% of ÖBf land. Protective forests cover about 150,000 ha of which about two-thirds are not commercially used at all; some commercial forestry takes place on the remaining third.

Defining the reference scenario is thus not straightforward. In a series of workshops, discussions and assessments with the ÖBf and other experts, based on current ÖBf statistics and management reports and strategies, we tried to quantify possible changes that would occur if the ÖBf did not follow multifunctional forestry strategies but adopted an intensive commercial forestry approach. However, as outlined above, such an approach would be limited by the (existing and evolving) legal frameworks of nature conservation and forestry. Basically, there are two ways of intensification. First, the intensity of forest (timber) use could be increased on land that is used today; a qualitative assessment of the assumed intensity of commercial forestry is presented in Table 1 (see the lower part of the right column). And second, land that is subject to weak conservation regulations today could also be used for commercial purposes. In the process of drafting the hypothetical reference scenario, we assume that (i) nature conservation land is, at the (legal) maximum, reduced to a share of about 40%, (ii) commercial forestry is intensified especially in forests that are already used for timber production, and (iii) compensating measures are taken in protective forests (e.g. wooden snow fences and bridges).

The value of the ecosystem services provided in the two scenarios (and specifically of the protective function of forests) varies considerably depending on the chosen methodology.

First, as mentioned in Section 2, the replacement cost approach takes into account the costs of technical substitute measures; the demand side (i.e. individual preferences) is left out. Therefore, it is reasonable to assume that if the protective function is somewhat reduced and technical measures are in place for its substitution, the change in costs will be exactly proportionate to the change in technical parameters.

Second, if we assume that the protective function is limited, real estate values in terms of hedonic prices, which are equally based on the supply and demand side, may be very different from those established with the replacement cost approach. A hypothetical improvement in the protective function of forests from the reference scenario to the

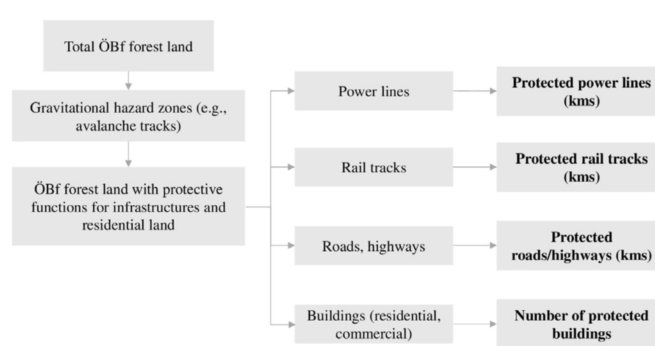

Fig. 2. Modeling approach for assessing the protective function of ÖBf forests in Alpine regions in Austria.
Source: Authors' concept.

Table 1
Categories of land, conservation, and intensity of commercial forestry in the status quo and the hypothetical baseline scenario.
Source: Authors' concept and assumptions based on ÖBf data.

Categories of land	Total area (hectares)	Share of land categories (% of total area)	Status quo[a] (business-as-usual scenario)	Reference (baseline) scenario
Total ÖBf area (rounded)	844,000	100%	100%	100%
Of which: forests	511,000	61%	61%	61%
Status of conservation[b]				
Strict conservation			8%	6%
Strong conservation			25%	20%
Weak conservation			17%	14%
Intensity of commercial forestry[c]				
Intensive commercial forestry[d]	336,000	40%	40%	++
Sustainable forestry[d]	5000			+
Protective forests without commercial use	97,280	12%	12%	0
Protective forests with commercial use	54,720	6%	6%	++
Other areas inside forests	18,000	3%		
Land with some conservation status (rounded, % of total land)			50%	40%

