The cost of provision of forest ecosystem services: An econometric analysis from private forests in Vietnam.

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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 by timber and non-timber forest products (NTFPs) production. From a social point of view there is an under-supply of positive forest externalities (non-marketed ecosystem services). The paper contributes to ecosystem services (ES) literature by assessing the production cost structure, i.e., the cost of timber production and provision of other ES, based on a survey of private forest owners in the Hoa Binh Province. The econometric analysis of the production structure 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 forest. This approach appears to be appropriate for handling the multiple joint outputs production in forest and substitution possibilities between forestry inputs. 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 seems to be cost efficient and may not conflict with timber production objectives. **Keywords: Dual cost function, private forest owners, forest ecosystem services, Vietnam**

1. Introduction

Forest ecosystem services (FES) play an important role in forest management and 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 timber production, 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 the provision of positive forest externalities on production cost. 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 evaluation 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 restimation 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 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 services from the same ecosystem when designing ecosystem management strategies and policies (Peerlings and Polman, 2004; Wossink and Swinton, 2007; Hodge, 2008; OECD, 2001). 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 forest ecosystem services. One reason The essential reason is due to specificities of forestry technologies. Forestry production is characterised by a very long production process (from 20 years to more than 100 years) and unequal operation costs during the time (Petucco, 2014). Accounting for the capital structure of forestry production is crucial, with forest land and (growing) stock of trees as the major quasi-fixed inputs (Wear and Newman, 1991; Newman and Wear, 1994). This implies different

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

technical difficulties to estimate the growth dynamics and the intertemporal decision for a forest owner, in particular due to the lack of adequate data, specifically difficult to gather in forestry. Another limitation is related to outputs and the difficulty to find a "good" measure of ES.

Vietnam has undergone a transition from net deforestation to net reforestation. In 1943, under the French colonial administration, the national forest cover was 4%. 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., 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 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 positive forest externalities (non-marketed ES) 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, i.e., the cost of FES provision, 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. Our paper quantifies the cost of FES by the estimation of the marginal cost of service provision and assess potential complementarity or competitivity between timber, NTFPs, number of deadwoods in the forests and forest carbon storage. Finally, we identify the drivers of cost efficiency in provision of these ES. This allows us to identify the minimum cost of the production of a given set of FES as well as assessing the trade-offs between different services.

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) in 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 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 the 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 (e.g Angelses et al. 1988, Olschewski and Benítez 2010, Ahtikoski et al. 2011, Man et al. 2015).

Households 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 Brucciamachie et al. 2012). 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 (e.g. 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 servicesare 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 spatial heterogeneity in provision of ES is significant 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 costs (Lien et al. 2007). Gary, et al. (2005) shows that technology adoption, i.e. biotechnology in loblolly Pine in the US, may also influence cost of production. .

The Non-Industrial Private Forest Owners (NIPF) are key stakeholders in the externality provision 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 timber harvesting behaviour and efficiency. 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). Chand et al. (2015) shows applying a stochastic frontier production analysis that, among others, social capital influences efficiency in ES provision in community forest in Nepal. 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 in analysing 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, 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), or in agroforestry (Ofori-Bah & 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 (1994), 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:

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

where the vector of (positive) input prices is referred as to $W \gg 0$, and F() 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 $VC(Y, W, K, Z)$, as it contains the same information as the original production process.

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. However, fixed inputs do

[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).

not necessarily achieve cost minimization. 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:

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

The parameters to be estimated are: α_0, α_i, β_j, γ_k, $\alpha_{ii'}$, $\beta_{jj'}$, $\gamma_{kk'}$, δ_{ij}, η_{ik}, θ_{jk}.

The econometric model

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

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

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 Province in the Western Ecological zone of Vietnam. The selected study districts sites 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 (Fig. 1). 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.

