Timber harvesting versus forest reserves - producer prices for open-use areas in German beech forests (*Fagus sylvatica* L.)

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Abstract

A strong demand for nature conservation can be ascertained in Germany. Several nature conservation groups argue that in order to provide nature conservation in considerable parts of the forest area forestry should sacrifice timber harvesting. For example, the abandoning of harvesting altogether is supposed to enhance and protect the species richness. This fact and the very low profitability of forestry in Germany motivated the writing of this paper. The paper explains a methodology for deriving producer prices involved in forest reserves, where harvest benefits are sacrificed totally. Such methodology can be useful to form a basis for private contracts between forest owners and nature conservationists, who demand forest reserves. The results of this methodology can also be integrated in financial programs for species and habitat conservation.

In a basic theoretical consideration it is demonstrated that a stand-by-stand evaluation approach may only serve as an initial step in deriving compensation prices for forest reserves. Due to the stochastic character of forest management a non-linear programming approach (NLP) was adopted to find an optimal operational plan for a hypothetical beech (Fagus sylvatica L.) forest. In both the constraints and the objective function the non-linearity is considered by integrating stochastic components. Additionally, only virtual homogenous forest reserves are considered. Firstly, a basic NLP solution for the hypothetical forest with the objective "maximise the net present value of timber harvests adjusted to risk" was obtained when considering several constraints subject to stochastic variation of net revenues and timber harvests without considering forest reserves. Secondly, other solutions allowing for forest reserves were computed. The decrease of the objective function when forest reserves were increased in periodic increments seemed well suited to mirror the opportunity costs of forest reserves.

The results showed that a stand-by-stand approach gave much greater compensation prices than the NLP approach. The reason for this lay in the consideration of a non-linear objective function as well as the non-linear constraints in the case of NLP. The first 42-hectare forest reserve was priced at 11,494 Euro/ha or, 483 Euro/ha/year expressed in infinite yearly compensation. The yearly compensation price for the last forest reserve had an increase up to 607 Euro/ha/year. A stand-by-stand approach, however, resulted with compensation prices from minimally 609 up to maximally 709 Euro/ha/year.

Various interest rates (3.2 and 5.2 %) caused different compensation price curves. The slope of the curves increased when the interest rate decreased.

The limits of the approach, the problem of deriving a demand for forest reserves and the opportunities for applying the presented approach to state forests are discussed.

Keywords: Compensation prices, nature conservation, operational planning, non-linear programming

1 Introduction

It is well known that the relevance of commercialised forest products, mainly timber, is negligible compared to the total economic performance in Germany (Bergen et al. 2002, p. 198). Furthermore, German forest enterprises show low profitability (Moog and Borchert 2001) through storm damage (König et al. 1995), bark beetle attacks and the consequently decreasing market prices for timber (Mosandl and Knoke 2002). In this situation nature conservation organisations, for example Greenpeace, argue that forestry should sacrifice the timber harvesting at rate of 10 % of the forest area (Sturm 1995), where forest reserves are to be established. Ammer (1991) reported of the demands that 20 % of the forest area should be allocated to forest reserves. Forest reserves, which in the long run would develop into natural forests, are obviously strongly in demand by specific groups of our societies. Especially the large stocks of dead wood in the natural forests provide a habitat for numerous highly specialised macromycetes and beetles (Albrecht 1991). Concurrent to this development, the European Community's declaration of "Natura-2000-areas" (Wagner 2000) also expresses a strong social demand for nature reserves in forests.

In future, the state could force forest enterprises to establish forest reserves in order to satisfy the social demands. Moog and Knoke (2003) recently reported on the appraisal of nature conservation restrictions and their adequate compensation. Alternatively, prices similar to market prices could be introduced, to encourage forest enterprises to establish forest reserves based on economic considerations. In this context the increasing demand for nature conservation may also be viewed as an opportunity because the population is prepared to spend a fair amount on nature conservation. Hampicke (1991, p. 134) for example, presented a study for Germany, which proved a willingness to pay for species and habitat conservation of between 1,500 and 3,800 Mio Euro per year. He also cited a study reporting a willingness to pay of 32 US$/year/household for establishing 4 Mio. ha nature reserves in Colorado (Hampicke 1990, p. 129). The total in this case amounted to 35 Mio. US$/year. Bergen et al. (2002, p. 185) cited similar findings for Scandinavian households, who would pay between 5 and 35 Euro/year/household to protect natural forests. Although this willingness to pay is impressive, the problem remains how to mobilise and transfer these funds to the provider of nature conservation, for example forest enterprises.

In practice, contracts for nature conservation may be made between nature conservationists and forest owners (e.g. Bergen et al. 2002, Moog and Brabänder 1994), in order to maximise the benefits of both groups. Such contracts would contain a price, to compensate the forest owner for establishing forest reserves, while being obliged to sacrifice any utilisation within the forest reserves.

But the problem is still not properly solved for deriving adequate compensation prices. Approaches focussing on a stand-by-stand compensation price considering all stands independently might often overestimate compensation prices for forest stands embedded in greater forest areas. Operational constraints (even flow of harvests, least surplus or sustainability) will not allow harvesting every single stand, either immediately or when achieving financial maturity. Furthermore, the stochastic components of forest management cannot be ignored, as for a risk-averse forest manager ignoring stochastic elements would also lead to an overestimation of compensation prices.

To contribute to solving at least a part of this problem, this paper seeks the solution to the following question:

“What must the compensation price be, in order to gain an economic advantage from forest reserves?”

Thus this paper’s objective is to derive appropriate compensation prices for forest reserves, which are computed as producer prices. In the following the theoretical approach, the methods and the data employed will be described in brief. The results consist of a comparison of compensation prices derived through a deterministic stand-by-stand approach and that achieved through an operational planning approach considering stochastic elements.

2 Theoretical approach

Here we will structure the problem, starting from a simplified stand-by-stand approach and ending with the actual approach chosen. Obviously, the establishment of a forest reserves involves opportunity costs, as the forest manager cannot harvest timber in a forest reserve. To begin with, we may consider the expected net revenue flows from timber harvesting, appropriately discounted, as the opportunity costs of a forest reserve. In Figure 1, the expected discounted net revenue flows are depicted schematically for four stands. The schematic picture shows that the opportunity costs of renouncing timber harvests in the forest stand A1 would be the lowest per unit area. In contrast the opportunity costs in stand A4 are approximately eight times higher per unit area. The opportunity costs of the four stands form a step function.

Assume that the potential consumer of forest reserves would value all four stands equally regardless of their age and structure. The step function could then be seen as a schematic "supply curve" for forest reserves. With increasing prices for forest reserves the forest manager would allocate a larger area to this option.

