Laboratoire d'Economie Forestière

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Abstract

Forest ecosystem services (FES) provisioning and management in Vietnam is highly rated in the Vietnamese's environmental agenda. The main rationale of private forest management is to maximise profit from timber and non-timber forest products (NTFPs) production. From a social point of view there is an under-supply of positive forest externalities (or non-marketed ecosystem services). The paper contributes to the ecosystem services (ES) literature by assessing the production cost structure, i.e., the cost of marketed production and provision of carbon and biodiversity, based on a survey of private forest owners in the Hoa Binh Province. The econometric analysis is carried out applying a dual cost function approach to analyse the trade-off between forestry costs and ecological performance. This is, to our knowledge, the first time such an approach is applied to estimate the production relationship between marketed outputs and non-marketed ES in the forest sector. This approach appears to be appropriate for handling the multiple joint outputs of production in forest. It allows us to estimate marginal costs and other cost measures such as cost complementarities in production of multiple ES. Our results indicate that there is complementarity in the provision of timber and carbon sequestration and therefore, policies enhancing carbon sequestration in private forest in Vietnam can be implemented without additional costs for the forest owner. We also find that keeping deadwood had no significant cost and was complementary with NTFP, but could increase the marginal cost of producing timber. This means that biodiversity can be enhanced without additional costs on the condition of limited quantity of deadwood.

Keywords: private forest owners, forest ecosystem services, Vietnam, cost function, cost complementarity

JEL codes:

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1. Introduction

Forest ecosystem services (FES) play an important role in forest management and ecosystem services research. This involves the conceptualisation of externalities, methodologies for assessment of their (physical and economic) values and their costs of provision, and the design of policy instruments regulating their supply and demand. FES like carbon sequestration or biodiversity can be seen as public goods associated with forest management[1]. In this paper we are focusing on the positive externalities associated with forest land use and, in particular, addressing the impact of their provision on production costs. Ecosystem services (ES) provided by forests have become increasingly important in recent forest economics literature as a result of forests multifaceted relevance to the society including their global support for climate change protection (Costanza et al., 1997; de Groot et al., 2002). The ecological and economic benefits of these services to society are often still undervalued and the methods for valuation are arguably limited and incomplete. Furthermore, it is a field facing problems of defining ecological functions and services, lack of reliable data, spatial aspects, and multiple scales, which complicate the assessment. Moreover, the link between biological indicators and the costs of supplying ES is still stammering. This is why the development of approaches to the estimation of marginal cost of ES provision is important. We show in this paper that estimation of a cost function based on forest property data may be a powerful tool to analyse the cost structure of multi-output forest management.

Imperfect knowledge concerning the impact of forest management activities, like harvest strategies on the ecosystems and service provision represent an important challenge for ecosystem management (Ninan and Inoue, 2013). However, it is important to understand the jointness in production, i.e. the interdependences in the provision of different ES from the same ecosystem when designing ecosystem management strategies and policies (Peerlings and Polman, 2004; Wossink and Swinton, 2007; Hodge, 2008; OECD, 2001; Ruijs et al 2015). Knowledge of the cost structure offers the basis for setting efficient targets for provision of externalities and for cost effective management strategies to meet such targets. Furthermore, the design of appropriate policy instruments, including market-based instruments, relies on an understanding of the factors having an impact on cost of provision (Robert and Stenger 2013). There are very few empirical studies investigating the cost of provision of FES.

Vietnam has undergone a transition from net deforestation to net reforestation. In 1943, under the French colonial administration, the national forest cover was very low. After a couple of decades of separation, the country was unified in 1975, but the forest cover decreased to 33.8% in 1976 (Lambini and Nguyen 2014). This trend had continued until 1990 when the forest cover reached its lowest level of 27.8% (Wil et al. 2006). During the period 1980–1995, Vietnam lost approximately 110,000 ha of natural forests annually (Nguyen et al. 2010). In addition to the loss in forest areas (i.e.,

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[1] In this paper, we use the terms ecosystem services, amenities, environmental services, and externalities interchangeably.

deforestation), forest quality also decreased (i.e., forest degradation). The forest area with rich and medium timber stock had declined while the area with poor stock (timber volume less than 80 m3/ha) had rapidly increased and reached 7 million ha in 1990. Due to the steep terrain in most forest areas and concentration of rainfall in summer, poor forest sites were further degraded because of water and soil erosion (Vu et al. 2014).

FES provisioning and management in Vietnam is highly rated in the Vietnamese's environmental agenda. For example, several private afforestation programs and programs for transition of forest ownership have been implemented. The Forest Protection and Development Plan for the period 2011-2020 include targets on afforestation, regeneration and improvement of quality of natural forests (FSDR, 2013). The main objective of the public forest programmes is to increase profits in timber and non-timber forest products (NTFPs) production. However, at the same time the supply of non-marketed FES are considered lower than the social optimum. Therefore, an assessment of the provision cost of (marketed and non-marketed) FES provides important information for policy makers designing forest regulation and subsidy schemes.

