Cost of Carbon storage in Private forests: A survey of ecosystem service provision in Vietnam

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Abstract:

Forest ecosystem services 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-market ecosystem services). The paper contributes to ecosystem services economics literature by assessing the production cost structure, i.e. the cost of timber production and ecosystem services, based on a survey of private forest owners in the Hoa Binh Province. The empirical estimation of the production structure is carried out applying a stochastic cost frontier approach to analyse the trade-off between cost and forest ecosystem services performance. This is the first time such an approach is applied to estimate the costs of production relationship between timber and ecosystem services provision in Vietnam. This approach appears to be appropriate for handling the multiple joint outputs production in forests. It allows us to assess the complementarities and trade-offs between different services. The results show that there is complementarity in production of timber and non-timber market products and carbon storage service. The results are important information development of ecosystem services payment schemes in Vietnam.

Keywords: Stochastic cost frontier, private forest owners, efficiency, forest ecosystem services, Vietnam

1. Introduction

Forest ecosystem services play an important role in forest management and research. This involves the conceptualisation of externalities, methodologies for assessment of their value and their costs of provision, and the design of policy instruments regulating their supply and demand. These ecosystem services, e.g. carbon sequestration, 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 production cost of forest management on the level of externality provision. Ecosystem services from forest has become increasingly important in recent forest economics literatures as a result of their multifaceted relevance to the society coupled with their global support for

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

climate change protection (Costanza et al., 1997; de Groot et al., 2002). The ecological and economic benefits of these services to society are still undervalued and the methods for evaluation are arguably limited, inconsistent, and incomplete. This evolving field is further faced with problems of defining limits of multifunctionality of forest ecosystem services, lack of reliable data for a concise and integrated valuation, spatial and scale issues and coupling of existing ecological and economic methods for valuation. The jointness in production and multifunctionality of forest ecosystem services further makes the study of these externalities complex due to their high non-linear relationships (Peerlings and Polman, 2004; Wossink and Swinton, 2007; Hodge, 1997; OECD, 2001). The demand and supply of these ecosystem services are complex as a result of different management practices to consider, joint provision of some of these services, transboundary scale and spatial challenges.

Assessment of the costs of provision of forest externalities is important for forest decision-making and management and policy reviews since we evaluate provision of both market and non-markets goods through the analysis of possible trade-offs between cost and environmental performance. Knowledge of the cost structure offers the basis for setting efficient targets for provision of externalities and for cost effective management strategies to meet targets since we are able to assess the cost consequences of expanding joint outputs or of adding a new product to the output mix. Furthermore, the design of appropriate policy instruments, including market-based instruments, relies on an understanding of the factors having an impact on cost of externality supply. Moreover the integration of the concept of production cost into forest ecosystem services actions and planning are very significant, especially at a forest land level.

Earlier empirical studies assumed that costs of production were constant and equal to land price per hectare (Ando et al., 1998; Stoms et al., 2004). However, some recent works demonstrate that agricultural and forestry production cost of joint outputs vary across land sites in response to several interactive and endogenous characteristics (Naidoo and Adamowicz, 2006; Strange, et al., 2007).

Frontier functions such as cost, production, profits or revenue functions are often used to measure firms' economic efficiency these are selected based on the economic behaviour of the firm. For example, if firms are believed to behave in a way that minimises cost, the cost functions are appropriate to apply. From this economic point of view, firms should seek an optimal scale at which their cost is minimised. These frontier methods can be traced back to the seminal theoretical work of Farrell, 1957 and Shephard, 1953 since they are able to differentiate between high costs that may be due to inefficiencies and those that arise because of scope economies.

This empirical study specifically develops a stochastic cost frontier model to analyse cost synergies between forest ecosystem systems and to analyse cost efficiency drivers in the in Vietnam.

Vietnam has undergone a transition from net deforestation to net reforestation. In 1943, under the French colonial administration, the national forest cover was 43 %. 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 the number of 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).

Forest ecosystem services provisioning and management in Vietnam is highly rated in the Vietnamese's environmental agenda. For example, several private afforestation programs and as well as programs for transition of forest ownership have been implemented. Forest Protection and Development Plan for the period 2011-2020 based on afforestation and regeneration and improvement of quality of natural forests has been annually budgeted for, to the tune of 2,045 billion dong. This plan is to protect and develop sustainably 13,388,000 ha of existing forests and 750,000 ha of regenerated forests; 1,250,000 ha of new plantations in the period 2011-2014; increase forest area to around 14,270,000 ha and 15,100,000 ha by 2015 and 2020 respectively with private forest owners, communities, households and individuals (FSDR, 2013).