[Figure 1]

When a specific price Y was offered for forest reserves, e.g. by a nature conservation organisation, the forest manager would be able to assign an area of X units for nature conservation. Where the "supply curve" intersects the "Y-line", the area X is determined. From an economic point of view establishing the forest reserves at X area units would prove to be advantageous for the forest enterprise. The grey area of Figure 1 depicts the producer surplus. The price achieved for forest reserves up to the X units is greater than the loss incurred, when sacrificing timber harvests in the stands A1 and A2. Thus, the forest manager would simply adjust the quantity of forest reserves to the price either given by a potential market or individually offered by groups demanding forest reserves. This could be done by extending the "supply" of forest reserves until the production rule "marginal cost" equalled "price", which could be obtained for the last unit area forest reserve.

Starting from an initial environment of stands in different age classes the described step function can be derived, for example, by linear programming (LP). Considering both, the objective "maximise the net present value of timber harvests" and no other constraints than the area units of the age classes, the LP solution results in shadow prices for the area units of the different age classes. Assuming the shadow prices are valid for the total area of each age class, they would indicate the opportunity costs involved when excluding one unit area from timber harvesting, because a forest reserve was established. Without considering constraints this method will show results identical to a stand-by-stand approach, as for example, Hampicke (2001) used to remunerate nature conservation.

However, the simple approach described serves only as an initial step in starting to solve the problem. The approach will generate prices for potential forest reserves, though not projecting a true picture for the following reasons. Firstly, the consumer will not value every stand equally regardless of its age or other properties. The stands in different age classes are too heterogeneous. Therefore, we will eventually only consider homogenous forest reserves with an identical composition consisting of stands of several age classes. Secondly, the simple approach assumes every stand can be harvested either immediately or when financial maturity is achieved. This is not realistic for bigger forest enterprises which strive for fairly even harvest flows or minimum net revenues per period. Here the harvest of some stands will be postponed even though they are already mature, while others will be harvested prior to maturity. We will consider this fact by introducing adequate constraints. Thirdly, our simple approach ignores the fact that timber prices and timber harvests have a stochastic character. Consequently, the expected net present values of timer harvests are subject to stochastic variation. This fact diminishes the utility of a given expected return, when considered by a risk-averse decision-maker. The stochastic character of forest management will be integrated by chance constrained programming and a specific objective function containing costs proportional to the stochastic variation of the expected net present values.

3 Material and Methods

In this section the applied methodology to solve the operational planning problem in forestry is demonstrated. Subsequently it is described how prices of potential forest reserves may be computed.

3.1 Formulating the operational planning problem in forestry

Planning problems in forestry are frequently problems of optimal allocation. Solving this problem has a long tradition in German forestry (e.g. Hundeshagen 1826). When an operational plan is put into practice, silvicultural activities, such as plantation, cleaning, tending, thinning, regeneration-harvests, and clear-felling have to be allocated to an optimal time period. The standard algorithm to solve such allocation problems is the linear-programming-algorithm (LP), which was already introduced around 1950 as a method in operations research (Dantzig 1966).

In forest economics, numerous operations research models were tested in order to solve operational planning problems. Today LP usually covers a section in standard forest economic textbooks (e.g., Rideout and Hesseln 2001).

Since Johnson and Scheurman (1977) gave an early introduction to LP in forestry, this or similar techniques were widely used internationally. So Hoganson and Rose (1987) optimised large scale timber management scheduling with a special solution technique while decomposing the large scale problem. The proposed technique involved dealing with risk. Hof et al. (1988) examined renewable resource linear programs under risk. An integer programming approach with adjacency constraints was employed by Barrett et al. (1998) in order to investigate clearcut restrictions. Based on a LP approach Eid et al. (2002) analysed timber production possibilities of the Norwegian forest area under environmentally oriented constraints. Olsson and Lohmander (2003) employed mixed integer programming in order to find an optimal forest transportation system.

Due to the stochastic character of forest management a non-linear programming approach (NLP) was adopted to find an optimal operational plan for a hypothetical beech forest with non-linearity in both the constraints and the objective function. A beech forest was chosen because beech would naturally be the native and dominant species at the majority of sites in Germany (Ellenberg 1986).

The planning horizon comprised of 30 years divided into six 5-year-periods. For different types of forest stands (8 types were defined) specific silvicultural activities had to be carried out. These activities needed to be allocated to the optimal time period resulting in an optimal area management and timber harvest schedule.

In the following sections the mathematical model is formulated. Then the objective function and the constraints are explained, together with the underlying assumptions and the data employed.

3.1.1 Model formulation

The objective function is formulated as follows:

(1) $$\max = \left[\sum_{t \in T} q^{-t}\left(\sum_{f \in F}\left(v_{f,t} p_{f,t} a_{f,t} - c_{f,t} a_{f,t}\right)\right)\right] - k\frac{S_{PV}^2}{2}$$

$$T = \langle t \,|\, 3,8,13,18,23,28 \rangle$$
$$F = \langle f \,|\, 1,2,3,4,5,6,7,8 \rangle$$

subject to

(2) $$a_{f,t_1} + a_{f,t_2} \le m_f$$

$$A = \langle m_f \,|\, 1713,1218,1466,1630,1412,1349,803,409 \rangle$$
$$T_1 = \langle t_1 \,|\, 3,13,23 \rangle$$
$$t_2 = t_1 + 5$$

(3) $$\sum_{t \in T}\sum_{f \in F} v_{f,t} a_{f,t} \le I$$

(4.1) $$P\left\{\left[\sum_{f \in F}\left(v_f p_f a_f - c_{oh}\right)\right] \ge 0\right\} \ge 0.8$$

(4.2) $$\left[\sum_{f \in F}\left(v_f p_f a_f - c_{oh}\right)\right] \ge 0 + F^{-1}(0.8) S_R$$

$$\forall t \in T$$

(5.1) $$P\left\{\left[\sum_{f \in F}\left(v_f a_f - 5\right)\right] \ge 0\right\} \ge 0.9$$

(5.2) $$\left[\sum_{f \in F}\left(v_f a_f - 5\right)\right] \ge 0 + F^{-1}(0.9) S_V$$

$$\forall t \in T$$

(6.1) $$P\left\{\left[\sum_{f \in F}\left(-v_f a_f + 11\right)\right] \ge 0\right\} \ge 0.9$$