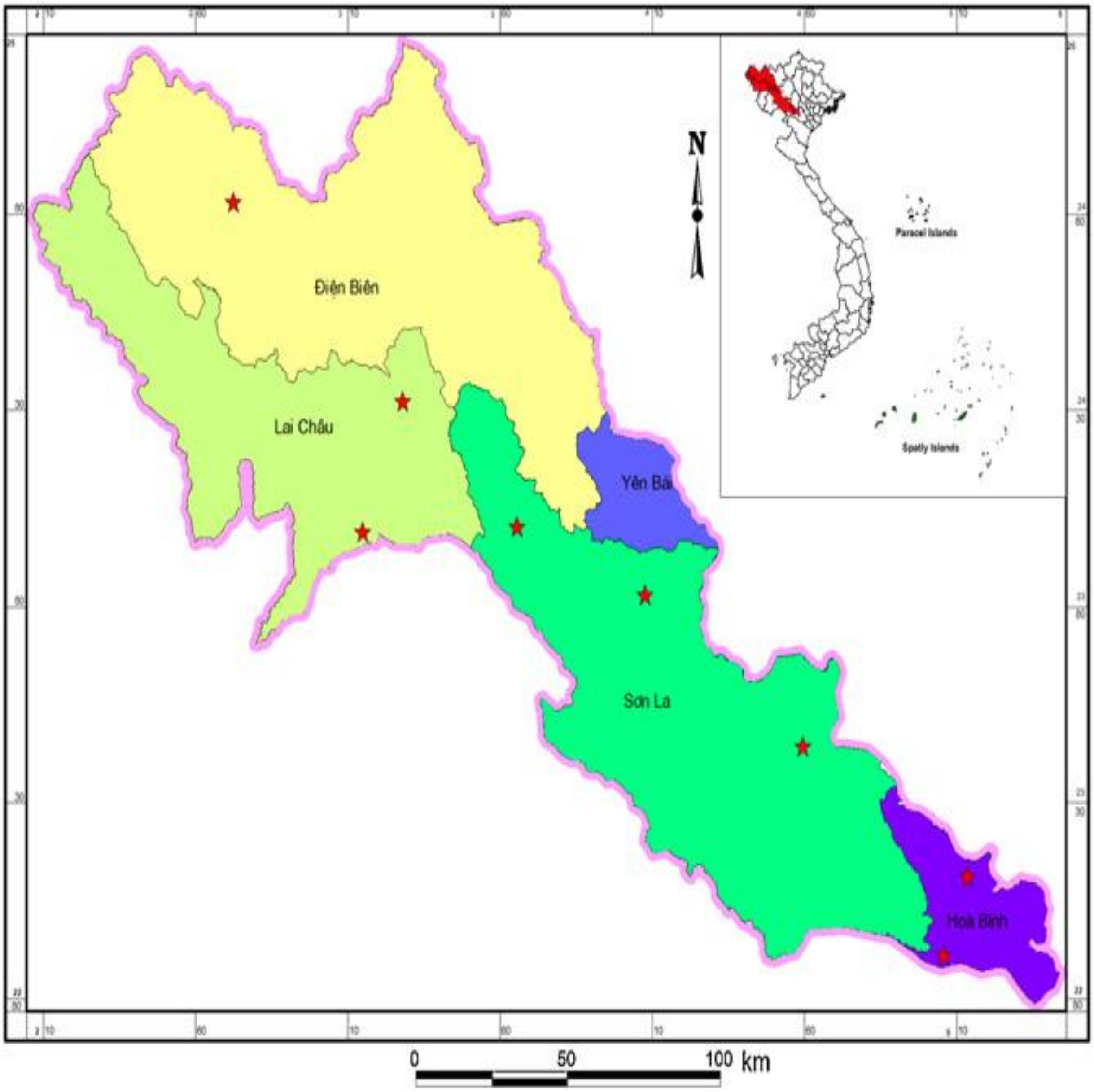

Fig. 1. Study districts (Cao Phong and Dabac)

