A utility theoretic approach to define the forest landowner’s minimum price demand for a biodiversity object[1]

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1 Introduction

New cost efficient biodiversity protection tools may demand bidding price definition from the seller side. For example, the commission that analysed the protection needs of the forests of Southern Finland and Ostrobotnia (Etelä-Suomen, Oulun läänin länsiosan… 2002), introduced several new instruments focusing strongly on private forests. These include e.g. competitive bidding, transactions of sites with nature value and joint network projects on forest biodiversity. In the use of these instruments, also sellers’ price demand may be asked. A low bidding price increases a chance that the forest area will be selected to the biodiversity protection program. An important characteristic of the introduced instruments is that both the seller and the buyer can retire from the negotiations if the conditions of the protection contract can not be accepted.

For non-industrial private landowners it can be difficult to define the price demand of the biodiversity object. They should be able to compare the benefits achieved from protecting the forest area (e.g. income from protecting the area, non-monetary benefits, timber production potential of the stand after protection period) to the situation where the stand remains in timber production and probably will be clear-cut and regenerated during the following years.

In addition to the price offer only from the buyer side and in addition to stand-level examinations, a broader approach is needed in the proper price definition process. Determination of the bidding price for protecting a biodiversity object should be assessed at the holding level. In addition to the properties of the protected stand, the bidding price depends at least on three holding-level factors: (i) the production possibilities of the other forest area of the owner (i.e. is there possibilities to adapt the treatments of other compartments due to the protection of the examined forest stand); (ii) objectives of the forest owner (i.e. the importance of the biodiversity goals in relation to other goals and the substitutability between the goals); (iii) the time horizon of the protection contract (permanent or temporary protection).

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This study aims to alleviate the problems of this new decision-making situation by presenting a method which helps forest owners in defining the minimum price for protecting certain forest area from his holding. The approach presented in this study explicitly includes all above-listed factors into multi-objective forest planning calculations where the price is defined. The method is based on the forest owner's utility function. The presented approach is suitable for situations where the ownership of the examined forest area does not change due to the protection contract. The protection period can be permanent or temporary. Furthermore, the landowner is participating to the protection program voluntarily.

2 Description of the method

In tactical forest planning, the forest owner's goals are typically strived for by formulating and solving a planning model, which consists of (i) alternative treatment schedules for individual forest stands; and (ii) the owner's utility model concerning the use of the forest resource. The utility model is optimized by searching the best combination of treatment schedules for the compartments.

In the presented method, the subsidized treatment schedules of the stand under examination for protection, and the treatment schedules of other stands, are evaluated towards the owner's holding-level utility model in the optimisation process. The result of optimization gives the optimal treatment proposal for each stand, and it also tells whether it produces more utility, at the whole holding level, to protect the examined stand with a given level of subsidy for biodiversity purposes, or is the utility bigger if the stand is clear-cut and regenerated during the planning period.

The amount of subsidy obviously affects the result of optimization. Furthermore, if the owner has biodiversity goals, the price demand will be lower. In addition, the substitutability of the objectives has an effect on the needed subsidy level. For example, if the utility loss caused by decrease in the cutting income can be partly or totally compensated with an increase in the standing timber stock, the subsidy level will be lower.

The method is formulated in the following way. Consider three goals, net income (INC), area of old forest (OLD) and timber volume (VOL), as the goal variables of the forest owner. The quantities that alternative forest plans produce the goal variables are denoted by q_{INC}, q_{OLD} and q_{VOL}, respectively. In the utility theoretic approach, these quantities are transformed to utility scale which measures the utility values that forest owner perceives from the goal variables. The first step is to specify the sub-utility functions, one for each goal. The sub-utilities are denoted by $u_{\mathrm{INC}}(q_{\mathrm{INC}})$, $u_{\mathrm{OLD}}(q_{\mathrm{OLD}})$ and $u_{\mathrm{VOL}}(q_{\mathrm{VOL}})$, where e.g. the $u_{\mathrm{INC}}(q_{\mathrm{INC}})$ indicates the sub-utility that the amount of net income q_{INC} will produce.

