Laboratoire d'Economie Forestière

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Serge GARCIA
Claudio PETUCCO
Bo JELLESMARK THORSEN
Suzanne Elizabeth VEDEL

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LEF – AgroParisTech/INRA – 14, rue Girardet – CS 4216 – F-54042 Nancy cedex
☎ 00 33 (0)3 83 39 68 66– 🖷 00 33 (0)3 83 37 06 45
http://www6.nancy.inra.fr/lef/

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Serge GARCIA[1], Claudio PETUCCO[2], Bo JELLESMARK THORSEN[3], Suzanne Elizabeth VEDEL[4]

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Abstract

Forests provide ecosystem services jointly with timber production. In some cases, private forest owners implement management actions in order to enhance the provision of such services. They may get direct benefits from this decision such as private amenity values or effects on (e.g., hunting), they may have altruist traits in their utility function for providing public goods (e.g., biodiversity conservation, carbon sequestration), or they may be incited for by a public authority and compensated for the costs. Specifically, this paper focuses on the decision of setting aside forest land. 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 set-aside choice 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. The percentages of old/mature deciduous and old/mature coniferous forests are used as biodiversity and carbon indicators. Results show that the set-aside choice depends on the landowners' income and on their socio-economic characteristics. Set-aside decision has a significant and positive impact on the management costs. This implies that the additional private and public benefits achieved from specialized relative to multiple-use management should exceed this cost premium.

Keywords: Forest; multiple-use vs. specialized management; household production model; cost function; corner solution; recursive mixed system

JEL codes:

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[1] UMR INRA – AgroParisTech, Laboratoire d'Economie Forestière, 54042 Nancy Cedex, France, serge.garcia@inra.fr
[2] UMR INRA – AgroParisTech, Laboratoire d'Economie Forestière, 54042 Nancy Cedex, France, claudio.petucco@inra.fr
[3] Department of Food and Resource Economics and Center for Macro Ecology, Evolution and Climate, University of Copenhagen, Rolighedsvej 23, DK-1958 Frederiksberg C, bjt@ifro.ku.dk.
[4] Department of Food and Resource Economics, University of Copenhagen, Rolighedsvej 23, DK-1958 Frederiksberg C, Denmark, sve@ifro.ku.dk

1. Introduction

Beside timber and non-timber products (e.g., game, cork, mushrooms), forest ecosystems provide a large number of non-marketed services such as recreational services, carbon sequestration, water regulation and biodiversity preservation. Consideration of non-timber forest goods and services and multiple-use forestry has a long tradition in the forest economics literature (Gregory, 1955; Hagenstein and Dowdle, 1962). However, following Hartman (1976) numerous studies analysed the forest as a multifunctional system. Since the standard framework introduced by Faustmann (1849) establishing the correct expression for the net present value of perpetual forest rotations, the optimal harvest age has been analysed in numerous variations where the forest provide a flow of valuable services in addition to the value of the timber growth, and many economic studies analyse forestry under a multiple-use forest management regime (Bowes and Krutilla, 1985).

Earlier studies have considered mostly the management of forests at the stand level. 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 management of forests 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? Economic studies, and especially empirical ones, should still investigate this issue to provide new insights relevant for assessing the potential welfare gains of observed practices like specialized and multiple-use 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) as reflected in the costs of forest management. Specifically, we empirically study the decision of setting aside forest land. Untouched forest can be recommended for biodiversity conservation and carbon sequestration as public goods, and be a part of public conservation programmes. However, forest owners could also set aside because they get private benefits from amenity values or indirect effects through hunting for instance. They might also have altruist traits in their utility function for providing public goods. We carry out 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.

Multiple uses can be modelled by joint production approaches. The joint production framework makes it possible to analyse synergies and trade-offs between different goods and services, but it is a relatively complex framework 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 attach importance to standing timber and the amenity values it provides. It has been shown that NIPF forest management is characterised by owners' multiple objectives relatively to management by industrial landowners (Newman and Wear, 1993). In this literature, models of 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 decision to specialise a part of the forest for biodiversity conservation and carbon sequestration is based on a household production approach.

From this framework, we derive a cost function integrating set-aside decisions along with decisions on 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 to use in the management of their forestlands and to help them adapt their practices to different exogenous shocks. 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 among landowners in order to be able to assess appropriately the costs and benefits of ES conservation. Finally, it is useful for assessing the cost-effectiveness of different economic instruments and mandatory regulations.