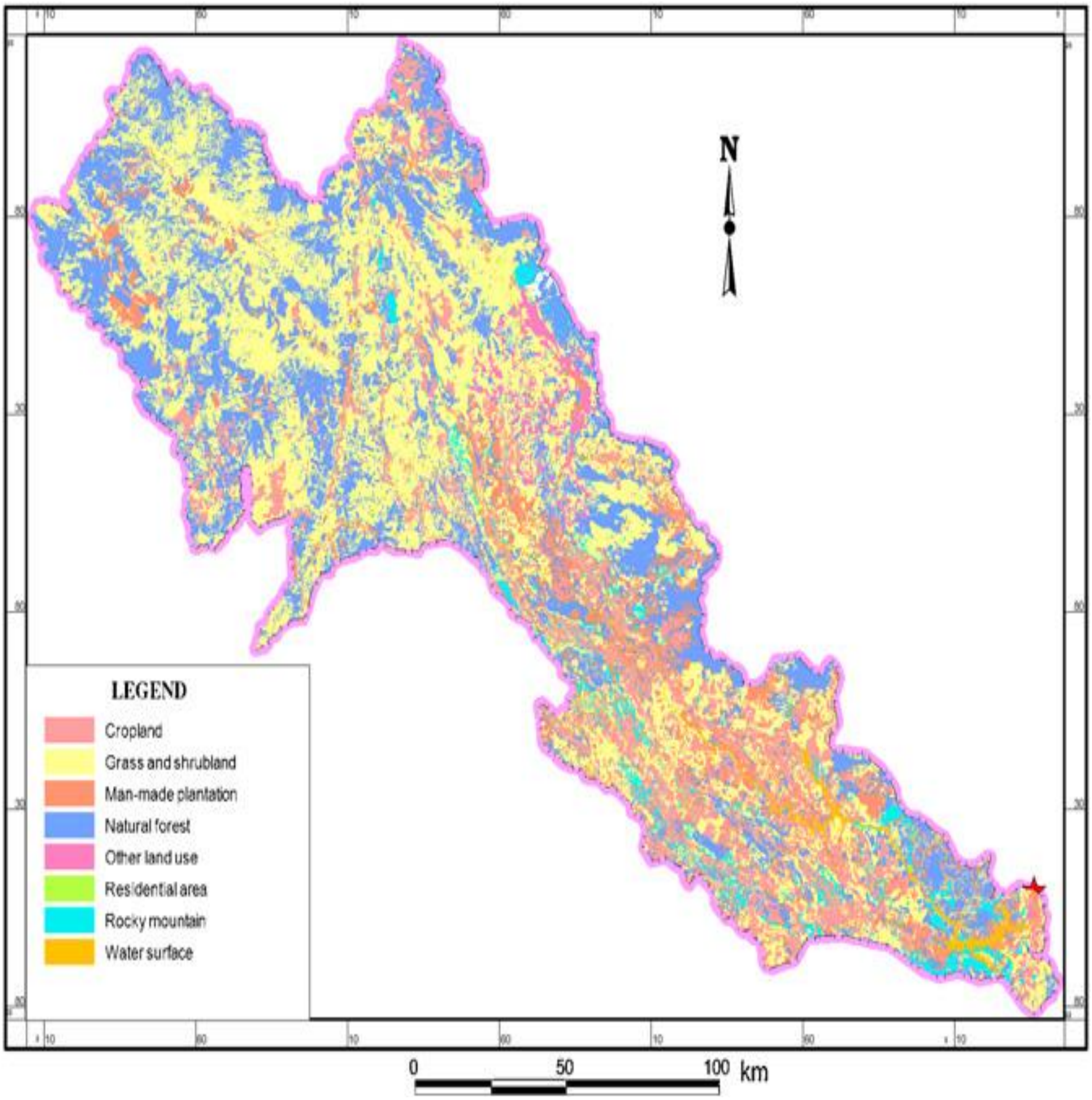

Fig. 2. Land use map

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 districts 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 and socio-economic of the private forest owners in the selected districts. A questionnaire were 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 Forest Services Division 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 was on FES Output Assessment Indicators. These data was collected based on several years of ES quantifications by the Vietnam Forestry University (Pham, 2009, 2011, Nguyen et al, 2013). The ES indicators considered for this study included (NTFPs diversity in the forest/ha, above and below ground carbon/tc/ha/yr and type of deadwood/ha). These ES indicators were used as output variables in the cost frontier model estimates.

