Multiple-use or specialized management for biodiversity conservation and carbon sequestration: Evidence from a survey on NIPF owners in Denmark

Abstract

Private forests are important as a source of both timber and forest environmental services that are often provided as a by-product of timber production. In some cases, however, non-industrial private forest (NIPF) landowners implement management action in order to enhance the provision of such services. Specifically, this paper focuses on the decision of setting aside forest land for biodiversity conservation and carbon sequestration. It raises the more general question of the efficiency of multiple-use vs. specialized management of forest lands. We propose an econometric analysis to identify factors of the choice of setting aside forest land and to measure the impact of this decision on forest management costs. A flexible cost function is modelled and estimated for both types of management. Results showed that the choice of setting aside depends on the respondents' household income and on their socio-economic characteristics. Setting aside 5% of the forest land has a significant impact of the management costs, and we show that the specialized management is a more costly solution than multiple-use forestry.

Keywords: Forest; multiple-use; specialized management; household production model; translog cost function; switching model, structural change

1. Introduction

Beside timber, forest ecosystems provide a large number of goods and services (Amacher et al. 2014), e.g., recreational services, carbon sequestration, water and biodiversity protection. Consideration of non-timber forest goods and multiple-use forestry is old in the forest economics literature (Gregory, 1955; Hagenstein and Dowdle, 1962). However, the article of Hartman (1976) is a reference as the start of numerous studies considering the forest as multifunctional. From the standard framework introduced by Faustmann (1849) and built from the net present value of the forest, the optimal harvest age is now analysed when the forest provide a flow of valuable services in addition to the value of the timber growth. Now, economic studies consider forestry as multiple-use forest management (Bowes and Krutilla, 1985).

These studies have considered mostly the management of forests at the stand level for a long time. Later contributions to the multiple-use forest management literature considered forest levels and the interaction between stands (e.g., Vincent and Binkley 1993; Swallow et al. 1997; Swallow and Wear 1993; Boscolo and Vincent, 2003; Zhang, 2005). As explained by Boscolo and Vincent (2003), fixed logging costs and administrative constraints on logging regulations can create non-convexities in forestry production sets that include timber and non-timber products. The most efficient management approach for jointly producing timber and non-timber products is not clear: Is a multiple-use management at the landscape level, where forest stands are completely or partially specialized in the production of timber and non-timber products, preferable? Or rather a uniform management that treats all stands identically? New studies, and especially empirical studies, should still investigate this issue to give new insights about potential welfare gains on some observed practices of specialized forest management.

In this paper, we focus on the choice of multiple-use forestry vs. forest-use specialization in order to assess potential complementarity or competition relationships between different ecosystem services (ES). Specifically, we empirically study the decision of setting aside forest land for biodiversity conservation and carbon sequestration. We do an econometric analysis to identify factors of the choice of setting aside forest land and to measure the impact of this decision on forest management costs. The analysis accounts for the endogenous nature of the choice of setting aside in order to avoid a problem of selection bias.

Multiple uses can be modelled by joint production approaches. Joint production framework makes it possible the analysis of synergies and trade-offs between different goods and services but is a relatively complex process because forest management, ecosystem functions and forest owners' objectives are interlinked.

Our approach is based on the behaviour of non-industrial private forest (NIPF) owners and offers an adequate way to study joint production in a context where landowners give more importance to standing timber and the amenity values they provide. It has been shown that NIPF forest management is determined by multi-objectives relatively to the management by industrial landowners (Newman and Wear, 1993). In this literature, models on the NIPF owner behaviour include amenities consumption (Binkley, 1981; Hyberg and Holthausen, 1989; Max and Lehman, 1988; among others). Thus, our economic modelling of the joint production of timber and non-timber services from NIPF is based on a household production approach.

From this framework, we derive a cost function integrating setting-aside decision next to the timber output. Knowing the cost structure of multifunctional forest management is important for several reasons. It is first a powerful tool for forest owners for the management of their forestlands and to help them to adapt their practices due to different exogenous shocks such as impacts of climate change (e.g., drought, fire occurrence, tree diseases). It is also directly connected with forest policy and the efficiency of economic instruments in favour of the provision of ES. Indeed, it is important to understand which factors influence the implementation of these instruments and to do a good assessment of costs and benefits of ES conservation. It is finally useful for assessing the cost-effectiveness between different economic instruments and mandatory regulations.