The main objective of such programmes is to maximise profit by timber and Non-Timber Forest Products (NTFPs) production. There is an under supply of positive forest externalities (non-market ecosystem services). Therefore, an assessment of the production cost of some forest services (market and non-market) 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 production timber and environmental services, based on a survey of forest owners in the Hoa Binh Province. The empirical estimation of the production structure is carried out applying the stochastic cost frontier function. This is the first time such an approach is applied to estimate the production relationship between timber and other forest ecosystem services. This approach appears to be appropriate for handling the multiple joint output production in forests.

Our paper quantity the cost of forest ecosystem service by the estimation of the marginal cost of service provision and assess potential complementarity or competitivity relationship between timber, non-timber forest products(NTFPs), number of deadwoods and forest carbon storage. Finally, we identify the drivers of cost efficiency in provision of these ecosystem services. This allows us to identify the minimum cost of the production of a given set of forest ecosystem services as well as assessing the trade-offs between different services.

This article seeks to fill several research gaps (1) contributes to forest economics literature by assessing the production cost structure, i.e. the cost of market goods (timber, non-timber forest products) and non-market goods (deadwoods, carbon storage); 2. develops an empirical stochastic cost frontier model with these externalities as joint outputs land and farm characteristics and 3. suggests important policy implications in provisioning of cost efficient forest ecosystem services by evaluating the cost synergies between these outputs.

The paper is organised into 5 sections, after this introductory section. Section 2 provides a state of the art literature relevant on forest ecosystem services cost drivers and variables that influence supply of outputs as well as introduces the study design. Section 3 focuses on theoretical cost function framework relevant to the study. Section 4 describes the empirical model specification for the cost estimation and results. Section 5 concludes and gives recommendation for the design of forest ecosystem services payment schemes and the sustainable supply of forest ecosystem services in Vietnam.

2. Ecosystem Services Cost of Supply Factors: A Literature Review

Cost of production of forest externalities are affected by various endogenous and exogenous variables and the estimation of cost of provisioning of ecosystem services must take into account all relevant variables and characteristics. This review demonstrates and contributes to the key drivers and inputs components that influence cost of provision of forest externalities taking into account joint cost of provision, multifunctionality of externalities and spatial issues. These factors include; firstly, the physical characteristics of the forest and resource availability, secondly, the current and proposed management characteristics of the forest owner, thirdly, the spatial characteristics that influence cost and finally the socio-economic characteristics of the forest owner household. The first relevant cost component discussed in this review is the physical value and fixed cost-forest characteristics and availability. Wear, 1994, assigns this component and elucidates that the physical description of the forest-the acreage in each forest type and age distributions across forest types are important features to take into econometric estimation of structural cost functions and productivity. The size of farm was also found by Kumbhakar, Biswas and Bailey (1989) and Hallam and Machado (1996) as a factor that could influence the production cost and efficiency. Forest properties in a typically rurally located area had a higher efficiency level and cost of management than those properties located close to urban areas. (Gudbrand, 2007). Estimating and analysing of forest externalities costs are closely connected with management practices and behaviours. Coelli et al. 2005 affirms that management practices could inherently influence cost of production of forest externalities such as the technological change i.e. new equipments, forest road construction since this could shift the production frontier of the forest function. Siry and Newman 2001 undertook a study on cost and provided evidence that cost of forest management could be affected by forest management practices of the Non-Industrial Private Forest Owner (NIPF) for example, there is higher cost if the Non-Industrial Private Forest Owner (NIPF) decides to privatise their forest. 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 minimise cost of production. (Gudbrand, 2007). Gary, et al., (2005), employ several cost inputs in the cost modelling of forest biotechnology for Loblolly Pine and Kraft Linerboard in the US by taking into account their management cost such as operating cost of site preparation, seedling, fertilizing, and rotation age. Providing a comprehensive cost analysis of amenities definitely takes into account the spatial and distributional aspects of cost since this varies across forest regions. (Ferraro, 2002.