This paper seeks to assess the production structure of FES based on a survey of forest owners in the Hoa Binh Province. The empirical estimation of the production structure is carried out applying a dual cost function approach, which appears to be appropriate for handling the multiple joint output production in forests. In our paper, we quantify the cost of FES by the estimation of the marginal cost of service provision and assess potential complementarity or competitivity relationship between timber, NTFPs, number of deadwoods in the forests, and forest carbon storage.

This article seeks to fill several research gaps: (1) contributing to forest economics literature by assessing the production cost structure, i.e. the cost of marketed goods (timber, non-timber forest products) and non-marketed goods (biodiversity, carbon storage) with data from the Hoa Binh Province in Vietnam; (2) developing and estimating a cost function where market and non-marketed goods are modelled as joint outputs; and (3) suggesting important policy implications for cost efficient FES provision by accounting for cost synergies or competitivity between these outputs. While cost function approach has been proven useful in analysing multiple output technologies, and used in the analysis of joint production in agriculture (Nilsson, 2009; Gullstrand et al 2014) this study is first application in the analysis of joint production of market and non-market services in forestry.

The paper is organised as follows. After this introduction, section 2 reviews the literature relevant on FES cost drivers and variables that influence supply of multiple outputs. Section 3 focuses on theoretical cost function framework relevant to the study. Section 4 presents and describes the empirical model specification for the cost estimation, as well as introduces the study design and presents the data. Econometric results are presented in section 5. Section 6 concludes and gives recommendation for the design of PES schemes in forest and the sustainable supply of FES in Vietnam.

2. A brief review of literature about costs of ecosystem service provision

Assessments of the costs of provision of FES have mostly been based on so-called engineering approach (Mäntymaa et al. 2014), where the costs of provision are based on the opportunity cost of restrictions on timber production (Olschewski and Benítez 2010**;** Ahtikoski et al. 2011).

Household models where forest management is integrated with the forest owners' consumption decisions have also been addressing the production of amenity values (Newman and Wear 1993; Pattanayak et al. 2002). However, the objective of these studies have focused on the impact of amenity consumption by the household on the forest management decisions.

There exists a relative large forest economic literature applying cost function models (Cubbage et al., 1989, Bauch et al. 2007) but few of these models are dealing with the joint production of FES (Hof et al., 1985; Bowes and Krutilla, 1989**;** Misra and Kant, 2005). Hof et al. (1985) and Misra and Kant (2005) apply linear programming to estimate shadow prices of non-marketed output based on a cost minimisation model and output distance function, respectively. While econometric estimation of cost functions which also include non-marketed good and services are non-existent in forestry they have been applied in agriculture to analyse the joint production of milk, beef, and biodiversity (Gullstrand et al. 2014) and joint production of agricultural products and biodiversity (Nilsson 2009). One limitation of cost function estimation is the lack of adequate data, specifically difficult to gather in forestry, because of the length of production process and unequal operation costs during the time (Petucco, 2014). Another limitation is related to outputs and the difficulty to use a "good" measure of ES. However, these limitations relate also other empirical approaches to the analysis of joint production.

The costs of FES provision are affected by various factors. These factors include: firstly, the physical characteristics of the forest (soil quality, climate, slope, tree species etc.), secondly, the spatial characteristics, thirdly, the management characteristics of the forest owner. Concerning the physical characteristics, Wear (1994) elucidates that the physical description of the forest, i.e. forest type and age distributions are important features to take into econometric estimation of production and cost functions. The size of forest and its location to urban areas influences also the production structure. For example, Lien et al. (2007) find that forest properties in a typically rurally located area had a higher efficiency level than those properties located close to urban areas. Naidoo and Ricketts (2006) emphasize that the significantly spatial heterogeneity in provision of ES may be due to physical characteristics of the ecosystems such as slope and soil type. Ownership may also influence the production efficiency. Siry and Newman (2001) find in a study of Polish forest districts that privatisation of timber harvest may increase productivity and Newman and Wear (1993) estimate restricted profit functions for Non-Industrial Private Forest Owner (NIPF) and industrial owners and find evidence that NIPF owners account for amenity values. Forest management plans are an important component of the administrative cost and could increase the cost of the forest owner even though a plan also increases technical efficiency and therefore also reduces long term costs (Lien et al. 2007).

The characteristics of Non-Industrial Private Forest NIPF) owners are a key feature in the cost estimation since they are often key stakeholders in externality provisioning and several studies has shown that forest owner or household characteristics may impact management significantly. Lien et al. (2007) find in the study of Norwegian forest owners that off-property wage income and income from on-property outfield activities such as recreational services and hunting lead to decreased technical efficiency, while properties combining forestry and agriculture (i.e., properties where income from agriculture is high) have a higher technical efficiency in timber harvesting. Characteristics of the owners, e.g. age and experience, have been shown to be significant determinants of efficiency (Carter and Cubbage, 1995, Lien et al., 2007). Misra and Kant (2005) include variables describing knowledge and decision making processes in joint forest management in Gujarat, India, applying an output distance function approach to explain cost of provision.