Data

Data are described in table 1. The cost variable *cost*, is interviewed households' stated total direct costs associated with managing their forest. This includes direct costs of planting, stand treatments, thinning, harvesting, transporting, and road maintenance during the last five years. This also includes additional costs incurred for biodiversity conservation and carbon sequestration, which could be related to actions such as avoiding clear cutting, even aged timber harvesting, changing from exotic to native species, reducing NTFPs collection, restoration of barre lands, denuded hills and degraded natural forest areas. 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 output variables considered include harvested timber volume, *timb*, the carbon stock (in standing timber and in soils), carb, and two indicators of biodiversity. The first is the number different non-timber forest products harvested in the forest, *ntimb* 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). Finally, we can differentiate between industrial and non-industrial private forest (NIPF) owners.

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
adcost	Additional cost of biodiversity conservation and carbon sequestration (Dong/5 years)	19,542,556	9,606,858	0	70,200,000
cost	Total costs (curcost + adcost)	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
ntimb	Number of non-timber forest products species (unit??)	4.4	1.2	2	7
carb	Carbon stock in the forest property (unit??)	66.2	55.8	2.4	254.8
wage	Hired wage (unit??)	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
<u>Type of forest</u>					
Production		0.43	0.50	0	1
Protected		0.32	0.47	0	1
SpecialUse		0.16	0.36	0	1
OtherType		0.09	0.29	0	1
<u>Forest composition management</u>					
Evenaged		0.24	0.43	0	1
Unevenaged		0.38	0.49	0	1
Clearcut		0.34	0.47	0	1
others		0.04	0.19	0	1
<u>Type of owner</u>					
NIPF owner		0.38	0.49	0	1

5. Results

All variables 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 3, and then from a translog specification are described in Table 4.

Table 3 Estimation results - Cobb-Douglas specification

Variable	Estimate	Std. Err.		Estimate	Std. Err.		Estimate	Std. Err.	
constant	17.0746	0.0280	***	17.1877	0.0650	***	17.2358	0.0692	***
timb	0.4714	0.0708	***	0.4562	0.0713	***	0.3388	0.0875	***
ntimb	0.4727	0.1115	***	0.4274	0.1111	***	0.4276	0.1364	**
deadw	0.1003	0.0773		0.0887	0.0766		0.0642	0.0919	
carb	-0.0048	0.0426		-0.0131	0.0422		0.0278	0.0532	
wage	0.2656	0.0410	***	0.2496	0.0408	***	0.2572	0.0519	***
work	-0.1543	0.0371	***	-0.1447	0.0374	***	-0.0838	0.0461	.
forha	0.0226	0.0689		0.0384	0.0679		-0.0382	0.0798	
forage	0.0209	0.0834		0.0095	0.0821		0.0241	0.0973	
production				-0.1617	0.0748	*	-0.1690	0.0752	*
protected				-0.1189	0.0760		-0.1074	0.0770	
clearcut				0.0567	0.0641		0.0375	0.0646	
evenaged				-0.1037	0.0722		-0.1283	0.0732	.
NIPF							-0.0913	0.0582	
NIPF*timb							0.3140	0.1483	*
NIPF*ntimb							-0.0677	0.2351	
NIPF*deadw							0.0519	0.1716	
NIPF*carb							-0.1104	0.0900	
NIPF*wage							0.0002	0.0844	
NIPF*work							-0.1705	0.0778	*
NIPF*forha							0.3448	0.1767	.
NIPF*forage							-0.0893	0.1811	
Adjusted R^2		0.405			0.4282			0.4421	
LR test (p-value)			11.42 (0.0222)			14.42 (0.1082)			

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

We estimated three competitive Cobb-Douglas cost functions. The first three columns show estimation results with only 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). Only timber and NTFP outputs have a significant (positive) impact on variable costs at the 0.1% level. Their estimated coefficients show output cost elasticities around 0.47, meaning that a 10% increase of their quantities leads to an increase of cost of only 4.7% each. Instead, we found no impact of production of deadwood and carbon on costs. Moreover, 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. The second estimated cost model (in the second three columns) is augmented with additional binary variables giving information on the type of management. Based on the LR test we conclude that this new model is preferred to the first one, with a value of the statistic of 11.42 and a p-value of 0.02. Estimation results indicate that costs in a forest managed for the production (of timber) are less c than forests dedicate dedicated to special use. We found a similar result for protected forests but at a lesser extent.