(6.2) $$\left[\sum_{f \in F}\left(-v_f a_f + 11\right)\right] \ge 0 + F^{-1}(0.9) S_V$$

$$\forall t \in T$$

(7) $a_{f,t} \geq 0$

$\forall f, t \in F, T$

T	Set of time periods (6 periods were defined)
F	Set of forest stand types (8 types were defined)
A	Set of areas of forest stand types (areas of stand types 1 to 8 are given)
S_{PV}	Standard deviation of expected net present values
S_R	Standard deviation of net revenue flows per period
S_V	Standard deviation of harvested timber volume per period
F^{-1}	Inverse of the standard normal distribution
t	Specific time
f	Specific forest stand type
q^{-t}	Discount factor: $q=(1+r)$ (where r is the interest rate)
$v_{f,t}$	Harvested timber volume in a specific forest stand type and time
$p_{f,t}$	Net price for 1 cubic meter timber in a specific forest stand type and time
$a_{f,t}$	Area where a silvicultural activity is taking place in a specific forest stand type and time
m_f	Maximum area at which a silvicultural activity may take place in a specific forest stand type once in 10 years
$c_{f,t}$	Payout for non-profitable silvicultural activities
c_{oh}	Overhead costs
k	Constant characterising the degree of risk-aversion of the decision-maker

3.1.2 Explanation of the model

3.1.2.1 The objective function

The objective function consists of the net present value (NPV) of all silvicultural activities during the planning horizon (as seen in Formula 1 in the square brackets) and a risk-cost. The NPV is formed by discounting all net revenue flows to the beginning of the planning horizon. The harvesting of a specific timber volume *v* per ha, selling each cubic meter at a net price of *p* times the area *a* where the activity is carried out together generate a net revenue flow. A negative net revenue flow *c* arises when activities like pre-commercial thinning, tending, cleaning or reforestation are carried out. The expected timber amount to be harvested *v* (Table 1) for every stand type and every period were adopted from Knoke (2002). For the mature stands, the results of the German Federal Forest Inventory (BML 1990, 1994) combined with recent simulation results (Knoke 2003 [a]) were adopted.

[Table 1]

In order to predict the expected market price *p* (net of logging costs) for the timber harvests an age-dependent function was derived from available data (Knoke 2002, 2003 [a]). Figure 2 shows the effect of the age on the expected timber market price. At first the price increases but in old stands it decreases due to the fact that red coloured heartwood occurs, which devaluates the timber (Knoke and Schulz Wenderoth 2001, Knoke 2002, 2003 [a], [b]).

[Figure 2]

For tending and cleaning activities expenses *c* of 1,000 Euro per hectare (500 Euro per hectare in 50-year-old stands) were assigned and a reforestation price of 2,000 Euro/ha was considered.

The optimisation algorithm now searches for an allocation of *a* areas (which are the decision variables to be optimised) to *t* periods and *f* stand types that basically maximises the NPV. However, the maximisation also integrates the dispersion of the expected NPV, which is expressed by S^2_{NPV} (the variance of the NPV). Hence, the NPV is reduced by a cost proportional to the variance of the NPV (computing the variance of NPV is described in section 3.1.2.3). A reduction of the NPV is correct if a risk-averse decision-maker is considered. He would prefer a financially secure NPV rather than one subject to dispersion (uncertainty), when comparing identical expected values[1]. The risk-costs derived in this paper

[1] Risk preferences were, for example, considered by Gong (1998) to derive harvest policies for forest stands. Also Weintraub and Abramovich (1995) presented an approach to integrate uncertainty in the objective function.

were based on a negative exponential utility function. When introducing the risk dependent reduction of the NPV, our objective function becomes an approximation for the certainty equivalent of the decision-maker, valid for small *k* (Gerber and Pafumi 1998, p. 77). According to Spremann (1996, p. 512) and Dieter (1997, p. 62) the constant *k* can be estimated by the quotient “1/purchase price” for a normally risk-averse decision-maker. In order to estimate a potential purchase price for our hypothetical beech forest we assumed a yearly surplus of 50 Euro/ha generated by beech management (BSFA 1995, 1996, 1997). This surplus was then appropriately capitalised resulting in a potential purchase price per ha.

3.1.2.2 The constraints

The NLP problem was thus based on a hypothetical forest consisting of beech stands. In order to achieve a realistic age-class structure, data of the German Federal Forest Inventory (BML 1990, 1994) was utilised. The constraints are explained numerically below.

Formula (2) The total of the hypothetical beech forest area is 10,000 ha. Silvicultural activities should only be carried out once in 10 years. Hence the sum of all activities in a period t_1 and in a directly following period t_2 may not exceed the available area m_f.

Formula (3) The sum of all timber harvests during the 30-year planning horizon should not exceed the expected increment volume *I* during this time. To estimate *I*, a yearly increment volume of 9.5 m^3/ha was assumed. In order to forecast the potential supply of rough timber in Germany until 2020, the BML (1996) used an increment for beech of 6.8 m^3/ha. This value was based on very conservative yield table predictions. As Reimeier (2001, p. 104) pointed out the real increment of beech in the past 15 years was 40 % greater than the yield table prediction. Hence, the 6.8 m^3/ha/year prediction was adjusted to a value of 9.5 m^3/ha/year.

Formula (4) The net revenue flow per period should at least cover the expected overhead costs c_{oh}. For the year 2001 the Bavarian State Forest Administration reported costs for the administration staff of about 200 Euro/ha (BSFA 2001), which was subsequently used for the calculations. The constraint 4.1 was first formulated as a stochastic constraint demanding that the overhead costs should be covered with a probability of at least 0.8. This formula was used so that the uncertainty factor could be taken into consideration, for example the market prices. In the past the timber price for beech showed a standard deviation of ± 12 % (BSFA 2001). But the uncertainty of the harvested timber volume had to be considered as well. Based on yearly growth level variations Valsta (1992) used a standard deviation of ± 17.8 % to model this effect. For the present study a standard deviation of ± 20 % was adopted. Combining the dispersions of ± 12 % (timber price) and ± 20 % (timber harvest) a standard deviation of ± 23 % was obtained for the net revenue flows. To be able to introduce this constraint in the NLP algorithm, the stochastic constraint (4.1) was transformed into the equivalent deterministic non-linear constraint (4.2) (e.g., Blohm and Lüder 1991, p. 310).

Formula (5) In order to use the labour capacity of the permanent staff, the timber harvest per period should not fall below 5 m^3/ha/year. Analogous to constraint 4 here too a stochastic component was considered. Consistent with constraint 4 a standard deviation of the timber harvest of ± 20 % was adopted.

Formula (6) The timber harvest should not exceed a maximum of 11 cubic meter/ha/year. This constraint was formulated similar to constraints 4 and 5 in order to integrate a stochastic element.

Formula (7) The case of negative area values was excluded.

3.1.2.3 Computing dispersions

The maximisation of the objective function and the constraints required for computing several dispersions is explained below.