The present study estimates econometrically a cost function to analyse the joint production of FES in Vietnam private forests. As explained in the next section, this approach allows us to derive directly from the estimated model conclusions about the degree of complementarity between different FES.

3. Modelling cost of provision of ES

A way to describe the joint production (or production “technology”) of ES is to use a cost function approach. As expressed by McFadden (1978), the cost function is a “sufficient statistics” for the technology since all economically relevant information about the technology can be gleaned by the cost function (principle of duality). The objective is thus to estimate the costs forest owners incur in providing FES as a function of outputs, input prices, and fixed input variables.

For this purpose, the forest is considered as a production process with several outputs where some may be positive externalities (e.g., biodiversity conservation, carbon sequestration), i.e., they are non-market goods or services and the owner is not remunerated for provision of these positive externalities. The provision of these different outputs (market and non-market goods and services) is typically considered as joint production and this is further seen in the literature on multifunctional agriculture (Lankoski and Ollikainen 2003). The relationship between multiple outputs depend on the impact of several sources: technical interdependency in the production process, output produced from fixed non-allocable inputs, and outputs competing for an allocable input fixed at the firm level (Hodge, 2008, Shumway et al. 1984). Several studies have recently considered joint production of market goods and amenities in agriculture (Peerlings and Polman 2004, Nilsson 2009, Gullstrand et al. 2014; Ruijs et al. 2015), or in agroforestry (Ofori-Bah and Asafu-Adjaye 2011).

In this section, we show how production analysis can help us to estimate cost of externality provision by the use of a cost function. A cost function describes the minimum costs of production for a given output, i.e. we assume that forest owners are cost-minimizing. We apply a cost function approach as it has several advantages compared to a production function or profit function approach. First, it is quite straightforward to include more than one output and to derive cost elasticities and the single output's marginal costs (Greene, 2008). A second advantage is that it can take into account the joint production relationship between marketed ES such as timber and non-marketed ES on the one hand, and also different ES on the other hand. It is relatively easy to perform statistical test of whether services are competitive or complementary. Third, the estimation of a cost function is often more tractable and needs fewer hypotheses than estimating the profit function.

A cost model for private forest owners

A forest land produces a vector of outputs $Y \geq 0$ (including harvested timber H and amenities A provided by the forest). The production process uses several variable inputs X and quasi-fixed inputs K (including forestland F and growing stock of trees S). We assume that forest owners have access to the same technology. As each forest owner faces a different production environment, several dummy variables such as the type of management or a specific regulation are considered as drivers of costs. All these variables are included in the vector Z. The technology is thus described by the following multi-output transformation function:

$$T(Y_t, X_t, K_t, Z_t) = 0, \tag{1}$$

where t is the time index. The dynamics of forest resource obeys the following equation:

$$S_t = S_{t-1} + G(S_{t-1} - H_{t-1}) - H_{t-1}, \tag{2}$$

where G is the natural growth function of the stock of trees.

The minimization of long-run costs (that takes intertemporal decisions into account) leads to a long-run cost function, which (perfectly) describes the multiple-output production. Given that we only have cross-sectional data for our empirical application, and following Wear and Newman (1991) and Newman and Wear (1993), we simply consider a (restricted) short-run cost function.[2]

The short-run cost function can be derived from the minimization of variable costs, which represents the expenditures E incurred by the forest owner, conditional to the technology and fixed and quasi-fixed input:

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[2] This short-run cost function will be estimates without bias on the condition that we have sufficient information on the capital structure of the forest (e.g., size, age, composition).

$$C(Y, W, K, Z) = \min_{X \geq 0} \{E = W'X \mid T(Y, X, K, Z) = 0\}\,, \tag{3}$$

where the vector of (positive) input prices is referred as to $W \gg 0$, and T () is the set of technology used by the private forest owners. It is also assumed that the cost function is non-negative and non-decreasing in $Y \geq 0$ and $W \gg 0$. The cost function is also homogeneous of degree one, concave and continuous with respect to W. We concentrate here on the conditional, variable cost function $VC(Y, W, K, Z)$.