Nevertheless, there is a lack of empirical studies on forest management costs when both timber and objectives on ES are analysed. Puttock (2005) estimated costs for integrated harvesting and other forest management activities applying the marginal cost and the joint production frameworks. The objective was to analyse the cost of producing fuel wood 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 the EU Natura 2000 policy.

This article uses a cost function analysis and presents an empirical application from a survey on NIPF owners in Denmark[5] to give new insights on the consequences of alternative management approaches on forestlands, including e.g. biodiversity preservation and carbon sequestration objectives. We used two indicators which can be interpreted as proxies for the biological richness and the carbon sequestration in our study: the percentages of old/mature deciduous and old/mature coniferous forests. Indeed, the biologically richest forests in Denmark are linked to old deciduous forests.[6] Moreover, old growth forests have been shown to be global carbon sinks (Luyssaert et al. 2008).

In our econometric approach, we deal with possible selection bias related to the decision to set aside a part of the forestland and with the endogeneity of harvested timber volume, by simultaneously estimating a set of equations using a recursive mixed-process model. Indeed, we have different kinds of dependent variables (i.e., continuous, binary and censored) appearing as explanatory variables in other equations.

Even though this study focuses on multifunctional forests, our approach could be applied to other ecosystems such as agriculture. In the next section, we present our database obtained from a survey on Danish NIPF owners and propose a first analysis of forest management costs according to the set-aside decision. Section 3 presents the econometric strategy from the economic modelling that accounts for the endogeneity of both the decision of setting aside and its impact on timber harvesting decisions. Section 4 describes the different econometric results while the last section discusses these results in the light of the debate on specialization vs. multiple-use management of forests.

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[5] 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.

[6] See http://www.prinsengineering.com/biodiv_dk.htm. PRINS Engineering specialised in digital remote sensing and GIS has participated in the framework of the ESA / EU program to a project intended to support the monitoring and mapping of biological rich forest areas in several countries, including Denmark.

2. Data and first empirical analysis

2.1. Data

The data we used in this study was obtained using an online survey of Danish forest owners, which was carried out at a national level in the period from June-August 2012. Forest landowners were randomly selected from a contact list obtained from the National Forest Inventory and a systematic stratification based on forest property size classes was implemented for selecting forest owners. We contacted forest owners through an official university letter including a leaflet with brief information on the survey and statements of support from the Danish Forest Owner Association. The letter included the name of the website where they could log-on to fill out a questionnaire online constructed using the software SurveyXact. Completing the questionnaire, the forest owners obtained the possibility to win a prize (3 × DKK1000 voucher to be spent in groceries stores).

The questionnaire was designed based on experience from previous studies on landowners (Boon et al. 2004, Broch and Vedel 2012). The questionnaire included questions regarding the landowners' forest property features, the forest management, cost and revenues as well as the forest landowners' socio-economic characteristics. The questionnaire also included a choice experiment which has been analysed in other studies (see Vedel et al. 2015). 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 their largest forest holding during the previous year (2011), including cost of harvesting, administration and taxes and excluding interest expenditures. Moreover, they were asked to report the harvested volume during that same year from that same forest and whether or not they had set aside at least 5% of their forest land as untouched. In Denmark, there exist nature protection programmes with targeted actions including securing specific forests with the designation of a share of forested areas for biodiversity. The forest owner is obliged to have forest on his land and to re-establish forest stands (e.g., clear cut) within a reasonable time period following (Danish Parliament, 2013).

A total of 1,429 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. This sample of 136 owners in total owned approximately 45,000 hectares of forest land. This corresponds to around 10 % of the privately owned forest area in Denmark.