Pellegrini and Fotheringham, 2002 and Obersteiner, 1999), incorporate characteristics of sites-distance between sites and respondents and between alternative sites influence cost of ecosystem services supply. Luisetti et al., 2008, measure cost by taking into account the importance of spatial context in aggregation of benefits of new wetland creation through distance attributes. Naidoo and Ricketts (2006), describes that disparity of ecosystem cost could be due to variability in spatial factors such as slope and soil type which affect ecosystem service provision across the landscape. These spatial disparities create variations in prices and cost as a result of demand and supply in the regions as emphasized in studies such as Ghebremichael et al. (1990), Abt et al. (1994), Bernstein, (1994), Lantz, (1995, 2004), Obersteiner, (1999), and Hailu and Veeman, (2003). Interestingly, Scarpa et al. (2000) found that spatial heterogeneity and variations have no significant influence on the cost analysis.

Many forestry cost studies have suggested that the socio-economic characteristics of forest owner must be in cooperated in timber cost assessment (Newman, 1994). The characteristics of the Non-Industrial Private Forest Owner (NIPF) has does become a key feature in cost estimation since they are the key stakeholders in the externality provision. These features effect depend not only on the household’s economic characteristics but also socio-demographic features of the forest owners (e.g., education and sex-composition; experiences (Coelli et al., 2005). Assessing cost in forestry, one needs to be able to determine and distinguish the ownership type and assess if the forest owner is a private owner who hold timber-using facilities, the forest industry, and all other private, or nonindustrial, owner. These two ownership groups display structural dissimilarities in their production behaviour and influence of provision of amenities (Newman and Wear 1993). Carter and Cubbage, (1995), measured technical cost efficiency by estimating a frontier production cost function by exogenous variables using forest owner’s characteristics to analyse exogenous factors influence on cost efficiency of pulpwood harvesting. The ownership characteristics that influence cost include occupational status, age, sex, income sources, number area of holdings, number of owners, educational status, possession of management plan, and objective of holding. Kline et al. (2000) provide a comprehensive overview on how non-industrial private forest owners ‘management objective and preferences could influence the cost and the provision of forest externalities.

Gudbrand, (2007) in their study on private forest owners harvesting behaviour and efficiency argue that forest owner’s income and younger forest owners had lower cost in management than older ones and highly educated forest owners had high cost and less efficient in management than lower educated forest owners in Norway. Moreover, off- forest and outfield income activities led to lower cost of ecosystem services efficiency, while properties combining forestry and agriculture (i.e. properties where income from agriculture is high) had higher cost efficiency. (Kumbhakar and Knox 2000). These review show cases the importance of taking into account several interactive endogenous and exogenous variable when estimating cost of production of ecosystem services in general.

2.1 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 and the average width is 1 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 average annual humidity is high of 80–85%. The topography is complex with elevations from 300 to more than 2000 m above sea level. Only 19% of the land area has the elevations below 500 m; and 34% of the land area have the elevations higher than 1000 m . The complex topography is also illustrated with the various levels of land slopes. Only 3% of the land area has the slopes less than 10◦; 54% of the land area have the slopes between 20 and 30◦; and 12% of the land area have the slopes of more than 30%. The downstream area of the Da River Watershed is the Red River Delta where Hanoi, the capital of Vietnam, is located. These indicate the

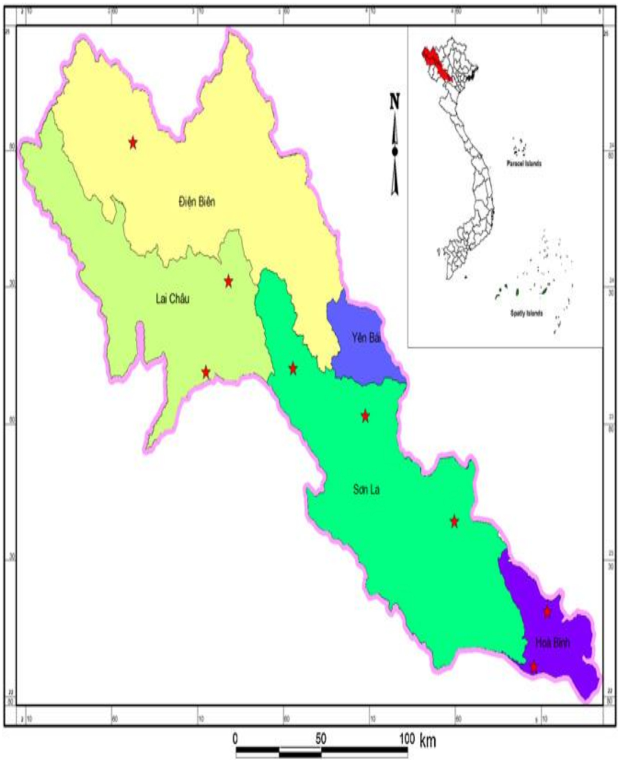

Fig. 1. Study districts (Cao Phong and Dabac)