The short-run cost function satisfies the same properties as the long-run cost function. However, it has to verify the additional property that it is non increasing in K. Furthermore, fixed inputs do not necessarily achieve cost minimization. Hence, the long-run total cost function can be recovered from the short-run cost function only if the latter is minimized with respect to K. Hence, first-order conditions for long-run cost minimization are satisfied if:

$$\frac{\partial VC(Y, W, K, Z)}{\partial K^*} = -w_K \tag{4}$$

where K^* is the optimal level of capital, and w_K its price. This condition can be used to test the good adequacy of forest capital to forest management. We may thus conclude that if this is not the case, i.e., if $\frac{\partial VC(Y,W,K,Z)}{\partial K^*} > -w_K$ or $\frac{\partial VC(Y,W,K,Z)}{\partial K^*} > 0$, then the forest management does not use all the capacity, e.g. forest land.

From the short-run cost function or the variable cost function, the marginal cost is given by $MC_y = \frac{\partial VC(Y,W,K,Z)}{\partial y}$, where y is an output belonging to Y. We can imagine differences in marginal costs according to different forest properties. Indeed, private forest owners’ production of a non-optimal level of timber and hence differences in efficiency between them may lead to differences in marginal costs. Also, the importance of asset fixity (or fixed factors and inputs) in the forestry sector implies that a forest area may face a corner solution due to capacity restrictions, heterogeneous private forest owners produce with different marginal costs.

An important objective of our study is to assess cost complementarities and trade-offs between the provision of different ES. The cost function, the estimated technological parameters and marginal costs make it possible to carry out a comprehensive analysis of the effect of outputs’ quantity levels (i.e., FES levels) on costs of forest management. According to Panzar (1989), (weak) cost complementarities between two outputs y_i and y_j are defined as:

$$\frac{\partial VC^2(Y, W, K, Z)}{\partial y_i \partial y_j} \leq 0. \tag{5}$$

Moreover, if a multiproduct cost function exhibits cost complementarities then economies of scope exist. This definition of cost complementarity will be used to investigate the concept of jointness in ES production as in Gullstrand et al. (2014).

4. Empirical application: Materiel and method

The translog specification

The choice of which functional form should be employed for estimating the cost function depends on several factors such as data availability, assumptions of firm's behaviour, and the purpose of the study. We chose a translog functional form (see Christensen et al. 1971, 1973) for the variable cost function. It is a second-order series Taylor approximation of the cost (in logs) with respect to explanatory variables (in logs). Its first advantage is that it imposes few restrictions a priori on the characteristics of the technology, so that it is considered as a flexible functional form. Second, it permits the direct estimation of price elasticities as well as cost elasticities, and thus economies of scale and other cost measures such as cost complementarities. Moreover, ecosystem services (joint outputs) are complex due to their high non-linear relationships hence a nonlinear specification of the cost function might have merit, and this in turn raises the question of what type of nonlinear representation of the cost equation might be appropriate. The translog approximation (without dummy variables Z) is:

$$\begin{aligned} \ln(VC) = \alpha_0 &+ \sum_i \alpha_i \ln(Y_i) + \sum_j \beta_j \ln(W_j) + \sum_k \gamma_k \ln(K_k) + \frac{1}{2}\sum_i \sum_{i'} \alpha_{ii'} \ln(Y_i)\ln(Y_{i'}) \\ &+ \frac{1}{2}\sum_j \sum_{j'} \beta_{jj'} \ln(W_j)\ln(W_{j'}) + \frac{1}{2}\sum_k \sum_{k'} \gamma_{kk'} \ln(K_k)\ln(K_{k'}) \\ &+ \sum_i \sum_j \delta_{ij} \ln(Y_i)\ln(W_j) + \sum_i \sum_k \eta_{ik} \ln(Y_i)\ln(K_k) \\ &+ \sum_j \sum_k \theta_{jk} \ln(W_j)\ln(K_k) \end{aligned} \tag{6}$$

The parameters to be estimated are: $\alpha_0, \alpha_i, \beta_j, \gamma_k, \alpha_{ii'}, \beta_{jj'}, \gamma_{kk'}, \delta_{ij}, \eta_{ik}, \theta_{jk}$.

The econometric model

The variable cost function under a translog form to be estimated can be simply written as:

$$\ln(VC_n) = \ln VC(Y_n, W_n, K_n, Z_n) + \varepsilon_{n,} \tag{7}$$

with the error term $\varepsilon_n \sim iid(0, \sigma_v^2)$. This model can be estimated using classical econometric techniques such as ordinary least squares method or the maximum likelihood estimation method (with the additional assumption of normality distribution of errors).

Study design: Study sites and data collection

The study was conducted in the Hoa Binh Watershed in North-Western Ecological Zone of Vietnam. The zone is characterised by the Da river upstream, river valley and hilly terrain within the low land district valley. The two sampled study districts sites in the catchment include Cao Phong (Binh Thanh village) and Dabac (Vay Nua village) located in the Reservoir on the Da River which is about 75 km west of Hanoi, Vietnam. The Da River flows from China via Vietnam to the East Sea. The length of the river in Vietnam's territory is 493 km. The total surface area of the Da River Watershed is nearly 2.6 million ha in five provinces, namely Dien Bien, Lai Chau, Yen Bai, Son La, and Hoa Binh . The climate of the sites is tropical monsoon with an average annual temperature from 22.5 to 23.2 °C. Annual precipitation ranges from 1300 to 2200 mm of which about 85% occur from May to September. The topography is complex with elevations from 300 to more than 2000 m above sea level.