Table 1. Descriptive statistics

		Total (N=136)		Set-aside Regime (N=78)		No set-aside Regime (N=58)	
Name	Variable	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
	Endogenous variables:						
SASIDE	Set-aside (y/n)	0.574	0.496	1.000	0.000	0.000	0.000
COST	Cost (in DKK)	505776	1478993	397884	848277	650872	2042381
VOL	Harvested volume (in m^3)	1467.1	3757.3	1349.1	3197.7	1625.9	4424.6
	Forest property characteristics						
SIZE	Size (in ha)	330.8	960.8	231.4	551.4	464.6	1320.7
PRICE	Timber price (in DKK)	283.1	198.1	289.8	222.7	294.9	171.0
PDEC	Percentage of broadleaves	0.364	0.315	0.311	0.286	0.435	0.340
PCON	Percentage of coniferous	0.358	0.300	0.346	0.283	0.374	0.323
PNOP	Percentage of non-productive forest	0.278	0.334	0.343	0.356	0.190	0.283
POLDDEC	Percentage of old and mature broadleaves	0.070	0.129	0.067	0.122	0.074	0.138
POLDCON	Percentage of old and mature coniferous	0.065	0.141	0.044	0.102	0.094	0.178
NGFOREST	Neighbouring forest land (y/n)	0.662	0.475	0.590	0.495	0.759	0.432
DFA	Member of a Danish forest association (y/n)	0.265	0.443	0.269	0.446	0.259	0.442
	Landowner characteristics:						
EDU	Landowner’s education (from 1 to 5)	3.588	1.380	3.756	1.261	3.362	1.507
INCOME	Landowner’s income (from 1 to 12)	8.162	2.865	8.372	2.750	7.879	3.015
	Landowner’s age class						
AGE24-45	24-45	0.199	0.400	0.269	0.446	0.103	0.307
AGE45-65	45-65	0.603	0.491	0.551	0.501	0.672	0.473
AGE65+	65+	0.199	0.400	0.179	0.386	0.224	0.421
	Reasons for owning a forest:						
HUNTINC	Gain income from hunting, greenery etc						
	1 no importance	0.390	0.489	0.346	0.479	0.448	0.502
	2 little importance	0.250	0.435	0.269	0.446	0.224	0.421
	3 great importance	0.176	0.383	0.179	0.386	0.172	0.381
	4 very great importance	0.184	0.389	0.205	0.406	0.155	0.365
FININVEST	Long-term financial investment						
	1 no importance	0.257	0.439	0.231	0.424	0.293	0.459
	2 little importance	0.294	0.457	0.269	0.446	0.328	0.473
	3 great importance	0.301	0.430	0.461	0.483	0.224	0.421
	4 very great importance	0.147	0.355	0.141	0.350	0.155	0.365

LEARN	learn about nature						
	1 no importance	0.199	0.400	0.103	0.305	0.328	0.473
	2 little importance	0.243	0.430	0.231	0.424	0.259	0.442
	3 great importance	0.456	0.500	0.538	0.502	0.345	0.479
	4 very great importance	0.103	0.305	0.128	0.336	0.069	0.256
PUBRECRE	Help supply recreational areas for the public						
	1 no importance	0.529	0.501	0.513	0.503	0.552	0.502
	2 little importance	0.316	0.467	0.385	0.490	0.224	0.421
	3 great importance	0.132	0.340	0.064	0.247	0.224	0.421
	4 very great importance	0.022	0.147	0.038	0.194	0.000	0.000

In Table 1, we report descriptive statistics for the variables used in the analysis. Means and standard deviations are presented for the whole sample and for two different subsamples, i.e. Set-aside Regime vs. No set-aside Regime. 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.

2.2. Forest management costs

Our objective is to study the difference in costs related to different management of forests (i.e., multiple-use vs. specialised 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. 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 of various sorts, 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.

An important feature of forest management is that it implies long-term decisions. Even when the problem is examined from cross-section data as in this study, we cannot ignore the capital structure of forest production and the temporal dimension of production decisions. This is why the analysis must account for the forest characteristics T (e.g., forest cover type, age of forest stands, the 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:

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

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

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:

$$\ln(\mathrm{C}) = \beta_0 + \beta_H \ln(H) + \beta_Z \ln(Z) + \frac{1}{2}\beta_{HH}[\ln(H)]^2 + \frac{1}{2}\beta_{ZZ}[\ln(Z)]^2 + \beta_{HZ}\ln(H)\ln(Z) + u$$

We present first estimation results of different cost function models. Model (1) is the translog cost function including the main explanatory variables of costs in log and mean-scaled: harvested volume of timber (VOL), size of forest (SIZE), as well as several variables giving information on forest composition: the percentage of coniferous in the forest property (PCON), the percentage of non-productive forest (PNOP), but also the composition in terms of old deciduous and coniferous trees (POLDDEC and POLDCON, respectively). Membership of a Danish forest owner association or extension service is also considered as a potential cost driver if membership leads to cost savings or to a learning process. Model (2) adds the dummy variable indicating whether a part of forest (that is 5% of the total owned forestland) has been set aside (SASIDE) by the forest owner. In model (3), cross terms has been built from the dummy SASIDE and cost factors VOL and SIZE.