[a] The status quo is a business-as-usual scenario and includes the current practice of multifunctional and in parts sustainable forestry.
[b] The status of conservation only considers conservation policies that have a legal basis (e.g. in protected areas); it does not take into account conservation measures that are included in forest management plans on a voluntary basis (e.g. limitation of clear cutting, toleration of deadwood). Examples for strict conservation: wilderness areas, core zones of national parks; strong: nature conservation areas, Natura 2000 sites; weak: landscape conservation zones.
[c] The intensity of the commercialization of timber production is described only in qualitative terms in the hypothetical reference scenario. ++ indicates a significant increase in intensity, while + stands for weak intensification. The value of 0 refers to an unchanged intensity of forestry.
[d] The current practice of intensive commercial forestry does, however, not suggest that these practices are not bound to certain sustainability frameworks; for instance, commercial forests are sustainably managed along the principles of harvesting an amount of timber that does not exceed the corresponding growth. Furthermore, the Austrian Forestry Act and other legal frameworks provide for environmental standards of pursuing forestry.

current management practice may just as well have no effect on the perceived risk to residential property or infrastructures by avalanches and other gravitational hazards. Natural hazard zones, as identified and established in official municipal and regional documents, will not be adapted quickly if the protective function of a forest changes. In addition, not all land that is protected by forests is also included in (potential) hazard zone maps. Furthermore, some areas that are still included in hazard zone maps are not in fact at risk from natural hazards, e.g. if technical measures have already been implemented successfully, or if the housing structure and infrastructure have changed over time, thus reducing the risks of natural hazards in general.[2] Market observations have shown that local real estate prices tend to drop sharply after a singular disaster (regardless of whether the area was included in a hazard zone map or not) but recover after a few years (Weberndorfer, 2009; cf. Damm et al., 2013).

In all three cases, the question remains whether changes in real estate prices actually reflect changes in objective risk or in subjective (i.e. perceived) risk.[3]

Summing up, the economic valuation of the protective function of forests is more closely connected with objective risks in the case of the replacement cost approach, while the hedonic pricing approach relies much more on both supply and demand, which leads to a more subjective (perceived) risk assessment that, in turn, does not necessarily correspond to official hazard zone maps.

4. Replacement costs of the protective function of Alpine forests

Fig. 1 presents all forest areas on ÖBf land with a protective function. Along the Austrian Alps, about one-third of all ÖBf forests (about 150,000 ha) fulfill a protective function for either residential or commercial areas or for infrastructures (e.g. power lines, rail tracks, roads and highways) and at the same time bear the designation of protective forests. The map also shows ÖBf forests in light and dark green which are commercial forests without a protective function in the narrow sense.

Based on our considerations presented in Section 3, the question remains which patches of land might lose their protective function if the ÖBf did not pursue the current management system of multifunctional forestry, but intensified and extended commercial forestry to a level only just within the legal framework. ÖBf currently produces some timber in protective forests (cf. Table 1). Assuming that these forests would be used more intensively than under the current management approach, one strategy might lie in the shortening of the average life span of forest stands by 20 years (e.g. from 100 to 80 years),[4] and in the clear cutting of larger plots, e.g. 1 ha, as opposed to the current practice of harvesting only single trees or smaller patches of up to 0.2 ha. In addition, new forest roads could be built in order to improve access to forests which could be harvested.

Based on the total area of protective forests used commercially (54,720 ha), the reduction of the life span of forest stands and the intensification of harvesting would lead to an additional area of 136.80 ha harvested annually with a corresponding reduction of the protective function of the forest.[5] The responsible authorities might prescribe

[2] The risk of natural hazards might also be increased if real estate owners (can) rely on the government to compensate them for damages. In Austria, the above-mentioned natural disaster fund can be thought of insurance for such risks. As with other types of insurances, this fund has been debated in the context of moral hazard (Perlinger, 2016; cf. Hudson et al., 2014) and charity hazard (Raschky and Weck-Hannemann, 2007). Therefore, even if a certain property is subject to high risks, and owners perceive these risks as such, they also rely on the compensation paid by the disaster fund in case of catastrophes. Thus, the risk from natural hazards might partially be ignored in real estate prices.

[3] There is a long and intensive debate in economics on the individual perception of risk, and the manifold problems associated with risk perception in terms of market failure (Slovic, 1987; Kahneman and Tversky, 1979). Regarding natural hazards, especially flood risks and landslides, recent studies deal with risk perception, disaster preparedness, public responsibility for mitigation measures, and the individual determinants of risk assessment (e.g., Eiser et al., 2012; Bubeck et al., 2012; Damm et al., 2013; Calvello et al., 2016).