There are different land uses in the province. Grass and shrub lands cover the largest share of the total land area, followed by forests which include natural forests and plantations. Other land uses in the watershed include residential area, water surface, rocky mountain, agricultural cropland and other land uses.

Data collection and survey protocol followed two approaches. The first component was to collect data on cost of forest management and socio-economic characteristics of the private forest owners in the selected districts of the watershed area. A questionnaire was designed and pre-tested with research assistants from the Vietnam Forestry University. In total, 180 private forest owners were interviewed face-to-face. The survey was carried out based on recommendations from the Hoa Binh Provincial Forest Protection Department (PFPD) and the Da River Forest Protection Association. The sample was restricted to only active private forest owners who have at least >0.5 ha forest land. The variables considered in this component included physical features of the forest (forest size, age, origin, type), management characteristics (forest composition, management style, ownership objective, harvesting practices, decision making), spatial issues (plot number and size, continuous property, distance to forest), variable and fixed inputs costs to estimate the total cost included (e.g. cost of management-planting, seeds, fertilisers, thinning, harvesting, labour cost, administrative cost, land tax, machines and equipment etc.). Socio-economic and demographic data on the household included, among others, ethnic group, marital status, household membership, sex, age, occupation, and income sources.

The other relevant data for the study was on FES Output Assessment Indicators. These data is collected based on several years of ES quantifications by the Vietnam Forestry University (Pham, 2009, 2011, Nguyen et al, 2013) and in close partnership with Hoa Binh Provincial Forest Protection Department (PFPD). The ES indicators considered for this study included (NTFPs diversity in the forest/ha, above and below ground carbon/tc/ha and quantity of deadwood/ha). These ES indicators were used as output variables in the cost model estimates.

Data

Data are described in table 1. The cost variables are obtained from interviewed forest owners who stated total direct costs associated with managing their forest. Two types of main costs were requested. The first ones concern cost information on the current management practices (referred as to $Curcost$). This includes direct costs of planting, stand treatments, thinning, harvesting, transporting, and road maintenance during the last five years. The cost estimate does not include costs of land and opportunity cost of household labor. Instead, we have included the variables $forha$ and *work*, representing forest size and hours that the household members have spent working in the forest, respectively. The second type of information requested concerns added costs for biodiversity conservation and carbon sequestration (referred to as $Addcost$), related to actions to avoid clearcutting or even-aged timber harvesting, change from exotic to native species, reduce NTFP collection, restoration of barren lands, denuded hills and degraded natural forest areas. Total costs are the sum of these two types of costs and referred to as $Totcost$.

The output variables considered include harvested timber volume, $timb$ and, the carbon stock (in standing timber and in soils), $carb$. The total carbon stock is the function of the above ground biomass *(agb*) and below ground biomass (*bgb*). The *agb* are estimated from the allometric equations (*ae*) that are developed based on the type of forest and management conditions as proposed by Chave et.al. 2005. The allometric equations include some measurable variables, such as, diameter at breast height (*dbh*), Height (*h*) and wood density (*wd*). The below ground biomass are estimated based on above ground biomass by using the linear function equation (Chave et.al. 2005) using the root/shoot ratio. The total carbon stock are then calculated from *agb* and *bgb* by using the default carbon fraction provided by IPCC from 0.47 – 0.50 (IPCC, 2006).

Two indicators of biodiversity as outputs are also included. The first is the number different non-timber forest products harvested in the forest, $NTFP$, and the second the number of dead trees in the forest $deadw$.

As the main variable input price, we have the labor price as the wage of hired labour ($wage$). We have no data on the growing stock of trees. However, different information can be used to describe the structure of the forest, such as the age of forest stands ($forage$), the type of forest (e.g., production, protected, special use), and the forest management composition (even-aged forest, uneven aged-forest, clear cut). We also use a variable for forest ownership objectives characterising other objectives than forest investment and revenue ($OtherObj$), such as emotional values (family heritage and connection to nature or ecosystem services conservation). Forest owners with this kind of objectives represent only 9% of the sample, but could have an impact on the cost-minimizing behaviour. For the econometric analysis, we used all 180 questionnaires.