Nevertheless, there is a lack of empirical studies on forest management costs when both timber and amenities are produced. Puttock (2005) estimated costs for integrated harvesting and other forest management activities according to the marginal cost and the joint product approaches. The objective was to analyse the cost of producing wood fuel from different integrated harvesting systems. Bair and Alig (2006) identified the costs of private timber management practices and studied the way these practices influence forest management and affect the future timber supply. Other studies using cost approaches aimed to assess the cost of specific ES, such as Moulton and Richards (1990) or Nielsen et al. (2014), who provided cost estimates for carbon sequestration through afforestation. Recently, Heshmatol Vaezin et al. (2014) and Hily et al. (2015) estimated cost functions for biodiversity conservation implemented through EU Natura 2000 policy.

This article uses a cost function analysis and presents an empirical application from a survey on NIPF owners in Denmark[1] to give new insights on the way to manage multiple uses on forestlands. Even if this study is focused on multifunctional forests, our approach could be applied to other ecosystems such as agriculture. In the next section, it is presented how we model the cost function in the household production framework. Section 3 presents the econometric procedure that accounts for the problem of sample selection related to the decision of setting aside. Section 4 presents the survey of Danish forest owners and the data used in our empirical application. Section 5 presents econometric results and last section concludes.

[1] Jacobsen et al. (2013) investigate the possible financial losses from placing some Natura 2000 management restrictions such as setting aside of individual trees for aging and natural decay.

2. Modelling NIPF landowners' decision and cost function

Our objective is to study the difference in costs related to different management of forests (i.e., multiple-use vs. specialized management) for biodiversity conservation and carbon sequestration. For this purpose, we observe landowners who set aside a fixed fraction of their forestland and others who do not. These forest landowners are NIPF owners, who has been shown to have diverse motivations and non-income objectives (see e.g., Binkley 1981, Max and Lehman 1988, Dennis 1989). We propose an econometric analysis to identify factors of the choice of setting aside forest land and to measure the impact of this decision on forest management costs. In our simplified setting, we consider that NIPF owners use their forest to produce and harvest timber, referred to as H, and to benefit from non-timber or forest amenity values, referred to as A. The production of the NIPF owner/household is a transformation function of different inputs, including the land L, and produced marketed good H and non-marketed goods and services A. Moreover, even when the problem is examined from cross-section data, we can ignore the capital structure of forest production and the temporal dimension of production decision. This is why the analysis must account for the forest characteristics T (e.g., forest cover type, age, percentage of non-productive land). At this stage of production, the owner is characterized by cost-minimizing behaviour with respect to the transformation defined above. The owner i's (short-run) cost function C can simply be written as:

$$C_i\big(H_{i,}A_{i,}, w_{i,}, L_i, T_i\big), \qquad (1)$$

where $X_i = (H_i, A_i, w_i, L_i, T_i)$ denotes the set of all cost determinants, including input prices $w_{i,}$, forest land, timber and amenity outputs, and the forest characteristics, and where $i = 1, \ldots, N$ is the index for forest owners.

As explained above, NIPF owners can voluntary set aside a fixed fraction of their forest property to conserve biodiversity and for carbon sequestration. In a second step, the NIPF owners maximising their utility choose whether or not to set aside a fixed fraction of their forest. U^* refers to as the (stochastic) indirect utility function, which we assume to be unobserved. Indirect utility V depends on the expected net revenues of the productive forest R (depending on the cost function C), on the levels of amenities A and on the forest owner's individual characteristics Y (e.g., income, age, management objectives):

$$U_i^* = V_i\ [R_i, A_i \mid Y_i] + v_i, \qquad (2)$$

where v_i is the error term.

We choose a simple linear function for the stochastic utility function, so that we can write it econometric form as:

$$U_i^* = \gamma' Z_i + v_i, \qquad (3)$$

where Z includes the determinants X of the cost function, as well as the forest owner's individual characteristics Y and the forest characteristics T. The vector γ denotes the set of parameters associated to Z, to be estimated.