[4] The harvesting age of trees on ÖBf land amounts to up to 140 years.

[5] This additional area is calculated – ceteris paribus – with the following formula: $C_a = C_c - C_m$, with C_a denoting the additional annual area of harvesting if commercial forestry is intensified according to the hypothetical reference scenario; C_c is the annual area which is harvested if the forest growth period is assumed to be 80 years ($C_c = A_p/80$, with A_p corresponding to the total area of protective forests commercially used), and C_m is the annual area of harvesting based on a 100-year growth period ($C_m = A_p/100$). We take only the additional harvested area even though under the current approach there is no clear-cutting of large areas but only single tree stems are extracted. This means our results are extremely conservative with respect to the altered protective function.

Table 2
Replacement costs of technically feasible measures to substitute the protective function of forests.
Source: Authors' calculations and data analysis based on information provided by the Austrian Agency for Torrent and Avalanche Control (Wildbach- und Lawinenverbauung – WLV, 2015) and Vallaster (2015).

	Steel snow bridge (m)	Avalanche (protection) gallery[a] (m)	Steel grid (net)[b] (m)	Wooden snow bridge & snow fences[b] (m)	Afforestation[c] (ha)
Manufacturing costs (EUR per unit)	1100	15,000	500	250	40,000
Units per hectare	600	100	600	600	1
Manufacturing costs (EUR per hectare)	660,000	1,575,000	315,000	157,500	40,000
Planning costs (% of manufacturing costs)	5.00%	5.00%	5.00%	5.00%	5.00%
Planning costs (EUR per hectare)	33,000	78,750	15,750	7875	2100
Maintenance costs (% of manufacturing costs)	0.50%	2.00%	0.25%	1.00%	1.50%
Manufacturing costs (EUR per hectare over 80 years, including all planning and maintenance costs)[d]	660,000	1,575,000	315,000	315,000	42,100
Present value of total production costs (EUR per hectare, incl. maintenance costs and reinvestments)	875,942	3,400,018	374,407	410,188	79,025
Total production costs (EUR per year and hectare, annuity)[e]	15,959	61,944	6821	7473	1440
Proportion of production cost to the cost of afforestation[f]	11	43	5	5	1

Assumptions for the calculations: Calculatory discount rate 1% p.a.; the production costs as annuities include all costs for the respective technical measures (planning and maintenance costs, reinvestments) over the whole technical life span of 80 years.
[a] Avalanche (protection) galleries substitute 1 ha of forests, but also affect areas above (in higher altitudes).
[b] Wooden snow bridges and steel nets are (from a technical point of view) the most common and adequate measures to substitute (or support) the protective function of Alpine forests.
[c] Afforestation may not only consist of planting and managing new trees but also of regulating the deer population which may also be a very effective measure to conserve protective forests.
[d] As a clear-cut forest will need about 30 years to be fully functional again in terms of protection, the minimum required technical life span is 30 years. However, the planning and calculation period was based on the technical life span of some of these measures extending to a maximum of 80 years; measures which have a shorter life span (e.g. wooden snow bridges) are assumed to require reinvestment after 30 years; in order to be able to compare the production costs of different technologies, all measures are based on a common planning horizon (80 years).
[e] The annuity of costs (TPC = total annual costs of production) of technology i was calculated by the following equation: $TPC_i = PV_i \cdot \frac{(1+d)^n \cdot d}{(1+d)^n - 1}$, with PV_i being the present value of all costs over the planning period (investment, re-investment, planning, maintenance cost), d is the discount rate of 1% p.a., and $n = 80$ years; $PV_i = \sum_1^a C_i / (1+d)^a$ with C_i = costs for technology i, and a is the year of the planning period for $a = 1...80$.
[f] When calculating the proportion of the costs of technical measures to those of afforestation, we assume that technical measures to deal with gravitational natural hazards are substitutes to protective forests; however, owing to climate change, other natural hazards (deadfall caused by storms), or a changing tree species composition based on nature conservation policies, some technical measures might still be necessary despite functional protective forests.