Table 1. Descriptive statistics (180 observations)

Variable	Definition	Mean	Std. Dev.	Min	Max
Curcost	Costs of forest current management (Dong/5 years)	9,460,294	6,447,055	2,400,000	53,032,700
Addcost (not directly used in the translog)	Additional cost of biodiversity conservation and carbon sequestration (Dong/5 years)	19,542,556	9,606,858	0	70,200,000
Totcost	Total costs (curcost + addcost) (Dong/5 years)	29,002,849	13,355,617	5,311,912	87,229,340
timb	Harvested timber volume (m3/year)	81.1	33.5	24	190
deadw	Number of dead trees	9.1	4.2	1	23
NTFP	Number of non-timber forest products species (total number of different NTFP species/ha/yr)	4.4	1.2	2	7
carb	Carbon stock in the forest property (tC/ha)	66.2	55.8	2.4	254.8
wage	Hired wage (Dong/Hlabour/forha/5 years)	752,158	949,822	144,761	9,850,550
work	Domestic work (hour/year)	1,021	856	30	3,024
forha	Forest size (ha)	7.5	3.4	1	16
forage	Forest age (year)	9.6	3.1	2	16
OtherObj (dummy)	=1 if forest ownership if for other objectives than forest investment or revenue	0.09	0.29	0	1
<u>Type of forest</u>					
Production (dummy)		0.43	0.50	0	1
Protected (dummy)		0.32	0.47	0	1

Special-use (dummy)	Cultural, historical and educational conserved forest sites	0.16	0.36	0	1
Other-type (dummy)		0.09	0.29	0	1
Forest composition management					
Evenaged (dummy)		0.24	0.43	0	1
Unevenaged (dummy)		0.38	0.49	0	1
Clearcut (dummy)		0.34	0.47	0	1
Others (dummy)		0.04	0.19	0	1

5. Results

All variables (except the dummies) in the cost function are first logarithmically transformed and then mean-scaled. The estimated coefficients can therefore be interpreted as elasticities at the sample mean values.

We display several estimated models. Estimation results from a Cobb-Douglas cost function specification are first presented in Table 2, and then from a translog specification are described in Table 3.

Table 2. Estimation results - Cobb-Douglas specification

	Model 1			Model 2		
	(dep. variable: Curcost)			(dep. variable: Totcost)		
Variable	Estimate	Std. Err.		Estimate	Std. Err.	
constant	15.8650	0.0480	***	17.0919	0.0466	***

timb	0.1107	0.0727		0.4582	0.0706	***
NTFP	0.3949	0.1138	***	0.4268	0.1105	***
deadw	0.1196	0.0788		0.0861	0.0765	
carb	-0.0271	0.0438		-0.0153	0.0425	
wage	0.4417	0.0421	***	0.2459	0.0409	***
work	-0.0083	0.0381		-0.1473	0.0370	***
forha	0.0679	0.0705		0.0414	0.0685	
forage	0.0700	0.0854		0.0151	0.0829	
Other obj	0.1968	0.1033	†	-0.0295	0.1003	
(ref.: clearcut)	--	--		--	--	
evenaged	-0.0052	0.0753		-0.1671	0.0731	*
unevenaged	0.0153	0.0665		-0.0751	0.0646	
(ref.: production)	--	--		--	--	
Protected	0.0336	0.0693		0.0461	0.0671	
Special-use	-0.0391	0.0897		0.1440	0.0869	†
Other-type	0.1816	0.1099		0.1774	0.1065	†
Adj. R^2	0.4735			0.4237		
AIC	180.35			168.83		
BIC	231.44			219.91		

Notes: †,*, **, and *** for significance level 10 %, 5 %, 1 % and 0.1%, respectively.

We first estimated two competitive Cobb-Douglas cost functions according to the cost variables used as dependent variables. Indeed, we have wondered whether all stated costs could be used as such, and compared two different dependent variables: the first one being the current forest management costs ($Curcost$) and the second one ($Totcost$) summing current management costs and costs incurred for biodiversity conservation and carbon sequestration

Model 1 and Model 2 show estimation results with all of outputs (i.e., timber harvests, NTFP, deadwood and carbon), input price (i.e., wage) and capital variables (including domestic work, forest size and forest age). We augmented this regression with binary variables giving information on the forest stand management (i.e., clear-cut, even-aged or uneven-aged), the type of forest (production, protected or for special use),[3] and a dummy variable characterising the objectives of forest ownership. This latter has a small but significant effect in the regression of current costs (Model 1) and none in Model 2. Moreover, based on a Likelihood Ratio (LR) test giving a statistic value of 12.112 and a p-value of 0.033, we conclude that forest type and forest stand management have both an impact on total costs (Model 2); whereas we found no significant effect on current costs (Model 1). Estimation results indicate that even-aged forests are significantly less costly than clear-cutting management and that production forests are less costly than all other types of forests (but the difference with protected forests is not significant). Looking at the significance of variables, Model 2 seems to fit the data better than Model 1, but its adjusted R^2 is lower. To choose the best model, we use AIC and BIC criterions, which with lower values both allow to conclude in favour of Model 2. This indicates that our multi-output cost model that accounts for all forest management costs, including those for biodiversity and carbon production; is the best to describe the data. This may be not that surprising as Model 2 also includes cost directly related to production of biodiversity and carbon storage which may depend on the explanatory variables related to type forest and the management objectives.