We assume that the forest owner seeks to maximize his/her expected utility. Thus, the forest owner compares this expected indirect utility when setting aside a share of his forestland (i.e., specialization) U_i^{*1}, with the indirect utility without setting aside (i.e., multiple-use management on the total forestland) U_i^{*0}. The forest owner decides to setting aside if $U_i^{*1} \geq U_i^{*0}$. Based on the difference in utilities, we can write the decision to setting aside as:

$$S_i^* = U_i^{*1} - U_i^{*0}. \qquad (4)$$

3. The econometric procedure

Our econometric analysis accounts for the possibly endogenous nature of the choice of setting aside forest land in order to avoid a problem of selection bias. Following Maddala and Nelson (1975), we use a switching regression model with endogenous switching.

Given that U_i^* is unobservable, what we observe is a dummy variable S (=1 if setting aside), which directly depend on the unobserved utility S^*:

$$S_i = \begin{cases} 1, & \text{if } \gamma' Z_i \geq v_i \\ 0, & \text{if } \gamma' Z_i < v_i' \end{cases} \qquad (5)$$

which allows us to estimate the parameters γ through a probit model. In particular, we consider that the landowner choice is determined by cost differences between the two regimes (setting a side or not) and other factors:

$$S_i^* = \alpha(C_{1i} - C_{0i}) + \delta W_i + v_i,$$

where S_i^* is the latent variable for unobserved forest owners' utility with the corresponding binary variable S_i. W_i is a vector of variables that influence landowner choice and v_i is an error term. The term $(C_{1i} - C_{0i})$ captures the cost difference between setting aside and no setting aside production.[2] The two different cost functions are defined as:

with setting aside: $$C_{1i} = \beta_1' X_{1i} + u_{1i}, \tag{6}$$

without setting aside: $$C_{0i} = \beta_0' X_{0i} + u_{0i}, \tag{7}$$

where C_i is the gross annual forest management cost, X is the vector of explanatory variables and β the associated coefficients to be estimated. We assume that v_i are correlated with u_{0i} and u_{1i} and that they are distributed as a trivariate normal distribution with mean zero vector and the following covariance matrix:

$$\Sigma = \begin{bmatrix} \sigma_{u_1}^2 & \sigma_{u_1 u_0} & \sigma_{u_1 v} \\ & \sigma_{u_0}^2 & \sigma_{u_0 v} \\ & & 1 \end{bmatrix} \tag{8}$$

with σ_v^2 set equal to unit, in order to estimate γ.

As suggested by Maddala (1983), it is possible to estimate cost equations in Regime 1 and Regime 0 simultaneously, using all observations on costs. This is highly desirable in our case since the number of observations in each regime is too low for a separate estimation. Since we use the same set of explanatory variables for the two regimes, i.e., $X_i = X_{1i} = X_{2i}$ the two cost equations (6) and (7) can be rewritten as:

$$\mathrm{E(C)} = \beta_0' \mathrm{X_i} + (\beta_1' - \beta_0')\mathrm{X_i}\Phi_\mathrm{i} + \phi_\mathrm{i}\left(\sigma_{\mathrm{u_0 v}} - \sigma_{\mathrm{u_1 v}}\right), \tag{9}$$

where $\Phi_\mathrm{i} = \Phi(\gamma' \mathrm{Z_i})$ is the normal cumulative distribution function and $\phi_i = \phi(\gamma' Z_i)$ is the normal probability distribution function. Hence, by substituting Φ_i with $\widehat{\Phi}_\mathrm{i} = \Phi(\hat{\gamma}' \mathrm{Z_i})$ and ϕ_i with $\hat{\phi}_i = \phi(\hat{\gamma}' Z_i)$ and regressing C_i on X_i, $\widehat{\Phi}_\mathrm{i}$ and $\hat{\phi}$, it is possible to test which coefficient differs between β_1 and β_0. In other words, since we use a flexible cost function specification, it is possible to test whether setting aside part of the forest property will affect the cost elasticities.

The estimation of the switching cost model typically proceeds in two steps: first, parameters γ of the probit equation (5) are consistently estimated by maximum likelihood estimation, and the predicted density and probability functions are then saved. In a second

[2] Some, but not all, of the variables in X may also appear in Z.

step, we estimate the cost equation by OLS. Finally, a simple likelihood-ratio test on the parameters $(\beta_1' - \beta_0')$ and $\left(\sigma_{u_0 v} - \sigma_{u_1 v}\right)$ makes it possible to conclude on the existence of selection bias.