technical measures to secure the protection of areas in hazard zones. In addition to the protective function that has to be substituted annually, we have to make two assumptions for the calculations (Table 2): (1) The period during which a formerly clear-cut protective forest regains its protective function after reforestation is assumed to be 30 years. (2) The same period is also assumed as the ÖBf's long-term planning horizon. In other words, technical measures to secure the protective function have to last a minimum of 30 years (which is true for all types of technical measures; wooden snow fences and bridges have a technical life span of 30 years). In addition, as some measures have a life span of 80 years (e.g. avalanche galleries), we extend the calculation period to 80 years for all measures (including those with a shorter technical life span by assuming regular re-investments) to come up with an annuity of replacement costs based on the same underlying assumptions. However, we also assume that the hypothetical reference scenario is already in place today so we can estimate that the average forest is without protection over a span of 15 years (see Table 3 for details of the derivation and calculation of these figures).[6] This means that the area on which additional technical protection measures would be necessary at any given moment is 2,051 ha in total (see Table 3).

Table 2 presents an overview of technical substitute measures to replace or produce the protection of residential and commercial land as well as infrastructure. Table 2 also includes the production costs over the technical life span of all measures, including planning and maintenance costs, and assuming a (real) discount rate of 1% p.a.[7] All technical measures are assumed to provide an equal protective function. Of course, though each measure has different technical specifications; for instance, the density of single elements or their specific functions (e.g. protection against avalanches vs. protection of rail tracks against all gravitational hazards) vary substantially.

In order to facilitate the comparison between technical measures, our calculations are based on 1 ha in the form of a square of 100 × 100 m. In addition, we do not only include the construction (investment) costs for all technical measures but also account for planning and maintenance costs over the technical life span of each measure (which is also different between measures). In order to calculate the costs of ensuring the protective function for 1 ha for each measure, we use the annuity of total costs as the relevant statistic for annual replacement costs.

Table 2 also shows that the cheapest technical measure for providing the protective function on 1 ha is the afforestation and management of protective forests[8]; the costs of the second most economical technical

[6] It has to be assumed that the hypothetical reference scenario exists over a longer period of time (and is not implemented only in 2016); from that follows that the relevant calculation period is 15 years (given the technical life span of wooden fences and bridges, and the regeneration of reforested trees): While the fully functional protective forest would need 30 years to regenerate, some protective function may already be in place after a much shorter period. In order to avoid the overestimation of the value of the protective function of forests, we assume a linear function of recovery over 30 years, and therefore presuppose that the full protection by technical measures is warranted over 15 years.

[7] The choice of an adequate discount rate with respect to the long-term valuation of ecosystem services is, of course, intensively debated in (ecological and environmental) economics. Many scholars argue for lower discount rates in the environmental policy realm, potentially in contrast to other public policies (e.g. infrastructure policies). For instance, Gowdy et al. (2011) argue for a discount rate close to zero for biodiversity and ecosystem services, and specifically base their reasoning on ethical standards and societal perspectives on future developments. Stern (2007) also discusses a wide range of reasons for low rates of discount in policies combatting or adopting to climate change. Taking these arguments together, and also accounting for the currently low real interest and economic growth rates (presumable staying at much lower levels than in the last decades), the real discount rate of 1% p.a. is chosen in this paper (see also Bateman et al. (2014) and Getzner (2000) with respect to discounting in environmental policy decisions).

[8] Afforestation and management of protective forests may also include deer management and regulation. Especially in slowly growing forests, deer may pose great threats to trees owing to the lack of natural predators. However, further research is needed to ascertain the positive welfare effects of stricter deer management on the natural conditions of protective forests (see also the discussion of the results in the conclusions section).

Table 3
Summary of calculation steps to arrive at a conservative estimate of the economic value of protective forests on ÖBf land by means of the replacement cost method.
Source: Authors' calculations.