Table 2. Cost function estimation

Variable	Model (1) COST (in log)	Model (2) COST (in log)	Model (3) COST (in log)
VOL (in log)	0.324***	0.348***	0.469***
	(0.0940)	(0.0921)	(0.124)
SIZE (in log)	0.666***	0.671***	0.502**
	(0.155)	(0.152)	(0.198)
VOL × VOL	0.158**	0.155**	0.150**
	(0.0726)	(0.0707)	(0.0707)
SIZE × SIZE	-0.206**	-0.190**	-0.137
	(0.0822)	(0.0804)	(0.0878)
VOL × SIZE	0.0192	0.00692	0.000292
	(0.0414)	(0.0406)	(0.0408)
PCON	-2.643***	-3.181***	-3.097***
	(0.895)	(0.895)	(0.895)
PNOP	-1.151	-1.690**	-1.671**

	(0.762)	(0.769)	(0.772)
POLDDEC	-2.473	-2.830*	-2.830*
	(1.721)	(1.683)	(1.689)
POLDCON	2.372	3.183**	2.671*
	(1.510)	(1.502)	(1.533)
VOL × POLDDEC	0.705	0.602	0.576
	(0.485)	(0.475)	(0.474)
VOL × POLDCON	-0.553	-0.310	-0.246
	(0.501)	(0.497)	(0.498)
DFA	-0.597	-0.747	-0.783
	(0.614)	(0.601)	(0.603)
SASIDE		1.102***	1.105***
		(0.406)	(0.406)
SASIDE × VOL			-0.230
			(0.153)
SASIDE × SIZE			0.332
			(0.247)
Constant	10.80***	10.54***	10.45***
	(0.633)	(0.624)	(0.626)
Observations	136	136	136
R-squared	0.577	0.601	0.610

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

All models fit very well the data with several significant coefficients, such as those of first-order and quadratic terms, with the expected signs, as well as a high R-squared (from 0.58 to 0.61). For instance, a value of 0.3 for the coefficient of VOL means that an increase of 1% of harvest increases the cost of only 0.3% and seems to indicate the existence of economies of scales in timber harvesting. Moreover, the negative sign of the coefficient associated with the variable PCON indicates that a higher percentage of deciduous trees (the dropped residual variable) increase forest management costs. Across the three models the percentage of non-productive land (PNOP) tends to decrease forest management costs in accordance with the expected lower management activity.

In model (2), the coefficient associated with the variable SASIDE is significantly positive at the 1% level, indicating that the set-aside decision correlates with increased forest management costs. Moreover, our ecosystem services indicators (e.g. for biodiversity and carbon indicators), which are the variables POLDDEC and POLDCON, have a significant impact on management costs: Managing the likely biological richest forest (a forest with a higher percentage of old deciduous trees) tends to be less costly, whereas carbon sequestration through e.g. old coniferous trees seems to correlate with higher cost at forest level. In model (3), the coefficients associated with the cross terms SASIDE × VOL and SASIDE × SIZE are not significantly different from zero at the 10% level. This means we find no interaction between the decision to set aside and timber harvesting or forest size, respectively, in terms of costs.

Thus, the above results suggest that the decision to set aside seems to have an impact on forest management costs. One may wonder whether the structure of technology could differ across owners who have or have not decided to set aside a part of his/her forest property. To do that, we estimated two different cost functions for each of the two sub-samples of forest properties. Table A2 in Appendix presents these estimation results and shows some significant difference between parameters (like those of VOL and SIZE) according to the cost function, but with a lower quality of fit to the data. Several econometric issues deserve to be studied because they could bias the results and the interpretation of a rough cost analysis if not taken into account. First, we found that the decision of setting aside had an impact on management costs in the forest. But we do not know if this decision is correlated with unobserved heterogeneity of owners regarding management of their forests or not. For instance, forest owners can decide to set aside a part of their property because they have no specific means to implement efficient forestry on this parcel. Second, we can think that the decision to set aside could have an impact on the harvested volume of timber if the part of productive forest declared untouched is important for production. We thus could think about two different and switching regimes, reflected in the decision to reserve a part of forest for biodiversity conservation or other non-timber uses or not.