In the case where no selection bias has been found, a structural change between the decision to set aside or not can exist. In this case, equation (9) is rewritten as:

$$E(C) = \beta_0' X_i + \left(\beta_{Set\_aside}' - \beta_0'\right) X_i \times Set\_aside_i + \beta_S Set\_aside_i. \qquad (10)$$

The existence of a structural change can be tested by a Chow test based on the null hypothesis H0: $\left(\beta_{Set\_aside}' - \beta_0'\right) = \beta_S = 0$. If H0 is rejected, then there are two different technologies according to setting aside forest land (for biodiversity conservation and carbon sequestration) or not.

We choose a translog cost function for the econometric application. This functional form is both flexible enough to characterize any form of technology and simple to derive different cost measures such as cost elasticities and returns to scale:

$$\ln(C) = Cte + \beta_Y \ln(Y) + \beta_Z \ln(Z) + \frac{1}{2}\beta_{YY}[\ln(Y)]^2 + \frac{1}{2}\beta_{ZZ}[\ln(Z)]^2 + \beta_{YZ}\ln(Y)\ln(Z) + u,$$

where Y and Z are variables chosen arbitrary, to show the form of the translog function.

4. Data

The data used in our study come from an online survey of Danish forest owners. The survey was carried out at a national level using the software SurveyXact in the period from June-August 2012. Through a systematic stratification based on forest property size classes, forest landowners were randomly selected from a contact list obtained from the National Forest Inventory during the previous years. Forest owners were contacted through a letter including a leaflet with brief information on the survey, the name of the website where they could log-on to fill out the questionnaire online and on the possibility to win a prize (3000 DDK voucher to be spent in groceries stores).

The design of the questionnaire was based on experience from earlier studies on forest owners and other types of landowners (Boon et al 2004, Broch and Vedel 2012). The questionnaire was included questions regarding the respondents' forest property features, the forest management, cost and revenues as well as the forest landowners' socio-economic characteristics. The questionnaires included also a choice experiment which was analysed in other studies. After testing the questionnaire within a focus group of forest landowners, the questions related to costs and revenues where revised and simplified in order to make them less burdensome to answer. Specifically, respondents were asked to state the gross cost/expenditures for the largest forest during the previous year (2011), including cost of harvesting, administration and taxes and excluding interest expenditures. Moreover, it was asked to report the harvested volume during the last year from their largest forest and whether they had set aside 5% of their forest land as untouched.

A total of 1429 forest owners were contacted and reminder letters were sent to the ones who had not replied during the three-four weeks following the first letter. Overall, 308 questionnaires were returned. Respondent who did not state their gross annual cost were eventually excluded from the analysis, leaving a sample of 136 forest owners.

[TABLE 1 APPROX HERE]

In Table 1, we report the descriptive statistics for the variables used in the analysis. Means and standard deviations are presented for the whole sample and for the two regimes (setting aside, not setting aside). The price variable was obtained by dividing the annual timber revenues by the annual timber volume produced. This value was available only for about 50% of the sample. Prices were hence predicted through a hedonic price model. The model and the estimated coefficients are presented in Appendix A.

5. Results

5.1. The setting aside decision

Table 2 presents the probit estimates from the setting aside decision model. The model fits the data well with a pseudo R^2 of about 36% and a number of 109 observations correctly classified (that is 79.41% of the total sample). Estimation results suggest that besides some forest management and forest property features, the setting aside decision is also influenced by the landowners' socio-economic characteristics, as well as the forest owners' motivations. Among the socioeconomic characteristics, we observe that the likelihood of setting aside a share of the property increases with the landowners' income (at the 10% level).

[TABLE 2 APPROX HERE]

Considering the forest owners motivations, respondents assigning great and very great importance to learn about nature as a reason for owning a forest have higher likelihood to set aside part of their forest land. Similarly, respondents who express some interest in owning a forest for enjoying wildlife and protect biodiversity seem to have a higher likelihood of subtracting part of the forest from the timber production compared to respondents who are not considering this reason for owning a forest as important. Similarly, landowners owning a forest with some interest in long-term financial investment have a lower likelihood of setting aside compared to respondents not interested in. Finally, forest landowners assigning great or very great importance in helping supply recreational areas for the public have lower willingness to set aside part of their forest land.

Regarding the forest property features, the results show that the probability of setting aside decreases with the percentage of broadleaved trees in the forestland. Interestingly, the probability of setting aside is lower is the forest estate is surrounded by forestland compared to other land uses. Cost determinants such as the harvested timber volume have no impact on the probability of setting aside. The negative sign of the parameter associated with the total size of the forest (in log) owned by the respondents suggests that it is less likely to set aside forestland in large property, but it is not quite significant.