Variance of the NPV

To compute the variance of the expected NPV the following formula was used:

(8) $$S_{PV}^2 = \sum_{t \in T} q^{-2t} S_R^2 + 2 \sum_{t_1 \in T} \sum_{\substack{t_2 \in T \\ t_2 \rangle t_1}} r_{t_1,t_2} q^{-t_1} S_{R,t_1} q^{-t_2} S_{R,t_2}$$

$r_{t1,t2}$ Coefficient of net revenue flow correlation of two time periods

When calculating the variances of the discounted net revenue flows per period $q^{-2t} S_R^2$, the correlations r_{t_1,t_2} of the discounted net revenue flows from one period t_1 to another period t_2 had to be considered for every possible combination of periods. The employed coefficients of correlations (Table 2) were obtained by Monte-Carlo simulation using an autoregressive price model, which generated beech timber price scenarios.

[Table 2]

Standard deviation of the net revenue flows

The standard deviation of the net revenue flows was computed according to Formula 9.

(9) $$S_R = \sqrt{\sum_{f \in F} a_f^2 s_{r,f}^2 + 2 \sum_{f_1 \in F} \sum_{\substack{f_2 \in F \\ f_2 \rangle f_1}} a_{f_1} a_{f_2} r_{f_1,f_2} s_{r,f_1} s_{r,f_2}}$$

$$\forall t \in T$$

$r_{f1,f2}$ Coefficient of net revenue flow correlation of two stand types

$s_{r,f}$ Standard deviation of net revenue flows in a specific forest stand type

The coefficient of correlation $r_{f1,f2}$ was set to 0.7 in order to consider the correlation of timber prices in one period.

Standard deviation of the timber harvest

The standard deviation of the timber harvests was computed according to Formula 10.

(10) $$S_V = \sqrt{\sum_{f \in F} a_f^2 s_{v,f}^2}$$

$$\forall t \in T$$

$s_{v,f}$ Standard deviation of timber harvests in a specific forest stand type

The NLP problem was then solved by means of the EXCEL solver. As a result of the non-linearity of the objective function and the constraints, the „generalized reduced gradient method" was used (see Fylstra et al. 1998, p. 41).

3.2 Evaluating the price of forest reserves

Particularly the mature stand types (aged 130 years and above) are attractive for nature conservation (Scherzinger 1996). Therefore only these were considered as potential forest reserves. The foundation for the computation of prices involved with forest reserves was formed by the basic solution obtained through the NLP method (the optimal operational plan without forest reserves). Beginning with the optimal operational plan, the area of forest reserves was expanded using 42-hectare[2] increments. Each 42-hectare forest reserve consisted of equal parts of the three stand types under consideration (14 ha of 130-year old stands, 14 ha of 150-year old stands and 14 ha of 170-year old stands). The reduction of the objective function by establishing forest reserves showed a decrease of the net present value (adjusted

[2] In fact Scherzinger (1996, p. 395) argues for a minimum area of 50 hectares. In contrast to this the average area of already existing natural forest reserves is 41 hectare in the case of the Bavarian State Forest Administration (Schmidt 1998).

with costs for risk) due to the establishment of one forest reserve. The loss of net present value was then multiplied by the interest rate in order to obtain an infinite yearly price for one additional forest reserve to be paid to compensate the forest enterprise for establishing this forest reserve.

When establishing forest reserves the overhead costs will eventually decrease because less forest area has to be managed. Considering this effect after a time lag of 10 years, the overhead costs were reduced proportional to the area allocated to forest reserves.

To value the prices for forest reserves, the problem of choosing an adequate interest rate had to be solved. Moog and Borchert (2001, p. 107) analysed the annual average rate of return of long term securities in Germany, corrected by the rate of inflation, and obtained an interest rate of 4.2 %. This interest rate was used for the present calculations.

4 Results

Although the focus is mainly on the results of the NLP approach, the problem was initially be investigated with a stand-by-stand LP analysis. Using a LP model formulation, which considered only the area units of stand types as constraints shadow prices for the area units of the 130-, 150- and 170-year old beech stands were obtained.

Under the stand-by-stand LP approach forest reserves result opportunity costs (shadow prices) of 16,883 Euro/ha in the 130-year-old stand types, 15,696 Euro/ha in 150-year-old stand types, and 14,505 Euro/ha in 170-year-old stand types. These data are the net present values of the timber harvest sacrificed in order to attain one hectare of a forest reserve. Multiplied by an interest rate of 0.042 the infinite yearly compensation prices of 709, 659, and 609 Euro/ha can be computed. Following the stand-by-stand approach the forest manager would demand these yearly compensation prices for providing forest reserves in the respective stand types.

However, these values form an upper limit, because they are based on inhomogeneous forest reserves, it is assumed that every mature stand may be harvested immediately, while the risk involved with forest management is ignored.

In order to analyse the NLP based compensation prices, the results of solving the allocation problem without forest reserves will first be presented (Table 3). In order to maximise the objective function silvicultural activities associated with negative net revenue flows were carried out at the latest possible moment. The scheduled timber amounts varied between 6 and 10 m^3/ha/year. The net revenue flows fluctuated from 242 to 464 Euro/ha/year. Subject to the standard deviations given in Table 3 these net revenue flows covered the overhead costs of 200 Euro/ha/year with a probability of 0.8 in every period.

[Table 3]

When introducing the first 42-hectare forest reserve, the objective function decreased by 482,746 Euro. Hence, one hectare of this forest reserve is priced at 11,494 Euro or, expressed as an infinite yearly compensation, 483 Euro/ha/year. This value lies far below the prices derived by the stand-by-stand LP approach. The yearly compensation price for the last forest reserve increases up to 607 Euro/ha/year when a maximum area of 1,134 ha is allocated to forest reserves (Figure 3). A larger area of forest reserves violated the constraints.

It becomes obvious that the NLP approach hardly reaches the lowest prices achieved with the linear stand-by-stand approach. This effect occurs when considering a non-linear objective function, non-linear constraints and risk.

[Figure 3]

Applying various interest rates of 3.2 and 5.2 % led to similar compensation curve patterns, though, with varying compensation prices below or above that computed for a 4.2-%-interest-rate (Figure 4). The slopes of the curves decreased with increasing interest rate. The compensation price is very sensitive to the interest rate applied.

[Figure 4]

However, employing the stand-by-stand approach resulted in a much greater influence of the interest rate. Here the compensation prices were 556 (3.2 %), 709 (4.2 %) and 853 Euro/ha/year (5.2 %), which form a difference between the results of the 5.2%- and the 3.2%-interest calculation of 297 Euro/ha/year. Contrarily, according to the NLP approach the maximum compensation prices were 517 (3.2 %), 607 (4.2 %) and 693 Euro/ha/year (5.2 %), giving a significantly smaller difference of 167 Euro/ha/year. Obviously, the latter approach shows a smaller sensitivity to the interest rate adopted.