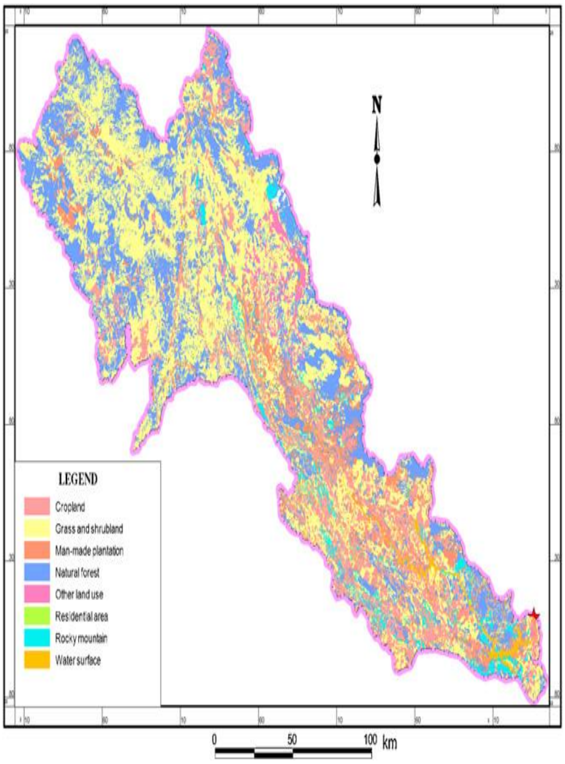

Fig. 2. Land use map

Importance of ecosystem services e.g biodiversity, carbon sequestration, regulation of water and prevention of soil erosion in the study area. The main soil type of the study area is Ferralsols (92%), including Rhodic Ferralsols, Xanthic Ferrasols, and Humic Ferralsols with the average initial topsoil (0–20 cm) contents of about 2% organic matter, 0.16% total nitrogen, 0.02% total P, 2% total K and 9.9 cmol per kg CEC. Average soil clay, silt and sand content are about 18, 29, and 53%, respectively (Dung et al., 2008). Soil infiltration rate varies much among soil and vegetation types. Under mature mixed plantations of Pinus massoniana and Acacia mangium on Humic Ferralsols, the initial soil infiltration rate ranges from 6.7 to 15.2 mm/min; the stable soil infiltration rate ranges from 2.5 to 8.0 mm/min (Pham, 2009). 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, a sample of 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 equipments etcs). 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 Forest Ecosystem Services Output Assessment Indicators. These data was collected based on several years of ecosystem services quantifications by the Vietnam Forestry University (Pham, 2009, 2011, Nguyen et al, 2013). The ecosystem services 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 ecosystem services indicators were used in selected in the cost frontier model estimates.

3. Theoretical Framework Cost Function Framework

A way to describe the joint production (or "technology") 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 forest externalities.

For this purpose, we assume that the forest owners consider their forest property as an enterprise like other firms. The forest is considered as a production process with several outputs where some are considered as positive externalities (e.g., biodiversity, carbon sequestration, water quality), i.e., they are non-market goods or services and the owner is not remunerated for provision of these positive externalities and not charged for provision of possible negative 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 ecosystem economic literature as found in the works of Lopez et al (1994), Lankoski (2003). The relationship between multiple outputs depend on the impact of all several sources-technical interdependency, fixed non-allocable inputs and outputs competing for an allocable input (Hodge, 2008).

Much research interest has been expressed in the use of cost and production functions in recent years in cost modelling for ecosystem services (Peerlings and Polman 2004).

Furthermore, Nilsson (2009) also shows the relevance of the use of cost function method in estimating the cost of biodiversity provision on Swedish pastures.

In this section, we show how production analysis can help us to estimate cost of externality provision by the use of the stochastic cost frontier. We consider the theory of producer behaviour and its implications for cost function analysis, in particular the derivation of cost of externalities provision. Moreover, we stress the importance of the spatial dimension by including neighbouring forests' provision of environmental externalities, as well as neighbouring production activities. The theoretical cost model has several advantages. First, it incorporates, instead of production functions, information about the optimizing behaviour (i.e., minimisation of cost under technological constraints in order to derive optimal demand of inputs). Second, it allows to focus on measurable costs and to directly derive useful notions as marginal costs. Third, in the framework of an empirical approach, the estimation of a cost function is more tractable and needs fewer hypotheses than a production function.