Finally, among the variables related to forest management, the timber price seems not to be a significant predictor of the setting aside decision..

5.2. The cost function

First, the switching cost model (9) is estimated according to the Maddala (1983) approach for all observations of both regimes (NIPF owners having set aside a fraction of their forestland those having not). From the estimation of the probit model, we saved the estimated normal density ϕ and probability Φ functions. Next, we estimate the translog cost equation[3] where the potential selection bias is corrected by crossing explanatory variables with the standard normal distribution function Φ. However, our results show no evidence of switching costs. Indeed, a likelihood-ratio test on the parameters associated with explanatory variables crossed with Φ indicates that the nullity of these parameters cannot be rejected. The estimation results from a simple cost function and the switching cost model are presented in Table 6 in Appendix.

Alternately, we estimate a model with structural change, consisting in crossing all explanatory variables with the dummy variable *S*, indicating the choice of setting aside. We can observe that two different cost functions are identified. Actually, the coefficients for the two cost functions estimated by a single model are different and significant. On one hand, we have the cost function for the properties in which a share of the forestland is set aside for the environmental services provision. On the other hand, we have the cost function when the set aside is not present. Concerning the latter, the coefficient can be directly read for the variables "volume", "volume^2", "size", "size^2", "volume * size", and "pdec". The estimation results from a simple cost function and the cost model with a structural change are presented in Table 3.

[TABLE 3 APPROX HERE]

[3] The translog function is a second-order Taylor expansion around the mean of observations; hence all right-hand side variables (in log) must be normalized by their sample mean.

Estimation results from Table 3 show that the translog functional form of costs fits very well the data with significant first and quadratic terms and with the expected signs. Moreover, the positive sign of the coefficient associated with the variable pdec indicates that a higher percentage of deciduous trees increases management costs. Instead, the percentage of non-productive land appears to have any effect on forest management costs.

In contrast, when the forest landowners set aside forestland for ecosystem services provision, the coefficients of the cost function have to be derived from Table 3 by subtracting the coefficients of the non-set aside variables by the coefficients of the respected variable multiplied by the estimated Φ. In other words, $\hat{\beta}_1 = \hat{\beta}_0 + \hat{\beta}_S$, where $\hat{\beta}_1$ are the estimated coefficients for the setting aside paradigm and $\hat{\beta}_0$ the coefficients for the no setting aside one (Table 4).

[TABLE 4 APPROX HERE]

Our estimation results points out that cost elasticities with respect to harvested timber volume are significantly less than one. This indicates the existence of strong economies of scale. However, the cost elasticity is lower when setting aside is present, meaning that an increment in the wood production will in percentage terms be less costly than in the no setting aside case. In contrast, in the properties with setting aside there is a higher marginal cost than in the no-setting aside ones, for all level of timber produced, because the average costs are much higher. These results clearly push in favour of multiple-use forest management.

6. Discussion

The results from the probit model showed that the landowners’ motivations as well as their socioeconomic characteristics are relevant predictor of the setting aside decision. This, consistently with our theoretical model, seems to confirm the hypothesis that NIPF owners are rather utility-maximisers rather that profit-maximisers framework (Binkley, 1981; Max and Lehman, 1988; Dennis, 1989; Hyberg and Holthausen, 1989; Newman and Wear, 1993). This is in line with a significant amount of empirical literature on NIPF landowners’ decisions

(Amacher et al., 2003; Beach et al., 2005).

By looking at the factor reducing the likelihood of setting aside, we observe that is decreases the higher the percentage of broadleaves are present in the property. This result may be explained by the different site productivities. Since broadleaved trees generally required good soil fertility, in sites covered by broadleaves we may expect a higher opportunity cost of setting aside forestland, and hence a lower likelihood of observing this decision.

Regarding the forest owner income, we observe a significant and positive relationship with the setting aside decision. This is in line with previous findings in which the ecosystem services provision, as biodiversity protection and carbon sequestration, can be seen as luxury goods, for which the consumption is increasing with the income. For instance some studies found a negative relationship between the likelihood of harvesting and the landowner's income (Hyberg and Holthausen, 1989; Denis, 1989). Of course, this result depends on the share of the total income that is generated by the forest property. We tested this variable in the model, but it did not turn out to be significant, hence we leave it out to improve the model performance.