From estimation results of Model 2, we found that timber and NTFP outputs have a significant (positive) impact on variable costs at the 0.1% level. Their estimated coefficients show cost elasticities of output equal to 0.46 and 0.43, respectively. A cost elasticity of timber equal to 0.46 means that a 10% increase of timber harvesting leads to an increase of cost of only 4.6%. Instead, we found no impact of production of deadwood and carbon on costs. We also found that wage variable is significantly positive at the 0.1% level, as expected. The coefficient associated with fixed domestic work is highly significantly negative. From eq. (4), this result does not allow us to reject the good adequacy of domestic human capital to forest management. Finally, both proxy variables for the forest capital and its structure (i.e., size and age) are found non-significant in this cost function.

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[3] Other variables describing the forest have been tested, such as the origin of the forest (e.g., plantation, natural regeneration forest, agricultural land) but found to have no impact on costs.

Table 3. Estimation results – Translog specification

	Model 1			Model 2			Model 3		
Variable	Estimate	Std. Err.		Estimate	Std. Err.		Estimate	Std. Err.	
constant	16.9639	0.0601	***	17.0281	0.0663	***	16.9845	0.0760	***
timb	0.3776	0.0779	***	0.4059	0.0768	***	0.3955	0.0788	***
NTFP	0.5389	0.1131	***	0.5366	0.1108	***	0.5022	0.1135	***
deadw	0.0697	0.0921		0.0704	0.0902		0.0676	0.0911	
carb	-0.0283	0.0421		-0.0288	0.0415		-0.0330	0.0416	
wage	0.2033	0.0453	***	0.1888	0.0447	***	0.1739	0.0454	***
work	-0.1251	0.0458	**	-0.1480	0.0456	**	-0.1325	0.0474	**
forha	0.1538	0.0840	†	0.1558	0.0822	†	0.1514	0.0823	†
forage	0.0841	0.0892		0.0854	0.0873		0.0824	0.0876	
timb*timb	-0.6535	0.2795	*	-0.5421	0.2767	†	-0.5075	0.2792	†
NTFP* NTFP	1.9381	0.6051	**	2.1383	0.5960	***	2.2114	0.6068	***
deadw*deadw	0.0542	0.1492		0.0731	0.1465		0.0724	0.1467	
carb*carb	-0.0412	0.0581		-0.0080	0.0582		0.0089	0.0596	
wage*wage	0.0683	0.0676		0.1021	0.0672		0.1060	0.0673	
work*work	0.0624	0.0485		0.0421	0.0480		0.0560	0.0486	
forha*forha	0.2507	0.1187	*	0.2066	0.1178	†	0.1783	0.1188	
forage*forage	0.1082	0.2352		0.1443	0.2309		0.1223	0.2328	
timb* NTFP	0.4272	0.3200		0.2253	0.3205		0.1821	0.3261	
timb*deadw	0.2314	0.1558		0.2566	0.1530	†	0.2214	0.1542	
timb*carb	-0.0933	0.0746		-0.1228	0.0737	†	-0.1252	0.0738	†
NTFP *deadw	-0.6328	0.2964	*	-0.6580	0.2904	*	-0.6597	0.2918	*
NTFP *carb	0.0295	0.1191		0.0106	0.1169		0.0051	0.1189	
deadw*carb	0.0498	0.0704		0.0629	0.0694		0.0625	0.0695	
(ref.: clearcut)									
evenaged				-0.2257	0.0756	**	-0.2066	0.0764	**

unevenaged			-0.0860	0.0626	-0.0787	0.0627
(ref.: production)						
Protected					-0.0136	0.0658
Special-use					0.0938	0.0869
Other-type					0.1450	0.1048
Adjusted R^2	0.463		0.4857		0.487	
AIC	163.19		157.09		159.10	
BIC	239.81		240.11		251.70	
LR test (CD vs. Translog)	33.84*** (0.0022)					
LR test (Forest composition)			10.08*** (0.0065)			
LR test (Forest type)					3.99 (0.2626)	

Notes: †,*, **, and *** for significance level 10 %, 5 %, 1 % and 0.1%, respectively. P-values of tests in brackets.

A LR test allowing comparison between the translog cost function (see Table 3) and the Cobb-Douglas specification (See Table 2), showed that the translog was a better specification than the former, with a statistic value of 33.84 and a p-value of 0.0022. In this study, our multiple-output cost function had no zero values for joint outputs enhancing the appropriateness and robustness of the use of translog specification strategy. Furthermore, using the translog cost function specification in the paper as an alternative cost-benchmarking provides more flexibility and better reflect the characteristics of the forest production.