Moreover, forest landowners in our dataset 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 thus propose an econometric analysis based on a household production model to simultaneously identify factors of the choice of setting aside forestland and to measure the impact of this decision on forest management costs. In the following section, we model the preferences of forest owners by deriving a household production model.

3. Econometric strategy for estimating NIPF landowners' decision and its impact on costs

3.1. The model of decision to set aside

As explained above, NIPF owners can voluntary set aside a fixed fraction of their forest property to e.g. conserve biodiversity and/or for carbon sequestration or other non-timber services. We assume that the NIPF owners maximising their utility of choosing 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 and timber prices), 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[7] (i.e., specialisation) 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 implicit utility of the decision to setting aside as:

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

3.2. The econometric strategy

In our econometric analysis, we encounter several econometric problems so that we cannot conduct ordinary least squares regression on different functions separately. First, we have to account for the possibly endogenous nature of the choice of setting aside forest land in order to avoid a problem of selection bias. In fact, setting aside a part of forest could be influenced by past levels of timber harvesting and expected differences in harvesting according to the two regimes (Set-aside vs. No set-aside). Simultaneously, the decision to set aside could

[7] The indirect utility when setting aside a share of forestland may account for the subsidy awarded by the government.

impact timber harvesting. Second, the timber harvest variable can also be a source of endogeneity in the cost function because unobserved cost heterogeneity can interact with harvest levels. Moreover, the nature of the data leads us to model the harvest function as a "corner solution" problem, since a large proportion of the observations are equal to zero (47 out of 136 observations). Following Maddala and Nelson (1975), we use a switching regression model with endogenous switching, in which harvested volume is explicitly estimated as a supply function

Given that U_i^* is unobservable, what we observe is a dummy variable S (=1 if setting aside, 0 otherwise), 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 harvest differences between the two regimes (Set-aside or No set-aside) and other factors:

$$S_i^* = \alpha(H_{1i} - H_{0i}) + \delta W_i + v_i, \qquad (6)$$

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 $(H_{1i} - H_{0i})$ captures the harvest differences between setting aside and no setting aside management.[8] The two different cost functions are defined as:

No set-aside: $H_{0i}^* = \beta_0' X_{0i} + \epsilon_{0i}$ (7)

Set-aside: $H_{1i}^* = \beta_1' X_{1i} + \epsilon_{1i}$ (8)

Equations (7) and (8) constitute standard censored Tobit models, where $H_i = H_i^*$ if $H_i^* > 0$, and $H_i = 0$ otherwise. In our framework where harvested volume is the output in the cost function (1), we have $H_i \equiv \text{clnvol} = \ln(1 + vol)$. X is the vector of explanatory variables and β the associated coefficients to be estimated.

The model to be estimated consists of the set-aside choice (6), harvest equations (7) and (8), and cost function (1).

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

We assume that v_i are correlated with ϵ_{0i} and ε_{1i}, and possibly with the error term u_i of the cost function and that they are distributed as a multivariate normal distribution with mean zero vector and the following covariance matrix:

$$\Sigma = \begin{bmatrix} \sigma_v^2 & \sigma_{v\epsilon_0} & \sigma_{v\epsilon_1} & \sigma_{uv} \\ & \sigma_{\varepsilon_0}^2 & \sigma_{\epsilon_0\epsilon_1} & \sigma_{u\varepsilon_0} \\ & & \sigma_{\epsilon_1}^2 & \sigma_{u\varepsilon_1} \\ & & & \sigma_u^2 \end{bmatrix} \qquad (8)$$

with σ_v^2 set equal to unit, in order to identify γ (probit model). Moreover the correlation parameter $\sigma_{\epsilon_0\epsilon_1}$ is set to zero since sub-samples for equations (7) and (8) do not overlap.

The estimation of the complete model consisting of four equations, which is assumed to have a recursive structure, is estimated in only one step by maximum likelihood, using the Conditional Mixed Process programme (CMP) developed by Roodman (2011).