In our household production model, we made the hypothesis that the cost function has an influence on the utility function. For this reason, the explanatory variables in the cost function are also included in the probit model. However, neither the volume variable (in log) is found significant nor the volume squared. The size of forest has a negative impact on the decision of setting aside a part of the forest land, but only at the 15% level.

Turning to the cost function estimation, our results bring some new insights on the efficiency of multiple-use forest management. The first important result is that it seems to be two different technologies in forest properties with a set aside area and in those without. The different cost structure seems to suggest the presence of different management paradigms. These results can be interpreted in light of the debate on specialization vs. multiple-use management paradigms. In other words, our model seems to suggest that, although the cost elasticity is lower (see Figure 2), the marginal cost of production is higher in the setting aside case (see Figure 1). These results push in favour of the increase of harvested timber in average to exploit some economies of scale, and of multiple-use forest management against specialised management.

Table 1. Descriptive statistics

Variable	Total (N=136) Mean	Std. Dev.	Set aside (N=78) Mean	Std. Dev.	No set aside (N=58) Mean	Std. Dev.
Cost (in DKK)	505776	1478993	397884	848277	650872	2042381
Volume (in m^3)	1467.1	3757.3	1349.1	3197.7	1625.9	4424.6
Set_aside (y/n)	0.574	0.496	1.000	0.000	0.000	0.000
Size (in ha)	330.8	960.8	231.4	551.4	464.6	1320.7
Percentage of non-productive forest	0.278	0.334	0.343	0.356	0.190	0.283
Percentage of broadleaves	0.364	0.315	0.311	0.286	0.435	0.340
Neighbouring land: forest (y/n)	0.662	0.475	0.590	0.495	0.759	0.432
Timber price (in DKK)	283.1	198.1	289.8	222.7	294.9	171.0
Landowner's education (from 1 to 5)	3.588	1.380	3.756	1.261	3.362	1.507
Landowner's income (from 1 to 12)	8.162	2.865	8.372	2.750	7.879	3.015
Landowner's age class						
24-45	0.199	0.400	0.269	0.446	0.103	0.307
45-65	0.603	0.491	0.551	0.501	0.672	0.473
65+	0.199	0.400	0.179	0.386	0.224	0.421
Reasons for owning a forest:						
Enjoy wildlife and protect nature						
- no importance	0.118	0.323	0.038	0.194	0.224	0.421
- little importance	0.044	0.206	0.038	0.194	0.052	0.223
- great importance	0.287	0.454	0.295	0.459	0.276	0.451
- very great importance	0.551	0.499	0.628	0.486	0.448	0.502
Long-term financial investment						
- no importance	0.257	0.439	0.231	0.424	0.293	0.459
- little importance	0.294	0.457	0.269	0.446	0.328	0.473
- great importance	0.301	0.430	0.461	0.483	0.224	0.421
- very great importance	0.147	0.355	0.141	0.350	0.155	0.365
learn about nature						
- no importance	0.199	0.400	0.103	0.305	0.328	0.473
- little importance	0.243	0.430	0.231	0.424	0.259	0.442
- great importance	0.456	0.500	0.538	0.502	0.345	0.479
- very great importance	0.103	0.305	0.128	0.336	0.069	0.256
Help supply recreational areas for the public						
- no importance	0.529	0.501	0.513	0.503	0.552	0.502
- little importance	0.316	0.467	0.385	0.490	0.224	0.421
- great or very great importance	0.154	0.363	0.103	0.306	0.224	0.421