After specifying the sub-utility functions, the next step is to estimate the overall utility U that alternative forest plans produce. Traditional additive utility function will be used, where the idea is to calculate the overall utility as the weighted arithmetic average of the sub-utilities. For this step, the forest owner assesses also the weights w_{INC}, w_{OLD} and w_{VOL} that describe the mutual importance of the goals. Usually the weights are scaled so that they sum up to one, i.e. $w_{\mathrm{INC}} + w_{\mathrm{OLD}} + w_{\mathrm{VOL}} = 1$. The additive utility function is of the form

$$U = w_{\mathrm{INC}} u_{\mathrm{INC}}(q_{\mathrm{INC}}) + w_{\mathrm{OLD}} u_{\mathrm{OLD}}(q_{\mathrm{OLD}}) + w_{\mathrm{VOL}} u_{\mathrm{VOL}}(q_{\mathrm{VOL}}). \quad (1)$$

To sum up, model (1) measures the overall utility that alternative forest plans formed by the compartment-wise treatment schedules will produce. The model is used to estimate the minimum price demand as follows:

a) Find a treatment schedule that maximizes the utility index U, when there are no protection limitations and no subsidy. Denote the optimum value of the utility index as U^*, and the values of the objective variables at the optimum by q^*_{INC}, q^*_{OLD} and q^*_{VOL}.
b) Find a treatment schedule that maximizes the utility index U, when certain forest stand is protected and subsidy is equal to S. The subsidy is treated as it would be timber harvesting income. Denote the optimum

value of the utility index as U_S^*, and the values of the objective variables at the optimum by $q_{\mathrm{INC},S}^*$, $q_{\mathrm{OLD},S}^*$ and $q_{\mathrm{VOL},S}^*$.

c) Try different values of subsidy and find subsidy S' such that $U_{S'}^* = U^*$. Then subsidy equal to S' is the minimum price demand that compensates the utility losses caused by the protection.

3 Example calculation

3.1 Planning area and goal variables

The total area of the example forest holding was 89.5 ha. This area was divided into 65 stands in the forest inventory. At the beginning of the planning period, the mean volume of the growing stock was very high, 174.2 m^3/ha. The proportions of pine (*Pinus sylvestris*), spruce (*Picea abies*) and broad-leaved trees were, respectively, 46.9%, 24.2% and 28.9%. The initial age distribution was as follows: younger than 20 years 5.4%; 20-39 years 23.5%; 40-59 years 10.5%; 60-79 years 13.0%, and more than 80 years 47.7%.

The minimum price demand for biodiversity protection was calculated for an old growth spruce stand (stand number 157). The characteristics of the stand were as follows: area 8 ha; total timber volume 264 m^3 /ha (volume of the saw logs 169 m^3/ha), the mean age of the trees 160 years, and the mean diameter of the trees 35 cm. In addition to these properties, the existence of big decaying trees, made the stand valuable object for biodiversity protection (Etelä-Suomen metsien …. 2003).

The length of the planning period was 20 years, and it included two 10-year sub-periods. The stand treatments were simulated to the midpoints of the first and the second sub-period. The Finnish treatment recommendations (Luonnonläheinen … 1994) were followed in simulations. Furthermore, alternatives with delayed cuttings were added for middle aged and old forest stands. For the stand 157, three alternative treatment schedules were simulated in the first phase. The first schedule was the "no treatments" alternative without subsidy. The second alternative included regeneration during the first sub-period. In the third alternative, the stand was regenerated during the second sub-period.

The holding level goals were net income during the planning period (INC), area of old forest (OLD) and timber volume (VOL) at the end of the planning period. The utility function was derived from these goals by defining weights and sub-utility functions for these variables.

The protection period of the stand 157 was set to be 20 years. It was assumed that the stand 157 can be used for conventional forestry purposes after the 20-year protection period. Hence, the standing timber volume from the stand 157 was included into calculation of the value of the VOL goal, old forest area objective and total utility.

Monsu forest planning software (Pukkala 2002) was used in the iterations concerning the minimum subsidy level. The best combination of treatment schedules from the perspective of holding-level objectives was searched by using a modified heuristic optimization based on simulated annealing (SA) technique (e.g. Dowsland 1993).

In the reference plan (no protection alternative, no subsidy) the stand 157 was clear-cut and regenerated during the planning period. After the production of the reference plan and before minimum price iterations were started, two regeneration treatment schedules were deleted among the treatment schedule alternatives of the stand 157. After this, the subsidy level was increased through an iterative process until the total utility value achieved the utility level of the reference forest plan.