5 Discussion and conclusions

Research question

In order to summarise the results, the research question

"What must the compensation price be, in order to gain an economic advantage from forest reserves?"

raised at the beginning of the paper can now be answered:

The results showed that compensation prices, which quantify the opportunity costs involved with the establishment of forest reserves and were based on the appropriately discounted value of timber harvest sacrificed, can be utilised to quantify the producer cost of forest reserves. The NLP approach was advantageously employed to consider the effects of the operational constraints and the risk induced non-linearity in both the objective function and the constraints. Due to the non-linearity of the planning problem the compensation prices increased from 483 to 607 Euro/ha/year when the area of forest reserves was extended from 42 to 1,134 hectare (at a 4.2-%-interest-rate). A stand-by-stand LP approach resulted in much greater compensation prices because operational constraints, as well as risks, were ignored.

In order to incite forest owners to abandon their harvesting altogether, Hampicke (2001, p. 119) derived present values of “amenity streams” as a basis for quantifying remuneration amounts. The approach Hampicke used was not operational, but was conducted on the single stand basis. Based on a 2-%-interest-rate Hampicke (p. 123 f.) computed that a forest owner had to receive 500 Euro/ha/year for a 100-year-old stand in cases where harvesting would be sacrificed. His age-dependent formula would amount to 750 Euro/ha/year for 150-year-old beech stands, which has a value of about 100 Euro greater than that derived by the stand-by-stand LP approach in this study. Hampicke’s compensation increases linearly with increasing age. That means a 200-year-old beech stand would require compensation of twice as much as a 100-year-old stand. This result ignores the considerable decrease in timber quality due to effects of red heartwood and wood decay evident in old stands. Besides, the stocking density in old stands is often already low and the timber value per unit area may well be on the decrease.

Limits of the approach

The employed approach has several limitations. Firstly, only a broad classification of stand types was used to keep the optimisation problem simple. In reality there exist considerable differences within one stand type. But the general conclusions are presumably not violated by this simplification.

The approach was based on the total renouncement of harvest. A delay of the harvest is also often considered (Höbarth and Lanschützer 2002). In this context Hampicke (2001) showed that the delay of harvests could not be recommended. Really mature stands containing decay stages, a great amount of dead wood and a richness in species cannot be achieved by merely delaying harvests.

The risk of storm damage, for example, was ignored. This can be justified, as according to Dieter (2001) this risk is very small for beech management.

Deriving a potential demand for forest reserves

For a single forest enterprise it is immaterial, whether the price for forest reserves is determined by a market or simply an offer made by an individual group demanding forest reserves. But a real market price formation would require a total "supply curve" derived from all individual "supply curves" as well as a "demand curve". This paper shows how difficult it is to derive a proper "supply curve". But deriving a "demand curve" creates even greater difficulties, as discussed below.

Fredman (1995, p. 310) has already defined several possible value components of a natural resource for people, which may also be applied to forest reserves. According to Fredman people derive benefits from a natural resource, such as forest reserves, either as a "non-consumptive use value", e.g. bird watching or hiking, or as an "existence value" just from the knowledge that forest reserves exist. Also an "indirect value" is possible, for example when people read a book or watch a TV-program on forest reserves. The value of forest reserves for citizens may be classified as an "existence value" (Fredman 1995). The Contingent Valuation Method quantifies such a value by means of interviews or questionnaires. This method was, for example, applied in Scandinavian countries (Wibe 1994) resulting in a willingness to pay (WTP) with regard to natural forests between about 5 and 35 Euro per household per year (Bergen et al. 2002). Wibe (1994, p. 16) however stated that studies on the "existence value" just demonstrate that people attach a value to the existence of forests or endangered species. But he would not use this to quantify a concrete forest value. Van Rensburg et al. (2002) also critically reviewed the WTP concept stressing the fact that WTP may depend on the attitude adopted by the questioned person. It is important, whether the WTP is indicated from the point of view of a citizen or a consumer. The derivation of a demand curve should relate the WTP for forest reserves to a specific given area. For this purpose the opportunities had to be known for substituting forest reserves with other nature conservation activities. This however, is not the case, making it almost impossible to derive an empirically sound demand curve for forest reserves.

Following-up the results of this paper, allocating 10 % of the beech forest area to forest reserves (scenario 1, 143,000 ha totally) would cost 592 Euro/ha/year. Using 5 % as forest reserves (scenario 2, 71,500 ha totally) would result a producer price of 520 Euro/ha/year. Hence, scenario 1 would generate a total cost of about 85 Mio. Euro/year. Scenario 2 would cost 37 Mio. Euro/year. Scenario 1 would, therefore, require a willingness to pay of about 2.30 Euro per German household[3]/year, while scenario 2 would need about 1 Euro per household/year. These values are much less than the real willingness to pay for species and habitat protection in Germany (see Hampicke 1991, p. 134) and thus establishing forest reserves on substantial areas seems quite realistic. However, scenario 1 would allocate only 1.4 % of the total German forest area to forest reserves, scenario 2 merely 0.7 %. Deriving a willingness to pay for forest reserves in beech forests apart from other nature conservation measures would seem problematic. To achieve this the nature conservation measures with which forest reserves could be substituted must be known. But as the results of this paper show, forest reserves may be priced and integrated in financial programs for species and habitat conservation (see Hampicke 1991, p. 290).

Although there is no sound answer to how the national or international demand may be estimated, the methodology to derive an individual compensation price curve based on producer prices seems helpful. The price curve can now be utilised to obtain compensation prices as a basis for nature conservation contracts between forest owners and nature conservation organisations. These prices could also be attractive to profit maximising forest managers, forming an incentive to provide forest reserves as a result of an economic calculus.

Benefits for federal and state forest services

State forest services have already established forest reserves in Germany, which are called natural forest reserves. In Bavaria for example 6,124 hectare of the state forest area were established as natural forest reserves (Schmidt 1998, p. 3). However, this area amounts to less than 1 % of the total forest area managed by the state forest service.

The methodology demonstrated in this paper could be used to quantify the opportunity costs of the existing forest reserves. These could be included in statements of accounts in order to report the producer costs.