Finally, a third Cobb-Douglas cost function includes a dummy variable for NIPF owners. This new model is validated only with a p-value of 0.1081. This dummy is crossed with all other first-order continuous variables. A positive and significant sign for the coefficient of NIPF*timb indicates a higher cost elasticity for timber output than for industrial owner. We also found a positive sign related to the NIPF*forha which should beadded to the coefficient of forhaseems to indicate that NIPF owners at the sample mean are characterized by excess capacities in forest land. On the other hand, we found a negative and significant coefficient for the variable work, which suggests a good adequacy of domestic labor of NIPF.

Table 4 Estimation results – Translog specification

Variable	Estimate	Std. Err.		Estimate	Std. Err.		Estimate	Std. Err.	
constant	16.9982	0.0684	***	17.1005	0.0894	***	17.0924	0.0965	***
timb	0.3766	0.0883	***	0.4070	0.0892	***	0.2287	0.1071	*
ntimb	0.4912	0.1248	***	0.4380	0.1250	***	0.5281	0.1459	***
deadw	0.2095	0.1042	*	0.1992	0.1025	.	0.1535	0.1203	
carb	-0.0343	0.0443		-0.0356	0.0440		-0.0073	0.0560	
wage	0.1646	0.0523	**	0.1426	0.0521	**	0.0876	0.0691	
work	-0.2047	0.0549	***	-0.1951	0.0563	***	-0.0696	0.0684	
forha	0.1923	0.0905	*	0.1910	0.0891	*	0.0943	0.1110	
forage	0.0701	0.0952		0.0665	0.0933		0.1910	0.1184	
timb*timb	-0.6753	0.3138	*	-0.4937	0.3137		-0.4249	0.3118	
ntimb*ntimb	1.5095	0.7862	.	1.5567	0.7800	*	1.7818	0.7750	*
deadw*deadw	-0.2043	0.2928		-0.1989	0.2871		-0.1092	0.2893	
carb*carb	-0.2437	0.1182	*	-0.2176	0.1172	.	-0.1835	0.1170	
wage*wage	0.1491	0.0940		0.1682	0.0932	.	0.1352	0.0963	
work*work	-0.0204	0.0851		-0.0220	0.0848		0.0249	0.0848	
forha*forha	-0.0409	0.2558		-0.1386	0.2533		-0.0675	0.2609	
forage*forage	-0.0727	0.2852		-0.1337	0.2805		-0.0184	0.2894	
timb*ntimb	0.4922	0.3813		0.3330	0.3803		0.3717	0.3778	
timb*deadw	-0.0145	0.2047		-0.0303	0.2021		0.0426	0.2095	
timb*carb	-0.1279	0.1061		-0.1377	0.1050		-0.1781	0.1061	.
ntimb*deadw	-0.0342	0.4432		-0.0791	0.4369		-0.3186	0.4499	
ntimb*carb	-0.0477	0.2059		-0.0997	0.2024		-0.0650	0.2010	
deadw*carb	-0.0143	0.1541		0.0215	0.1522		0.0070	0.1589	
forha*timb	0.1922	0.1779		0.1274	0.1775		0.2174	0.1811	
forha*ntimb	0.0281	0.3124		0.0740	0.3068		0.0746	0.3025	
forha*deadw	0.0741	0.2389		0.0153	0.2356		0.0238	0.2329	
forha*carb	0.3287	0.1608	*	0.3500	0.1584	*	0.2634	0.1603	
forha*wage	0.1466	0.1223		0.0716	0.1225		0.1208	0.1216	
forha*work	-0.0517	0.1070		-0.0302	0.1055		-0.0378	0.1035	
forha*forage	-0.7136	0.3007	*	-0.6494	0.2965	*	-0.6923	0.3053	*
forage*timb	-0.1237	0.2923		-0.1142	0.2866		-0.1480	0.3027	
forage*ntimb	0.2529	0.3903		0.2391	0.3848		0.2037	0.3794	
forage*deadw	-0.1146	0.3237		-0.1204	0.3174		-0.0657	0.3101	
forage*carb	0.1599	0.1503		0.1561	0.1472		0.1646	0.1493	
forage*wage	-0.0692	0.1330		-0.1222	0.1317		-0.0726	0.1313	
forage*work	0.1170	0.1176		0.1241	0.1161		0.2031	0.1166	.
wage*timb	0.1561	0.1063		0.0954	0.1071		-0.0064	0.1111	
wage*ntimb	0.3963	0.1866	*	0.4955	0.1861	**	0.5394	0.1899	**
wage*deadw	0.0289	0.1482		0.0007	0.1488		-0.0032	0.1528	
wage*carb	-0.0241	0.0697		-0.0221	0.0690		-0.0703	0.0708	
wage*work	0.0014	0.0739		0.0078	0.0731		0.0985	0.0805	
work*timb	0.1211	0.1140		0.1124	0.1133		-0.0017	0.1181	
work*ntimb	-0.2933	0.1935		-0.2407	0.1905		-0.2520	0.1881	
work*deadw	0.1824	0.1363		0.1878	0.1338		0.1429	0.1346	
work*carb	0.0088	0.0747		0.0053	0.0734		0.0429	0.0744	
production				-0.1351	0.0791	.	-0.1434	0.0785	.
protected				-0.1639	0.0783	*	-0.1773	0.0785	*
clearcut				0.0411	0.0646		0.0332	0.06444	
evenaged				-0.1360	0.0772	.	-0.1640	0.0778	*
NIPF							0.0059	0.0635	
NIPF*timb							0.3850	0.1641	*
NIPF*ntimb							-0.2356	0.2344	
NIPF*deadw							0.0724	0.1894	
NIPF*carb							-0.0699	0.0980	
NIPF*wage							0.0428	0.0944	