4. Results

The model to be estimated is a recursive mixed system as it is composed of several equations with different structures along with linear regressions and continuous variables, some being non-linear (such as the set-aside decision which is modelled as a probit), others being censored (i.e., the timber supply functions modelled as standard Tobits). Moreover, our model includes a switching regression since it incorporates two timber supply functions estimated from two subsamples according to the switching rule of setting aside or not. Finally, the model is recursive because some endogenous variables appear on the right-hand sides as observed: the harvested volume (VOL, in log) and the binary decision to set aside (SASIDE) in the cost function. The system is estimated by full-information maximum likelihood method and estimation results are presented in Table 3.

Table 3. Estimation results of the complete model

Equation	Variable	Coefficient	Standard Error
SASIDE			
	INCOME(in log)	0.587*	(0.345)

	SIZE (in log)	-0.161*	(0.0961)
	PCON	2.085***	(0.732)
	PNOP	2.212***	(0.642)
	POLDDEC	0.283	(1.494)
	POLDCON	-1.321	(1.259)
	NGFOREST	-1.071***	(0.356)
	LEARN2	1.029*	(0.602)
	LEARN3	1.538**	(0.622)
	LEARN4	2.874***	(0.745)
	FININVEST2	-1.174*	(0.666)
	FININVEST3	-0.514	(0.506)
	FININVEST4	-0.978*	(0.526)
	PUBRECRE2	-0.358	(0.416)
	PUBRECRE3	-2.548***	(0.747)
	PUBRECRE4	-	
	HUNTINC2	1.352***	(0.466)
	HUNTINC3	0.994*	(0.561)
	HUNTINC4	1.894***	(0.603)
	AGE45-65	-0.698	(0.438)
	AGE65+	-0.805	(0.497)
	EDU2	1.816**	(0.813)
	EDU3	0.923*	(0.555)
	EDU4	0.317	(0.595)
	EDU5	0.770	(0.495)
	Constant	-2.550***	(0.969)
VOL (in log) - No set-aside			
	PRICE (in log)	1.561*	(0.939)
	SIZE (in log)	0.389*	(0.205)
	PCON	2.208	(1.990)
	PNOP	0.792	(2.037)
	POLDDEC	0.00654	(2.575)
	POLDCON	2.199	(2.343)
	DFA	2.162**	(0.894)
	Constant	-10.71*	(5.650)
VOL (in log) – Set-aside			
	PRICE (in log)	0.123	(0.560)
	SIZE (in log)	0.564***	(0.181)
	PCON	2.292*	(1.375)
	PNOP	0.369	(1.262)
	POLDDEC	3.291	(2.517)
	POLDCON	-6.269**	(2.964)
	DFA	2.623***	(0.787)
	Constant	-2.894	(3.519)
COST (in log)			
	SASIDE	2.511***	(0.775)
	VOL (in log)	0.657***	(0.245)
	SIZE (in log)	0.403**	(0.185)
	VOL × VOL	0.162***	(0.0620)
	SIZE × SIZE	-0.0696	(0.0834)
	VOL × SIZE	-0.0215	(0.0402)
	PCON	-4.230***	(1.055)

	PNOP	-1.930**	(0.890)
	POLDDEC	-3.708**	(1.875)
	POLDCON	4.670***	(1.757)
	DFA	-1.810**	(0.784)
	SASIDE × VOL	0.192	(0.167)
	VOL × POLDDEC	0.727*	(0.432)
	VOL × POLDCON	-0.555	(0.459)
	Constant	10.29***	(0.695)
$ln(\sigma_{\varepsilon_0})$	Constant	0.879***	(0.107)
$ln(\sigma_{\varepsilon_1})$	Constant	0.892***	(0.103)
$\ln(\sigma_u)$	Constant	0.856***	(0.114)
$\text{atan}(\sigma_{v\varepsilon_0})$	Constant	-0.280	(0.685)
$\text{atan}(\sigma_{v\varepsilon_1})$	Constant	0.804*	(0.475)
$\text{atan}(\sigma_{uv})$	Constant	-0.501**	(0.249)
$\text{atan}(\sigma_{u\varepsilon_0})$	Constant	-0.0684	(0.252)
$\text{atan}(\sigma_{u\varepsilon_1})$	Constant	-0.860***	(0.224)
Observations		136	
Log likelihood		-640.91	
LR test of overall model fit $\chi^2(52)$		249.80	P=0.0000