Considering intergenerational equity and choosing an appropriate discount rate, the application of the presented results (based on a relatively great interest rate) to state-owned forests may give rise to discussion. For example, Toman and Ashton (1996) criticised the conventional economic approach of discounting all future costs and benefits. By weighing the present and future costs and benefits differently (e.g., Heal 1985, Chichilnisky 1996, Price 1997) the application of an interest is supposed to discriminate future generations: “The arithmetic of discounting means that any potential damages inflicted upon the next generation

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[3] 37.5 Mio. households do exist in Germany (Statistisches Bundesamt 1999).

by the current generation are of almost no consequence …" (Toman and Ashton 1996). Beltratti, Chichilnisky and Heal (1996) pointed out empirical evidence that the discount rate, which people apply to projects "…declines with the futurity of the project." They mention an interest rate of about 2 % for a time horizon of one hundred years.

In this study the sacrificed timber harvest in the mature stands allocated to forest reserves would have been carried out relatively soon without forest reserves. Although the last harvest is scheduled after 28 years a considerable amount of timber would be harvested after 3 or 8 years. Therefore, an application of the 4.2 % interest seems appropriate. A discrimination of future generations through this procedure cannot be seen. Introduce economic incentives to provide nature conservation, which would especially meet the demands of future generations, is by far the better solution.

Acknowledgements

The authors wish to thank PD Dr. Dr. habil. Michael Weber and PD Dr. Christian Ammer for useful comments and Mrs. Edith Lubitz for the language editing of the manuscript.

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Figure captions:

Figure 1. Schematic step function for the supply of forest reserves (A1, A2, A3, A4 denote different stand types).

Figure 2. Net-value of one solid cubic meter of beech timber depending on stand age.

Figure 3. Compensation prices for forest reserves.

Figure 4. Compensation prices for forest reserves and various interest rates.