Table 2. Estimation result of the setting aside decision - probit model

Variable	**Coef.**	**Std. Err.**
Timber price (in log)	0.4378	0.3995
Household monthly income before taxes (in log)	0.6287*	0.3312
Volume (in log)	-0.0173	0.0699
Size (in log)	-0.1812	0.1264
$Volume^2$ (in log)	0.0392	0.0618
$Size^2$ (in log)	0.0858	0.0742
Volume * size (in log)	0.0015	0.0346
Percentage of broadleaves	-2.038***	0.7199
Percentage of non-productive land	-0.1687	0.6479
Neighbouring land: forest	-1.304***	0.3694
Age class (26-45 ref group)		
45-65	-0.4339	0.4593
65+	-0.5669	0.5466
Enjoy wildlife and protect nature (no importance ref. group)		
- little importance	-0.1078	1.003
- great importance	0.6848	0.7207
- very great importance	0.5181	0.7454
Learn about nature (no importance ref. group)		
- little importance	1.245*	0.6647
- great importance	1.815**	0.7153
- very great importance	2.304***	0.8099
Long-term financial investment (no importance ref. group)		
- little importance	-1.120**	0.5547
- great importance	-0.4656	0.5258
_ very great importance	-1.050*	0.5643
Help supply recreational areas for the public (no importance ref. group)		
- little importance	0.0362	0.4112
- great or very great importance	-1.655***	0.4916
Edu2	1.120	0.7578
Edu3	0.7651	0.5739
Edu4	0.5445	0.6003
Edu5	0.6340	0.5174

Constant	-3.222	2.319

Log likelihood = -59.7158

LR $chi^2(27)$ = 66.15 (P-value = 0.000)

Pseudo R^2 = 0.3565

Correctly classified = 79.41%

Notes: N = 136. *, ** and ***: significant at 10%, 5% and 1%, respectively.

Table 3. Estimation results of cost functions and test of structural change

Variable	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**
Volume	0.2819***	0.0888	0.5229***	0.1393
Size	0.6265***	0.1364	0.3342	0.2255
$Volume^2$	0.1674**	0.0815	0.3626**	0.1562
$Size^2$	-0.1906**	0.0830	-0.2547*	0.1311
Volume * Size	0.0183	0.0419	-0.0548	0.0734
Percentage of broadleaves	1.2159*	0.6302	1.4303	0.9033
Volume * Aside			-0.3772**	0.1823
Size * Aside			0.5485*	0.2875
$Volume^2$ * Aside			-0.2738	0.1829
$Size^2$ * Aside			0.3139	0.1990
Volume * size * Aside			0.0006	0.0980
(Percentage of broadleaves) * Aside			0.0008	1.3084
Aside			1.5472*	0.9252
Constant	8.9990***	.4484	7.8836***	0.6679
F stat.	25.84		13.75	
(Prob > F)	(0.000)		(0.000)	
Adj. R-squared	0.525		0.551	
Chow stat. (P-value)		15.35	(0.032)	

Notes: N = 136. *, ** and ***: significant at 10%, 5% and 1%, respectively.

Table 4. Estimated marginal effects for two technologies (setting aside, not setting aside)

	$\hat{\boldsymbol{\beta}}_0$	$\hat{\boldsymbol{\beta}}_1 = \hat{\boldsymbol{\beta}}_0 + \hat{\boldsymbol{\beta}}_S$
Volume	0.5229	0.1458
Size	0.3342	0.8828
$Volume^2$	0.3626	0.0888
$Size^2$	-0.2547	0.0593
Volume * Size	-0.0548	-0.0542
Percentage of broadleaves	1.4303	1.4312