Computation step/assumption	Area or costs, resp.
Total area of protection forests according to the GIS analysis[a]	176,551 ha
Of which: Currently intensively used commercial forests[a]	26,483 ha
Of which: Currently commercially used protective forests	54,720 ha
Current annual use (harvesting) of timber in protective forests (by means of clear cutting), assuming a growth period of 100 years	547.20 ha
Theoretically possible/feasible annual use (harvesting) of timber by means of clear cutting, assuming a growth period of 80 years (hypothetical reference scenario)	684.00 ha
Difference (corresponding to the marginal change) of large commercially used forest areas which would have to be secured (comparison between current multifunctional forestry and the hypothetical reference scenario)	136.80 ha
Total area of formerly protective forests that would have to be permanently secured at any given moment (i.e. average over 15 years)[b]	2,051 ha
Mean production costs of technical measures to ensure protection against gravitational natural hazards (EUR per hectare and year; values taken from Table 2)[c]	EUR 7,147
Total economic value of the protective function of forests on ÖBf land (current management practice compared to the reference scenario) (EUR m per year)[c]	EUR 14.672m
Total economic value of the protective function of forests on ÖBf land (current management practice compared to the reference scenario) (EUR per hectare and year)[c]	EUR 268

[a] Table 1 reports a smaller land area as protective forests; the reason lies in differences between the official designation of protective forests and the protective forests modeled by GIS depending on the danger zones based on the gravitational hazard tracks.
[b] It has to be assumed that the hypothetical reference scenario exists over a longer period of time (and is not implemented only in 2016); from that follows that the calculation period is 15 years (given the technical life span of wooden fences and bridges, and the regeneration of reforested trees).
[c] All values (EUR) are based on the annuity of production costs calculated in Table 2.

measures (wooden snow bridges and fences, steel grids and nets) are about five times higher.

The cost associated with ensuring the protective function of ÖBf forests under the current management regime is compared to that of the reference scenario assuming maximum commercialization within legal limits. Table 3 presents an overview of the steps taken to calculate the value of the protective function of forests on ÖBf land as an annual flow of services. As a simplifying assumption – given the lack of concrete information on the location and type of protection forests – a mean value of the two most economical measures is calculated; the annual flow amounts EUR 7,147 per hectare. At any given moment, the ÖBf (or the taxpayer) would have to substitute the protective function of forests on over 2,000 ha. As a result, the annual value of the protective function of forests on ÖBf land – based on the comparison between the current management regime and the reference scenario – is estimated at EUR 14.7 m. This value corresponds to EUR 268 per hectare and year (based on the total area of protective forests currently used for commercial forestry; see Tables 1 and 3).

There are several uncertainties involved in this calculation:

- The number and intensity of technical measures as well as the choice of the technology itself depends, of course, on the local specifics (e.g. slope, type of ground, geology, topology).
- Cost estimates at this pre-planning stage are usually assumed to be subject to an a priori uncertainty range of ±15% (ÖNORM B 8101-1 [ÖNORM, 2009]).
- The hypothetical reference scenario, such as any planned change of management, is drafted on the basis of the only just legal intensification of commercial forestry. Thus, we have to base our calculation on a number of assumptions regarding the marginal change of timber extraction (e.g. size of clear cutting, reduction of harvesting age) and the effect of different management regimes on the protective function of forests. In addition, we have to make an assumption regarding the extent to which the authorities would prescribe certain protective technical measures (e.g. if they would allow for a reduction of the protective function of forests at all).

Given these assumptions, and the rather small marginal change based on the comparison of the two management regimes, the value of the protective function of forests provided today may be considered rather low. However, on the other hand, even if commercial forestry was intensified within the legal limits, protective forests would still be effective but would have to be supported by technical measures to a substantially higher extent than today.

5. Hedonic pricing: valuing the risks of gravitational hazards

For the valuation of the protective function of forests by means of the hedonic pricing method, studies are needed that ascertain the price discount for residential or commercial property located in hazard zones. As a complication, natural hazard zones are declared by local and regional authorities in Austria and mapped in local land use plans. These zones do not necessarily reflect the actual state of hazards; a property might still lie within a natural hazard zone even though the hazards had been removed (e.g. through torrent control measures), while another property might be at risk but not be located within a designated hazard zone. Furthermore, many buildings and infrastructures were built in former hazard zones only because technical measures or newly planted protective forests had been in place. In addition, hedonic prices reflect the perception of risk; the designation as a hazard zone in land use plans is certainly an experts' judgement which is not necessarily connected to a corresponding perception of risk on real estate markets (see the discussion of risk perception above).