A cost model for industrial private forest owners

In a multiproduct framework for a multiple-use forest, the « technology » describes the relations between inputs and outputs and is modelled by a transformation function:

$$T(Y, X) = 0$$

where Y is a vector of variable outputs (timber, environmental services) and X is a vector of variable inputs (land, labour…). A cost function can (perfectly) describe the multiple-use production (duality[2]): Hence the short-run cost function for a farm is given by:

$$C(Y, W, Z) = \min\{c(\boldsymbol{Z}, \boldsymbol{X}, \boldsymbol{W}) | \, F(\boldsymbol{X}, \boldsymbol{Y} \mid \boldsymbol{Z}) = 0, \boldsymbol{W} > 0, \boldsymbol{P} > 0\}$$

where **Y** is a vector of variable outputs (including timber and biodiversity), **X** is a vector of variable inputs, **Z** is a vector of quasi-fixed inputs (including valuable pastures), **W** is a vector of input prices while **P** is a vector of output prices and **F**() is the set of technology used in the private forest owners land. All input and output prices are assumed to be exogenous to the forest land area and each farm has access to the same set of technology. It is also assumed that the cost function is non-decreasing in output quantities or in input prices and is concave in input prices.

Our point of departure when it comes to assessing cost complementarities and trade-offs between the provision of different services affects the cost structure of forest land area is the marginal-cost function, which is given by:

$$MC_y = \frac{\partial C(Y, W, Z)}{\partial y}$$

where y is an output. The marginal cost, as discussed by Wieck and Heckelei (2007), is assumed to be equalised in a competitive market since all forest areas are assumed to be cost minimising and face the same set of prices. The violation of this assumption may be due to private forest owners' production of a sub-optimal level of timber and hence differences in

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[2] The cost function is the optimal result of the programme of cost minimisation of forest owners taking the transformation function defined above into account.

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. This violation is particularly valid when we face heterogeneous fixities (as discussed in Just and Pope, 2001) such as different types of soil, family labour or capital restraints as well as environmental restrictions. We use the marginal cost of outputs in order to investigate the concept of jointness in production as discussed in Havlik (2008).That is, we evaluate how the marginal cost of one ecosystem service reacts when another service is changed:

$$MC_{y_1,y_2} = \frac{\partial C_{y_1}(\cdot)}{\partial y_2}\begin{cases} > 0, & \text{competitivity} \\ = 0, & \text{no jointness} \\ < 0, & \text{complementarity} \end{cases}, \quad y_{1,}y_2 \in \boldsymbol{Y} \tag{1}$$

Complementary relationship is identified in the production structure if the marginal cost of y_1 decreases when the output of y_2 increases, since a lower marginal cost will lead to an increased output of y_1 as well. On the other hand we find a competitive relationship between two outputs if the marginal costs of y_1 increases as the output of y_2 increases. If the marginal cost of one output is unchanged when the other output increases, then we have no jointness in production. This empirical relationship, as discussed in Hodge (2008) and in Peerlings and Polman (2004), depends on the context of land use management practiced, we have no strong prior about whether biodiversity has a complementary or a competitive relationship with the production of different market goods. If we add some structure to the problem, then we may hypothesise that it is more likely that a competitive relationship will be found between timber or non-timber forest production and biodiversity on valuable forest land area since due to technology interdependence. That is, harvesting used as timber or non timber forest input will affect biodiversity. A similar technical relationship is not found between timber production and biodiversity on valuable forest land areas.

An example for a two-jointed forest outputs (timber, biodiversity)

A production of biodiversity *B* is assumed to be a function of the growing stock (or the forest size) *S* and the timber harvested *H*:

$$B = B(S, H)$$

Omitting other factors for the sake of simplicity, the cost function providing both timber and biodiversity can be defined as:

$$C = C(H, B)$$

where *C* represents the annual total cost taking into account all costs generated for management and timber harvesting and (possibly) additional costs of preserving biodiversity.