Figure 1. Marginal costs

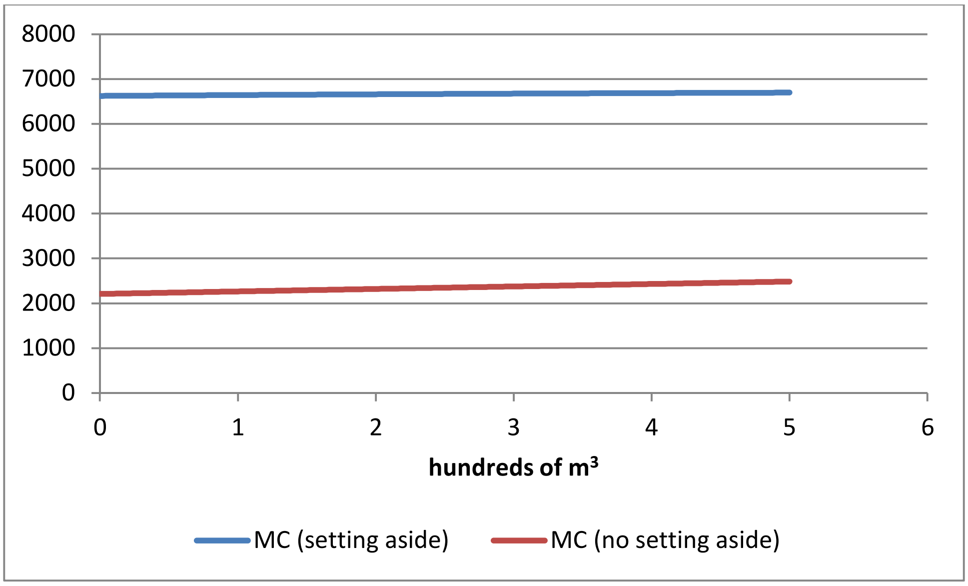
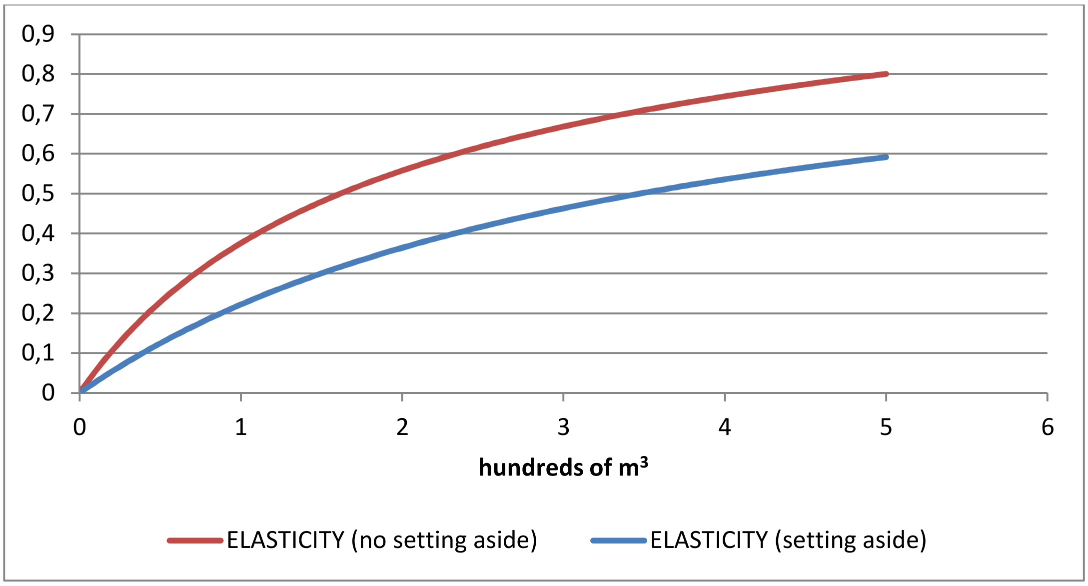


Figure 2 Cost elasticities



7. Appendix

Table 5. Hedonic price model (dependent variable: Timber price in log)

Variable	Coef.	Std. Err.
Size (in log)	0.098	0.071
Percentage of broadleaves	1.068**	0.411
Certification of forest (y/n)	0.800**	0.331
Membership of at least one forest organisation (y/n)	0.568**	0.283
Neighbouring land: agriculture (y/n)	-0.402	0.364
Constant	4.627***	0.369
F(5,61)	7.060	
Prob > F	0.000	
R-squared	0.367	
Adj R-squared	0.315	

Notes: N = 67. *, ** and ***: significant at 10%, 5% and 1%, respectively

Table 6. Estimation result of the switching cost model

Variable	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**
Volume	0.2819***	0.0888	0.5373***	0.2044
Size	0.6265***	0.1364	0.4275	0.2831
Volume^2	0.1674**	0.0815	0.1905	0.1750
Size^2	-0.1906**	0.0830	-0.3098	0.1909
Volume * Size	0.0183	0.04190	0.0134	0.0991
Percentage of broadleaves	1.2159*	0.6302	0.9803	1.0999
Volume * Φ			-0.4520	0.3397
Size * Φ			0.4219	0.4578
Volume^2 * Φ			-0.0243	0.2315
Size^2 * Φ			0.3285	0.3522
Volume * size * Φ			-0.0516	0.1808
(Percentage of broadleaves) * Φ			0.9897	1.7433
ϕ			-0.2298	1.7635
Constant	8.9990***	0.4484	8.8421***	0.7208
F stat	25.84		11.95	
(Prob > F)	(0.000)		(0.000)	
Adj. R-squared	0.5247		0.5133	
LR stat (P-value)		4.37	(0.737)	

Notes: N = 136. *, ** and ***: significant at 10%, 5% and 1%, respectively.

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