Given these various caveats and the lack of additional data, the value of protected property may be reduced if – ceteris paribus – the object lies within a hazard zone. We used a GIS model in which all areas located in the direction of potential flow of avalanche or slide tracks are defined as risk areas. Besides a digital elevation model, land cover and other variables, the model also uses modeling results of Perzl and Huber (2014). The GIS analysis indicates that the protective forests on ÖBf land (see Fig. 1) in total protect 14,583 residential and commercial properties with an average gross floor space of 210 m^2. As the protected land is located in 42 out of the country's 100 administrative districts, real estate prices vary substantially across districts and municipalities. Assuming a weighted mean price[9] based on market statistics, we arrive at a property value of EUR 6.403bn of residential and commercial buildings that are protected by forests on ÖBf land (details of the estimations and GIS results are summed up in Table 4).[10]

In order to calculate the discount of the property protected compared to real estate outside natural hazard zones, we base our calculation of price discounts on a comprehensive hedonic pricing study by Weberndorfer (2009), who studied the Austrian real estate market and estimated the price discount of property located in hazard zones in a range of 2–5%. However, the question remains whether a change in natural hazard zones in a land use plan or the improvement or deterioration of the protective function of forests would have a significant marginal effect on property values.

In light of the above-mentioned property value of EUR 6.403bn for land protected by forests, it is important to clarify whether the price discount has already been accounted for in real estate prices. Vallaster (2015) shows for the case of the municipality of Hallstatt (Upper

[9] The weighted mean price was calculated based on relative prices of residential and commercial property, and on the price differences between municipalities; see Getzner et al., 2016, for details.
[10] This is, of course, only a minor fraction of the total property protected by protective forests in Austria – the ÖBf manages only about 15% of all forests, located in particular in peripheral and less densely populated areas.

Table 4
GIS model results on the protective function of forests on ÖBf land.
Source: Authors' calculations based on the authors' GIS model.

Parameter/result	Area or number, resp.	Comments
Avalanche/slide tracks (total area)	1,417,680 ha	Authors' GIS model results based on the GRAVIPROFOR project (Perzl and Huber, 2014)
Forest areas in avalanche/slide tracks (total area)	911,435 ha	
Of which: Protective forests in avalanche/slide tracks on ÖBf land	176,551 ha	
Total construction area (buildings) on land located in the direction of flow of avalanche/slide tracks[a] (built-up area)	18,107,555 m^2	
Number of buildings in avalanche/slide tracks (total)	88,119	Estimation based on the share of ÖBf forests in total forests in avalanche/slide tracks
Of which: Buildings in avalanche/slide tracks protected by protective forests on ÖBf land	14,583	
Average built-up area of buildings[b]	205 m^2	Authors' calculation based on the authors' GIS model
Estimated effective floor space per building (mean m^2)[c]	210 m^2	Based on a gross floor space multiplier of 1.5 and an effective floor space factor of 0.68

[a] This area is taken as a proxy of gravitational natural hazard zones (e.g. red or yellow zones in the official land use plans).
[b] Land consumed by the respective buildings (i.e., excluding yards, entryways etc.).
[c] Assumed proportion of residential to commercial buildings of 2:1; the “effective floor space” is the net living space of a residential building after deduction of walls, general and traffic space such as stairways and aisles.

Austria) that 85% of property prices have already been discounted on the basis of their location in hazard zones. He concludes that only about 15% of property prices might not be discounted due to a lack of risk perception on the real estate markets. However, this 85% share seems too high as an average for the above-mentioned sample of protected property since the example of the municipality of Hallstatt can be considered a special case in terms of the above-average residents' risk perception of landslides and avalanches. Therefore, and after consideration and consultation of Weberndorfer (2009), we assume that in 50% of cases, the hazard-related price discount would eventually be priced into the market property value. Based on the total property value of EUR 6.403bn for land protected and a price discount of 2–5% (mean 3.5%), and estimating this reduction of stock value into an annual flow by computing the annuity of this reduction (1% discount rate over 50 years), we arrive at a mean annual value of the protective function of forests on ÖBf land of EUR 2.857 m (i.e. 50% of EUR 5.715 m of the total mean price discount for buildings in gravitational natural hazard zones; see Table 5 for all calculation steps and detailed assumptions). As Table 5 shows, this value can be considered as the real estate value that is currently being secured owing to the protective function of forests in the multifunctional forest management regime compared to the baseline scenario (see Section 3).