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Whereas estimation results of the simultaneous equation model are presented in a whole table, we prefer to discuss each equation in turn and thus discuss results on the set-aside decision to begin, and then the timber harvest and cost functions, for clarity. However, to begin, observing the more general results is useful to assess the relevance of the model. In particular, the significance of several of the correlation coefficients confirms the links between equations, especially concerning unobserved heterogeneity. More specifically, the choice of a switching regression for the timber supply functions is validated by the coefficient $\sigma_{v\varepsilon_1}$ found as significantly different from zero. The size of forest being controlled in the regression, this means that when forest owners decide to set aside a part of their forest, timber harvesting is more intensive or more regular on the part not enrolled in the set-aside program. We also find a negative and significant correlation between the set-aside and cost equations (i.e., the parameter σ_{uv}). This means that the variable SASIDE is endogenous in the cost equation and that there exist unobservable heterogeneity decreasing management costs when a part of forest is set aside. Similarly, there is a negative and significant correlation ($\sigma_{u\varepsilon_1}$) between the disturbances of the harvest equation in Set-aside Regime and the cost equation, leading to conclude that unobserved factors explain lower costs by increasing harvesting when setting aside is adopted.

4.1. The set-aside decision

The upper part of Table 3 presents the probit estimates from the set-aside decision model. Estimation results suggest that besides some forest management and forest property features, the set-aside decision is also influenced by the landowners' socio-economic characteristics, as well as their motivations for owning a forest. Among the landowners' characteristics, we observe that the likelihood of setting aside a share of the property increases with the landowners' income (significant at the 10% level). Moreover, the decision is influenced by the age of the forest owner and his/her education level. Younger forest owners with a lower level of education tend to decide to set aside forest more often than other forest owners.

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 gaining income from hunting, greenery etc. seem to have a higher likelihood of subtracting part of the forest from the timber production compared with respondents who have not expressed these objectives. On the contrary, landowners owning a forest with the greatest interest for a long-term financial investment have a lower likelihood of setting aside compared with respondents who have not expressed this motive. Finally, forest owners assigning 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 increases with the percentage of coniferous trees in the forestland. Interestingly, the probability of setting aside is lower if the forest estate is surrounded by forestland compared to other land uses. The negative sign of the parameter associated with the total size of the forest (in log) owned by the respondents suggests that owners are less likely to set aside forestland if they own a large property, but it is significant only at the 10% level. Finally, we notice that the percentages of old deciduous and coniferous forests have no effect on the set-aside decision and conclude that forests with high potential for biodiversity and carbon sequestration are not the target of forest owners.

4.2. The timber supply and cost functions

Turning to the switching regression of timber harvesting, we find that the price of timber positively increases the timber harvesting in No Set-aside Regime, as expected. Similarly, the size of forest land implies a higher harvesting. We also find that membership of a forest association increases harvesting regardless of the regime. In Set-aside Regime, the size of forest has a significant and positive impact on timber harvesting. Moreover, the significantly positive coefficient associated with the variable PCON shows that harvesting levels are higher in forest with a higher part of coniferous. Also, timber harvesting is lower in forests with a high percentage of old and mature coniferous stands (supposed to be reserved for carbon sequestration). Finally, we find no significant change in harvesting for properties with old deciduous forests.

In the cost equation, we find several significant parameters with the expected sign, such as for the variables VOL, SIZE and VOL × VOL. We also find that a forest with a higher proportion of coniferous trees is less costly than forests where deciduous trees predominate. The same applies for when the percentage of non-productive forest increases, probably because labour is much less important in this part of the forest owner's property. While it was found that deciduous forests generated higher management costs, the significantly negative sign of POLDDEC indicates that costs are decreasing when deciduous trees are old and mature. However, our estimation shows that management costs increase significantly when coniferous trees are old and mature (POLDCON). We also find that costs significantly decrease when the forest owner is a member of a forest association.