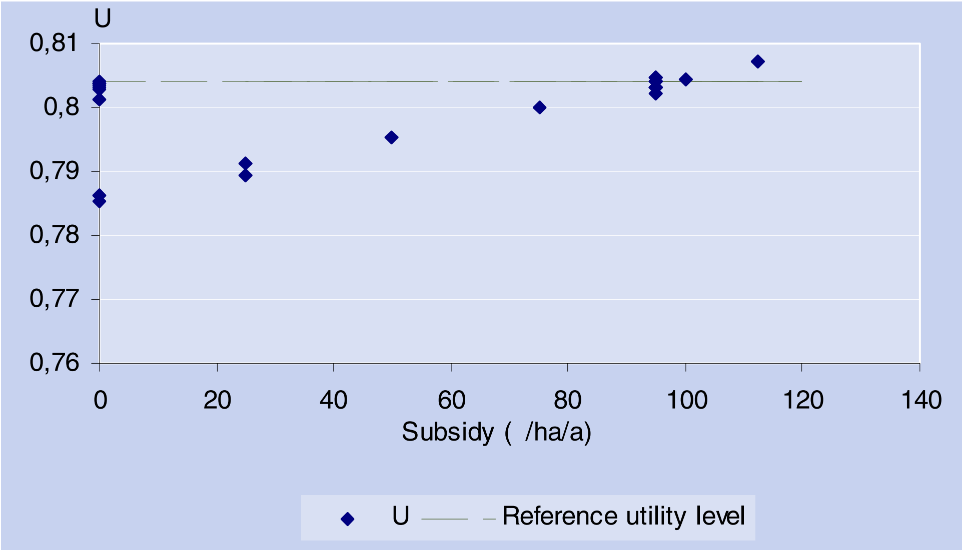

Figure 1. Development of the total utility in the 20-year protection case. The difference between two point groups at the y-axis (when subsidy=0) describes the effect of limited production possibilities due to the elimination of the regeneration alternative from stand 157.

3.2 Results

The elimination of regeneration alternatives from stand 157 caused a clear decrease in the total utility level (Fig. 1). Increasing the subsidy level increased the total utility steadily. The subsidy-level that produced the same total utility on the holding level than clear-cutting the stand was 95 €/ha/a.

The subsidy paid for the whole planning period (20 x 95 €/ha/a) was clearly lower than the stumpage value (11 400 €/ha at the midpoint of the second planning period) of the stand 157. This was due to weight given to other objectives. The stand produces utility to the owner because it is old forest and because it increases standing timber volume of the holding at the end of the planning period.

Compared to the reference plan, protection of the stand 157 changes the holding level solutions (Table 1). Due to the sub-utility formulation, net income is in all plans 300 000 €. When the stand is protected but no subsidies are paid, timber volume at the end of the planning period and old forest area are at lower level. When the subsidy is 95 €, standing timber volume and old forest area are near the amounts that the reference plan produced.

Table 1. The holding-level values of goal variables at the end of the planning period in example calculation. The subsidy is included in the net income that is presented in the table. The reference plan level situation without protection is presented in boldface letters.

	Timber volume (m^3)	Area of old forest (ha)	Net income (€)
No subsidy, stand regenerated	12 848	37.1	299 935
No subsidy, no treatment of the stand, 20-year protection	12 525	35.2	299 157
Subsidy 95 euros/ha/a, no treatment, 20-year protection	12 898	36.8	299 572

4 Discussion

Due to the holding-level analysis applied in the presented approach, the minimum price demand definition is in direct connection to the multi-objective forest planning process. Therefore, its practical applicability is rather good, as it utilizes almost the same information as the regular forest planning process should utilize.

Obligatory or voluntary forest planning process is carried out in many countries regularly, e.g. in Finnish private forests about 10 - 20 -year intervals. In this process, forest inventory is carried out, the goals of the forest owner are analyzed, and finally, the forest plan is created for the following planning period. In the inventory, the characteristics of valuable areas can be measured more accurately, and during the goal analysis the forest owners willingness to participate can be clarified. After this, the calculation of the price demand with the presented method would be rather straightforward. In addition, if the protection contract is signed, its preconditions and consequences can be included in the forest plan.

Correctness of the used utility function is a key factor of the presented method. According to other calculations that have been made with the method, the achieved price level depends strongly on the objectives, their weights and sub-utility formulations. In addition, the properties of the forest holding are, of course, important. The utility function used in the price definition can be the same that has been used to define the forest plan for all the forests of the owner. It thus has been already accepted on the holding-level. If the subsidy level defined by this utility function is not acceptable, the utility function can be adjusted. This can be the case if other factors that are not included in the utility function used in the earlier forest planning process are affecting the price definition.

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