6. Discussion, summary and conclusions

This paper provides a detailed and realistic valuation of the protective function of forests on land owned by the Austrian Federal Forests (Österreichische Bundesforste – ÖBf). We relied on two methodological approaches: (1) the replacement cost estimation considers the technical measures necessary to substitute the protective function of forests, while (2) the hedonic pricing approach values the price discount of real estate located in (potential) natural hazard zones (e.g. avalanches, rockfall, mudslides). While the research question of this paper seems straightforward, a fundamental question arises: Which marginal change of the protective function of forest is an adequate basis for its economic assessment and valuation?

Therefore, the marginal change to be considered is the sustaining of the protective function of forests on ÖBf land by the current management regime of multifunctional forestry as compared to a baseline that assumes a (hypothetical) intensification of commercial forestry with the aim of harvesting the maximum of timber within the existing legal boundaries. The research question does not address the efficiency or effectiveness of the legal frameworks per se but the marginal change (the potentially different intensity of harvesting timber) as the subject of valuation. One of the main tasks of this paper and the underlying

Table 5
Estimated values and price discounts for real estate located in natural hazard zones.
Source: Authors' calculations.

	Total value of real estate located in natural hazard zones (EUR million)	Average value per building (EUR)	Annuity of the price discount owing to the location in a natural hazard zone (EUR 1000 per year)[b], for all buildings in hazard zones
Value of real estate (built-up property) protected by forests on ÖBf land[a]	6,403.490	439,000	
Price discount of 2% (lower bound)	128	8,780	3,266
Price discount of 5% (upper bound)	320	21,950	8,164
Mean price discount	224	15,365	5,715
Total economic value of the protective function of forests on ÖBf land (current management practice compared to the hypothetical reference scenario), under the assumption of a priced-in share of 50% (EUR million per year)			2.875
Total economic value of the protective function of forests on ÖBf land (current management practice compared to the hypothetical reference scenario), under the assumption of a priced-in share of 50% (EUR per hectare and year)			53

[a] The (stock) value presented here as a measure of the protective function of forests is only adequate if we assume that none of the respective real estate is currently in a natural hazard zone, and that the reduction (elimination) of the protective function of these forests leads to a declaration of new hazard zones in land use plans, and thus has an impact on the property value.
[b] The annual loss of value is calculated on the basis of the reduced stock value (second column) under the assumptions of a legal tax depreciation period of 50 years (residential and commercial buildings) and a discount rate of 1%. The estimated annuity does not present the actual value of the protective function of forests because the change in management, and the discount priced-in, need further assumptions (see text).

study was, therefore, to define a reference scenario which can be used to assess the value of the ecosystem services provided by ÖBf forests.

The value of the protective function of forests on ÖBf land according to the replacement cost method is estimated at about EUR 14.7 m per year (EUR 268 per hectare, based on the area of protective forests currently used for commercial forestry) alone, which may be considered substantial non-market benefits when compared to the ÖBf's total annual profits of about EUR 30 m (ÖBf, 2015). Of this, timber production accounts for about 50%. These non-market benefits are also remarkable given that the leeway for commercialization of forestry in protective forests is limited by the legal frameworks (e.g. the Austrian Forest Act) and nature conservation efforts (e.g. protected areas based on national or international regulations). Therefore, the hypothetical reference scenario, which serves as the baseline for the assessment of the marginal change in ecosystem services that is subject to economic valuation, includes a reduction in the growth period of trees (of about 20 years) and clear cutting confined to small patches (usually 1 ha). In other words, the welfare benefits of the protective function of ÖBf forests alone are about equal to total current forestry profits.[11] The replacement costs are calculated on the most plausible technical measures; however, there might be other policies to conserve protective forests such as deer management. Such alternative policies are not discussed in the current paper but highlight the need for further research for effective management of protective forests.