NIPF*work							-0.2664	0.0901	**
NIPF*forha							0.2650	0.1942	
NIPF*forage							-0.3513	0.1926	.
Adjusted R^2	0.4816			0.5038			0.5328		
LR test (p-value)				67.35 (0.0012)			23.66 (0.0049)		

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

Let's move on to the translog cost function (see Table 4), which has been tested as better than the Cobb-Douglas specification (with a value of the LR statistic of 78.47 and a p-value of 0.0001). We comment only on the estimation results of the most complete model, tested to fit the data best (as given by the results of LR tests in Table 4) and shown in the last three columns. Focusing on second-order (crossed) terms, we have several interesting results. Concerning cost complementarities between outputs, we find only one significant relationship between timber and carbon. We use the marginal cost of outputs in order to investigate the concept of jointness in production as discussed above (in eq. 5). The associated coefficient is negative, suggesting the marginal cost of timber harvesting decreases when the amount of carbon sequestration increases. We also find that the marginal costs of timber and carbon increase with the size of forest (with values of 0.22 and 0.26, respectively), but these results are not significant according to conventional tresholds. Instead, the negative and significant sign of the coefficient of forha*forage suggest that costs decrease with the size of the forest when the trees are old.

6. Discussion

Private forests in the Hoa Binh Province provide a number of different ecosystem services. This 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 complementary production of timber harvesting. This indicates that production-oriented forests may not have negative impact on carbon storage.

One of limits of the present study is the rather coarse proxy used to represent the timber stock in the forests (the tree ages). 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 three age variable (forage) was only (weakly) statistical significant when interacted with the NIPF variable. It is negative as expected. We have compared different specifications of the cost functions, i.e. Cobb-Douglas and a translog specification, 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 had no impact on cost in any of the six 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 applies within the range of carbon sequestration experienced today by forest owners. More drastic policies which implies 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.

The cost of keeping more dead wood in the forest had only a significant cost in the translog function and keep deadwood had no effect on the cost of provision of other services. 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 timer is kept and may therefore represent a significant cost.

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