FIGURE 1

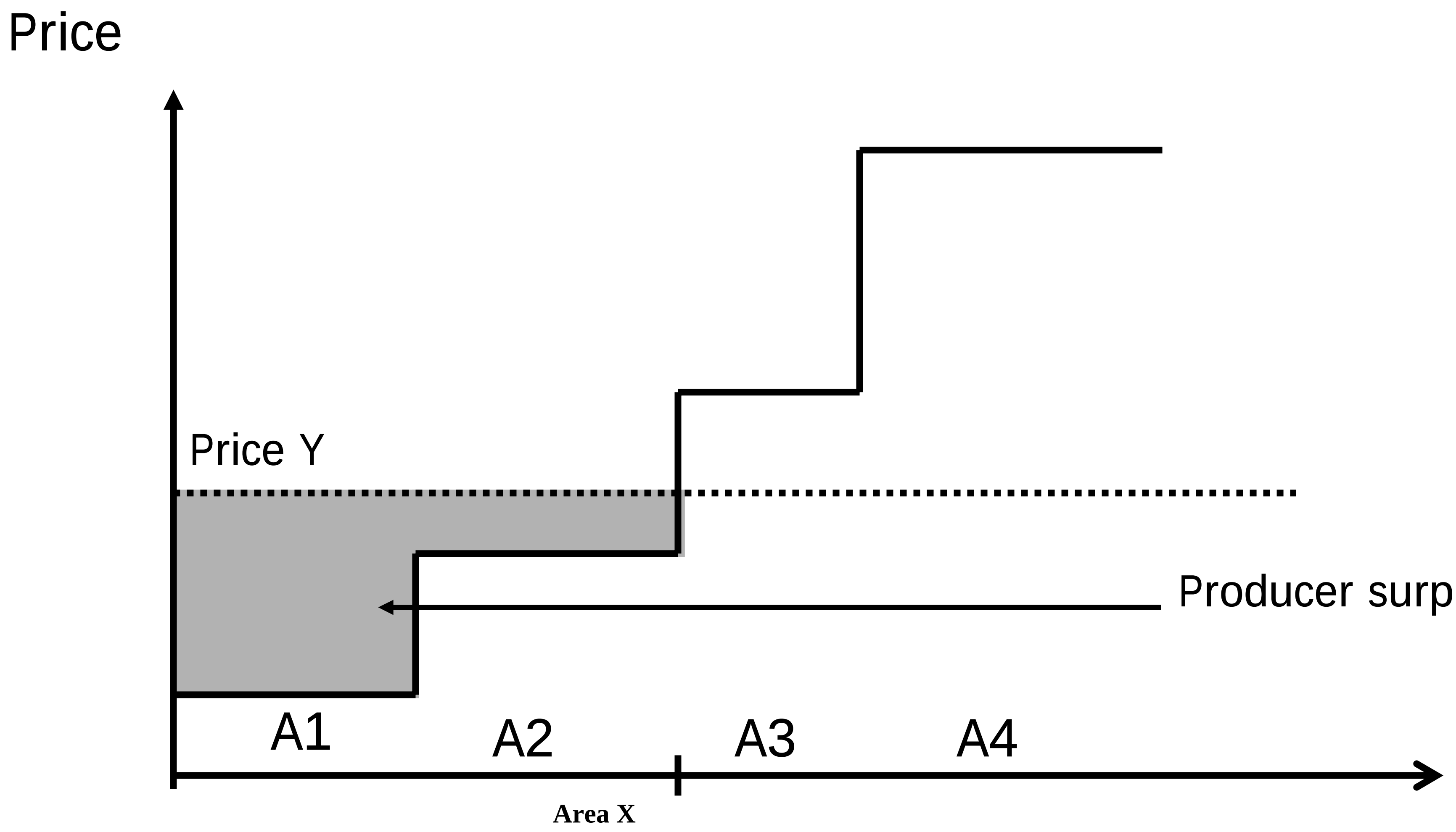

FIGURE 2

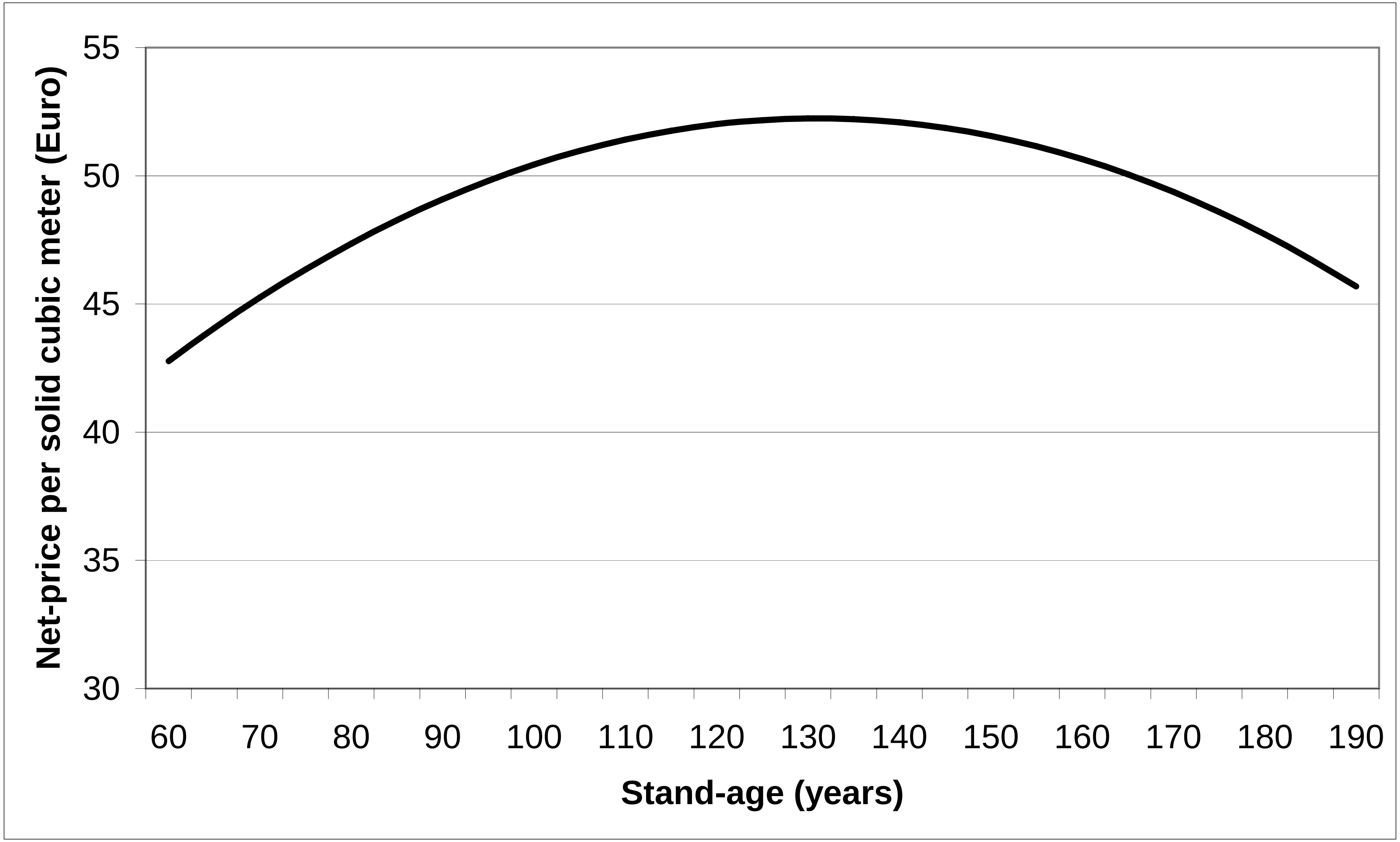
55
50
45
40
35
30
Net-price per solid cubic meter (Euro)
60
70
80
90
100
110
120
130
140
150
160
170
180
190
Stand-age (years)

FIGURE 3

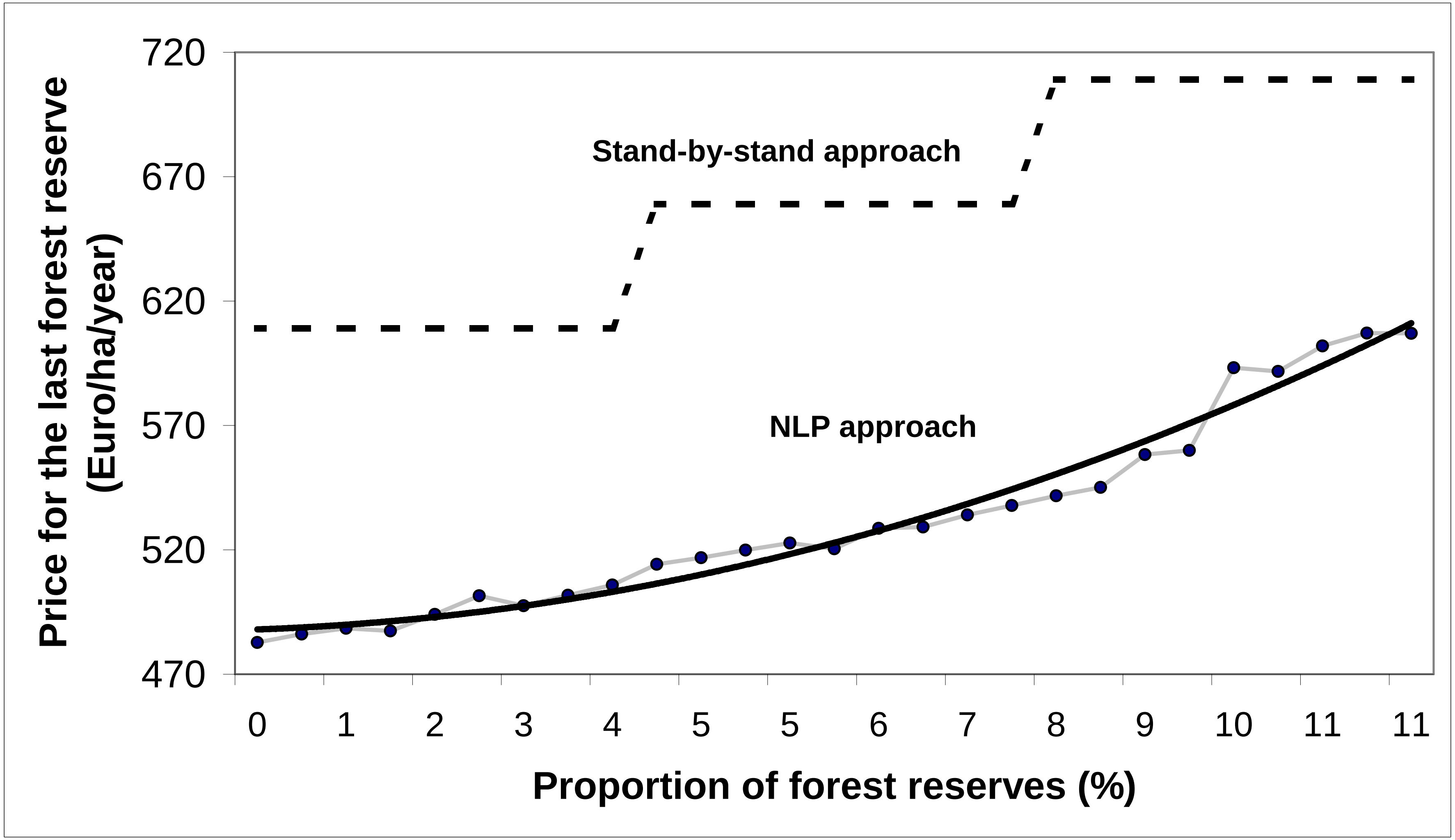
720
670
620
570
520
470
Price for the last forest reserve
(Euro/ha/year)
Stand-by-stand approach
NLP approach
0
1
2
3
4
5
5
6
7
8
9
10
11
11
Proportion of forest reserves (%)