While the valuation of the protective function by means of replacement costs is rather straightforward, a number of additional assumptions are required for the hedonic pricing approach. For instance, we have to make assumptions about the pricing-in of the discount for real estate located in hazard zones. It is also questionable whether this price discount should be based on official land use maps (indicating these hazard zones) or on the factual (effective) extent to which land is protected by technical measures or protective forests. Given these crucial uncertainties, our estimate of the monetary value of the protective function based on real estate prices is comparatively low at about EUR 2.9 m on average (EUR 53 per hectare).

As discussed above, the two valuation approaches lead to different valuation results. Valuing the protective function by substitute technical measures (replacement costs) results in an annual per-hectare value of EUR 268 compared to the hedonic price approach yielding an annual per-hectare value of EUR 53. These differences are not surprising: Technical measures are designed by expert planners to minimize risks according to, e.g., legal standards and the precautionary principle. The state of the art in avalanche and landslides prevention and control is high, as are the costs associated with these standards. On the other hand, hedonic prices are based on perceptions of risk by private real estate owners (households, companies). The problems of individual risk perception suggest that the risks perceived might be significantly different to the "objective" risks assessed by experts. Values based on technical measures are, from the viewpoint of the authors, therefore much more reliable for land use planning and policy decisions, while the perspectives of real estate markets highlight the subjective/perceptional viewpoint of economic agents. Basically, the difference therefore is caused by market failures such as incomplete information, myopia, moral and charity hazard, and a general failure to assess risks adequately.

This paper applied two standard valuation methods to an apparently substantial ecosystem service, the protection from natural hazards. However, the most important step in the valuation procedure was not to estimate the cost of technical measures to substitute the protective function of forests or the price discounts for real estate located in hazard zones. Our research question was not to value the ecosystem service per se but to value the benefits of the current multifunctional forestry regime. This is why the most important step was the definition of the baseline to which the current management regime was to be compared. Therefore, we concentrated only on the benefits attributed to the current management regime of state-owned forests and not on regulations (e.g. forest laws, European nature conservation directives). Given the experience of this research project, we doubt how far the assessment of benefits of the protective function of forests might actually be extended in the case of protective forests: As environmental valuation and benefit-cost analysis do not address general equilibrium effects (e.g. the quality of life in Alpine regions if the protective function was substantially lower), the marginal change to be valued has to be rather small in order to achieve reasonable economic values (otherwise, we would have to employ a different economic methodology in order to account for the economic value of a change of the whole system). As outlined above, the approach chosen in this study is not able to account for large-scale changes, nor for a system change leading to very different natural and economic conditions in the Alpine environment. It can therefore be concluded that the benefit transfer of values or a presentation of different values from different countries with very specific local contexts is not easy, and can only be done if these specifics are clearly analyzed and discussed in detail. In other words, our approach to a detailed discussion of a plausible baseline has proven most useful for policy recommendations as we are able to differentiate between the scenarios in great scrutiny.

As a policy conclusion, the results of this paper – even in light of the diverse uncertainties concerning, with equal weight, the ecological and economic assessments as well as the assumptions of the scenario design – point to the potentially enormous economic value of protective forests. Even under very conservative assumptions, the non-market benefits of protective forests (which may be lost if commercial forestry on ÖBf land is intensified) are approximately of the same magnitude as the profits from producing timber. Therefore, policy-makers should place much more emphasis on sustainable forest management in terms of conserving the protective function of forests. From the authors' perspective, the results suggest that a further reduction of timber production especially in protective forests, and policies to conserve this protective function by, e.g., sustainable forest and deer management, may lead to substantial non-market benefits – the production of which may be considered a major task of state-owned forests.

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[11] This comparison is, of course, not entirely adequate since the values (benefits) refer to non-market goods and services in terms of economic welfare whereas market profits of timber production do not reflect welfare benefits correctly.

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