We then used LR tests applying a backward strategy by testing if variables from a general model including management and forest type variables could be removed without reducing fit. Whereas variables proxying management composition are found to have a significant impact on costs, the null hypothesis of joint nullity of coefficients associated with forest type variables cannot be rejected, so that Model 3 is found less good than Model 2. Finally, we tested interaction terms from other variables (i.e., wage and capital variables), but none of null hypotheses has been rejected by LR tests.[4] These tests further confirm robustness of our model estimates since it requires both the restricted and unrestricted estimates of parameters. Hence correct cost inferences on outputs can be realised since our paper presents an estimated cost model that adequately, significantly and better fits the data. Hence, we'll comment only on the estimation results of Model 2.

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[4] We implemented different LR tests from each variable X crossed with all the other ones, so that we test the null hypothesis: $X \times timb = X \times NTFP = X \times deadw = X \times carb = X \times wage = X \times work = X \times forha = X \times forage = 0$. All results are available from authors upon request.

Compared to estimates from a Cobb-Douglas specification, we now find a significant and positive coefficient associated to the size of forest property, considered here as the main capital in the forest "technology". From equation (4), we saw that a necessary condition for the forest owner program to correspond to long-run cost minimization was a negative marginal cost with respect to capital. We may then conclude that as this is not the case, then there is capital over-investment. In other words, estimates of cost elasticities with respect to $forha$ being positive, this suggests that forest properties at the sample mean are characterized by an excessive size of forest.

Focusing now on second-order (interaction) terms, we have several interesting results. First, we find a negative coefficient of the squared term of $timb$, meaning that the marginal cost of timber harvesting is decreasing with increasing volume of timber. Instead, the positive sign of the coefficient of the squared term of $NTFP$ indicates that its marginal cost of production is increasing with the number of non-timber forest products species found on one ha of forest.

Concerning cost complementarities between outputs, we find three significant relationships between outputs. We use the marginal cost of outputs in order to investigate the concept of jointness in production as discussed above in equation (5). The coefficients of timb*carb and NTFP *deadw are significantly negative, suggesting the marginal cost of timber harvesting decreases when the amount of carbon sequestration increases (i.e., complementarity between timber and carbon), and even for the marginal cost of NTFP with respect to number of deadwood, also meaning output complementarity. The positive sign of the coefficient associated with timb*deadw seems to indicate competitivity between timber production and presence of deadwoods. All these results are summarized in Table 4.

Table 4. Jointness in FES production

	Estimate		Standard Error	Confidence interval 2.5%	97.5%
timb*NTFP	0.4431		0.3286	-0.2010	1.0872
timb*deadw	0.2852	*	0.1543	-0.0171	0.5876
timb*carb	-0.1345	*	0.0778	-0.2869	0.0179
NTFP*deadw	-0.6202	**	0.2937	-1.1958	-0.0447
NTFP*carb	-0.0048		0.1193	-0.2387	0.2290
deadw*carb	0.0608		0.0691	-0.0745	0.1962

Notes: Estimates based on the coefficients of Model 2 in Table 3.

Standard errors are computed with the delta method.
$***$ Significant at 1%, $**$ at 5%, $*$ at 10%.

6. Discussion

Private forests in the Hoa Binh Province provide multiple ecosystem services. These include, among others, timber and non-timber products, carbon sequestration, and biodiversity. We show that using data from a face-to-face survey and a cost-function approach it is possible to get relevant insights into the cost structure of provision of multiple outputs from private forests in Vietnam. The results indicate that carbon sequestration in the forest is a complementary production of timber harvesting. This indicates that production-oriented forests may not have negative impact on carbon storage.

We find that the cost of keeping more deadwood had no significant cost but that keeping deadwood had a negative effect on the marginal cost of NTFP and a positive effect on the marginal cost of producing timber. One may imagine that keeping some deadwood have no significant costs as some wood is damaged during harvest and has therefore no value. However, if a larger amount of timber is kept, also valuable timber is kept and may therefore represent a significant cost.

One of the limits of the present study is the rather coarse proxies used to represent the growing timber stock in the forests (i.e., the forest age and size). While forest management is a long-term investment and represents a dynamic optimisation problem where the standing stock is an important variable influencing decisions and costs, the stand age is not directly correlated with standing stock. This may also explain that the forest age variable (forage) was not statistical significant We have compared different specifications of the cost functions, i.e. Cobb-Douglas and translog specifications, as well as different assumptions about fixed costs and other potential determinants of the cost structure. This allows us also to assess the robustness of our results. We find over all models the cost elasticity was significant positive for timber and non-timber outputs while carbon storage and deadwood had no impact on cost in any of the five models estimated.

We can conclude that policies enhancing carbon storage can be implemented without additional costs for the forest owner. However, it should be noted that our results only apply within the range of carbon sequestration experienced today by forest owners. More drastic policies which imply huge increases in carbon storage will probably imply new management practices which are not observed today among forest owners. Such policies cannot be evaluated based on our results.

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