FIGURE 4

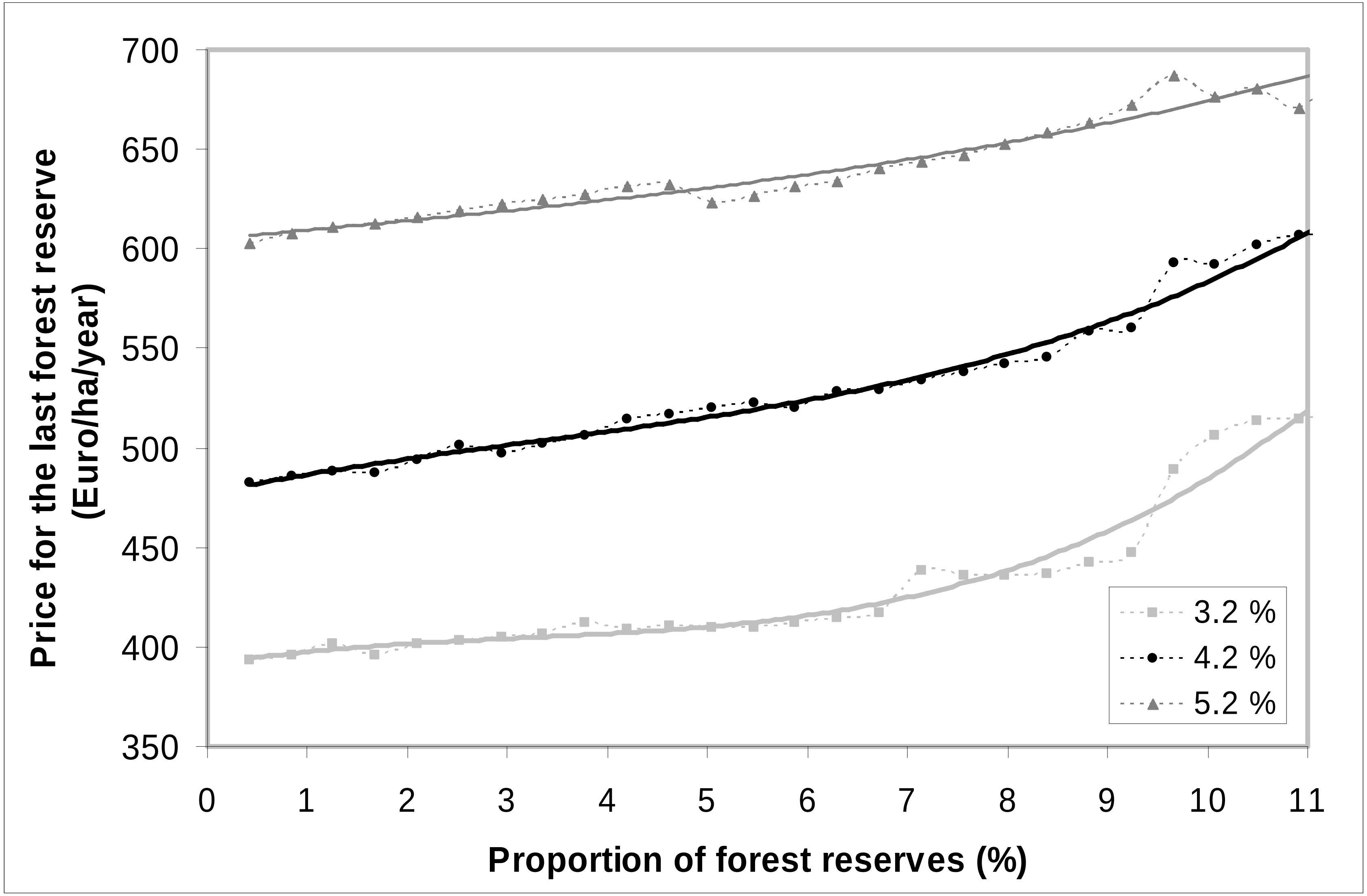
Price for the last forest reserve (Euro/ha/year)
700
650
600
550
500
450
400
350
0
1
2
3
4
5
6
7
8
9
10
11
Proportion of forest reserves (%)
3.2 %
4.2 %
5.2 %

TABLE 1. Volume amounts to be harvested in several periods and stand types.

Timber volume to be harvested (m^3/hectare)								
Mean age (years)	Stand type	Silvicultural measure	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
20	Pole-sized stand	Tending	20	20	20	20	20	20
50	Young sized stand	Tending	30	30	46	46	52	52
70	Immature stand	Thinning	52	52	70	70	64	64
90	Immature stand	Thinning	64	64	46	46	40	40
110	Immature stand	Thinning	40	40	35	35	121	138
130	Mature stand	Thin out	0	55	107	148	199	240
		Clearing	404	459	501	542	584	625
150	Mature stand	Thin out	0	45	82	118	158	194
		Clearing	385	430	466	502	538	574
170	Mature stand	Thin out	0	41	77	107	141	171
		Clearing	383	424	455	485	516	546

TABLE 2. Coefficients of correlation of net revenue flows between the periods.

Coefficient of correlation						
	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Period 1		0.20	0.12	0.06	0.03	0.03
Period 2			0.37	0.14	0.06	0.02
Period 3				0.41	0.16	0.09
Period 4					0.42	0.19
Period 5						0.42

TABLE 3. Optimal area allocation to periods and stand types.

Optimal NLP solution without forest reserves (hectare)								
Mean age (years)	Stand type	Silvicultural measure	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
20	Pole-sized stand	Tending	0	1713	0	1713	0	1713
50	Young sized stand	Tending	0	1218	1218	0	1218	0
70	Immature stand	Thinning	1466	0	1466	0	1466	0
90	Immature stand	Thinning	1630	0	1630	0	1630	0
110	Immature stand	Thinning	1412	0	1412	0	0	1412
130	Mature stand	Thin out	0	1292	0	762	0	0
		Clearing	0	57	239	291	439	324
150	Mature stand	Thin out	0	36	0	0	0	0
		Clearing	435	332	36	0	0	0
170	Mature stand	Thin out	0	0	0	0	0	0
		Clearing	227	182	0	0	0	0
		Timber harvest (m^3/ha/yr)	10	8	8	6	10	9
		Standard deviation (± m^3/ha/yr)	0.94	0.69	0.76	0.65	1.15	1.13
		Net revenue flow (Euro/ha/yr)	460	253	405	242	464	378
		Standard deviation (± Euro/ha/yr)	100	63	85	50	101	91