The impact of set-aside decision on management costs is tested by directly introducing the variable in the cost equation. We find a positive and highly significant impact on the costs. Moreover, we measure the effect on the marginal cost of harvesting by crossing the variable VOL with the dummy variable SASIDE. The coefficient associated with this new variable is non-significant. This seems to indicate that harvesting and reserving a part of forest for biodiversity and carbon sequestration are independent in terms of management costs. However we find a significant and positive sign for the coefficient of the interaction term VOL × POLDDEC. This result seems to reject the hypothesis of complementarity of costs between timber production and biodiversity conservation, thus meaning the existence of a trade-off between timber and biodiversity.

5. Concluding Discussion

The results from the probit equation showed that the landowners' motivations as well as their socioeconomic characteristics are relevant predictors of their decision of setting aside forest or not for the provision of non-timber services, e.g. biodiversity protection or carbon sequestration. This is consistent with our theoretical model and seems to confirm the hypothesis that NIPF owners are utility-maximisers in a broader sense than implied by the assumption of profit-maximisation (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' decision making (Amacher et al., 2003; Beach et al., 2005).

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

Regarding the forest owner income, we observed a significant and positive relationship with the set-aside decision. This is in line with previous findings in which a negative relationship was found between the likelihood of harvesting and the landowner's income (Hyberg and Holthausen, 1989; Denis, 1989). This suggests that forest owners' utility of providing biodiversity conservation and/or carbon sequestration or enjoying amenity values from set-aside decision, is increasing with their income. 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.

Turning to the production part of the model (i.e., timber supply and cost functions estimation), our results bring new insights on the efficiency of multiple-use forest management and the forest owners' behaviour concerning timber supply. The first important result is the structural difference between the timber supplies according to the type of management (multiple-use vs. specialised management). Our results clearly show a more intensive timber harvesting in the case of specialised management and that is quite independent of price levels. It would seem that when the forest owners are engaged in a program in which they have set aside 5% of their forest land as untouched, then they allow themselves to make more intensive timber harvesting on the remaining lands.

The second important result is that there is a high and significant extra annual overhead cost in specialising a part of forest for biodiversity conservation and carbon sequestration. However, this result is lessened by more intensive harvesting making it possible to exploit scale economies in the case of setting aside. Another result is the absence of interaction between harvesting and specialised management in terms of costs, indicating an equal marginal cost of harvesting whatever the type of management chosen. However, the positive interaction between harvesting and old deciduous forests seems to show the existence of trade-off between timber production and e.g. biodiversity conservation. But, at the same time the greatest gains in biodiversity are connected with old areas with deciduous trees (indigenous to the area). Hence, from a social planner point of view setting aside deciduous forest for biodiversity preservation would be more cost-efficient.

These results can be discussed in light of the debate on specialisation vs. multiple-use management paradigms. In other words, our model seems to suggest that forest management costs are higher in the case of specialised management. Moreover, this type of management seems to correlate with the forest owner harvesting more on remaining forest lands and even independently of timber prices. At the same time, we find an average cost scale elasticity lower than one, making it possible to exploit some economies of scale, and we show that increasing harvest in the case of specialised management reduces overall cost. Apart from these scale economies, our results suggest that forest management costs are generally lower in multiple-use forest management than in specialised management properties. This observation suggests that the additional benefits achieved from specialized relative to multiple-use management should exceed this cost premium, also from the forest owner's utility point of view.

6. Appendix

Table A1. Hedonic price model (dependent variable: Timber price in log)

Variable	Coef.	Std. Err.
SIZE (in log)	0.098	0.071
PDEC	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. *** p<0.01, ** p<0.05, * p<0.1

Table A2. Separated Translog cost function estimations

Variable	Cost (in log) No set-aside	Cost (in log) Set-aside
VOL (in log)	0.701***	0.171*
	(0.211)	(0.0917)
SIZE (in log)	0.285	0.839***
	(0.290)	(0.157)
VOL × VOL	0.314*	0.0901
	(0.163)	(0.0694)
SIZE × SIZE	-0.249	0.00263
	(0.159)	(0.121)
VOL × SIZE	-0.0475	-0.0421
	(0.0801)	(0.0515)
PCON	-3.093**	-2.578**
	(1.516)	(1.060)
PNOP	-1.455	-1.425
	(1.478)	(0.882)
POLDDEC	-3.633	-1.455
	(2.761)	(2.042)
POLDCON	2.254	3.677
	(2.353)	(2.371)
Constant	1.427	2.077***
	(1.017)	(0.697)
Observations	58	78
R-squared	0.522	0.702

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

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