Marginal costs with respect to timber and biodiversity can be written as:

$$C_H = \frac{\partial C(H, B)}{\partial H}$$

$$C_B = \frac{\partial C(H,B)}{\partial B}$$

In a joint production approach, a natural question is that of compatibility between outputs (i.e., complement or substitute goods). It is possible to characterise jointness in production by investigating whether multi-output production is less costly than the production of separated single products:

$$C(H,B) < C(H,0) + C(0,B)$$

Scope (or jointness) economies are defined as:

$$S_C = \frac{C(H,B) - C(H,0) + C(0,B)}{C(H,B)}$$

$S_C<0$ means cost savings from producing both timber and biodiversity, whereas $S_C>0$ implies diseconomies of costs related to multiproduction and thus a more efficient specialised production.

The equation of scope economies raises the issue of definition set of costs. While zero timber harvesting is conceivable as well as the definition of $C(0,B)$, it is less so for biodiversity, i.e., $B = 0$, that probably corresponds to a situation of clear-cutting. Hence, the case with $C(H,0)$ probably doesn't exist. One possible solution would be to define the lowest biodiversity level $\underline{B}$. For instance, in the case where the number of tree species is an indicator of biodiversity, this lowest bound would be $\underline{B} = 1$.

Another way to overcome this difficulty is to use the second-order partial derivatives of the multiproduct cost function. It allows us to understand how the marginal cost of harvesting is modified by a small variation of biodiversity:

$$C_{HB} = \frac{\partial C(H,B)}{\partial H \partial B}$$

A sufficient test of (low) cost complementarity is:

$$C_{HB} \leq 0$$

The cost of providing a specific output can be derived from the incremental cost of a single product:

Cost of wood production:

$$IC_{H/B} = C(H,B) - C(0,B)$$

Cost of biodiversity provision:

$$IC_{B/H} = C(H,B) - C(H,0)$$

Stochastic cost frontier

We analysed the production structure applying a stochastic cost frontier model. This allows, one the hand, to reveal the production structure, including the joint production of timber and forest ecosystem services and, on the other hand, to calculate measures of efficiency. The advantage of a stochastic frontier analysis is that it incorporates random errors, thereby avoiding their inclusion as elements of inefficiency. The stochastic cost frontier model to be estimated is specified for land owner i

$$C(Y_i, Z_i, W_i) = CF(Y_i, Z_i, W_i) + \ v_i + \ u_i$$

where $CF(Y_i, Z_i, W_i) + \ v_i$ is the stochastic cost frontier where $C(Y_i, Z_i, W_i)$ is the deterministic element of the stochastic frontier and $CF(Y_i, Z_i, W_i)$ is the observed costs ($C(Y_i, Z_i, W_i) \geq CF(Y_i, Z_i, W_i) + \ v_i$). The disturbance term is assumed to have two error terms (v_i+ u_i). v_i is the idiosyncratic error with the symmetric distribution with variance σ_v^2 and u_i is a nonnegative component and representing an inefficiency term. Both error terms are distributed independently of each other and of the covariates in the model. The other variables are specified as above. We have extended the model to include exogenous variables which are supposed to affect the distribution of efficiency (Huang and Liu 1994, Belotti et al. 2012). These variables are neither inputs nor outputs but nonetheless expected to affect the productive performance. The simplest way to model the efficiency is to let the mean of the efficiency distribution be a function of the exogenous variables:

$u_i \sim N^+(\mu_i, \sigma_u^2)$ and $\mu_i = s_i' \varphi$

Where s_i is a vector exogenous variables and φ is a vector of parameters to be estimated.

4. Empirical Specification of the stochastic cost frontier function

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. The trans-log cost function is applied in this empirical study since this function is flexible enough for estimating economies of scale and scope. 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 empirical cost function is a simplified trans-log function which includes quadratic terms in outputs, i.e.

$$\begin{aligned}\text{Ln}\big(C(\boldsymbol{Y}_i,\boldsymbol{Z}_i,\boldsymbol{W}_i)\big) &= \alpha_0 + \textstyle\sum_{n=1}^{N}\alpha_{1n}\ln(Y_{ni}) \\ &+ \textstyle\sum_{m=1}^{M}\alpha_{2m}\ln(W_{mi}) + \frac{1}{2}\sum_{m=1}^{M}\sum_{n=1}^{N}\alpha_{3mj}\ln(Y_{ni})\ln(Y_{ji}) \quad + \\ &\textstyle\sum_{l=1}^{L}\alpha_{4l}\ln(Z_{li}) + \varepsilon_i\end{aligned}$$

$$where\ \varepsilon_i = v_i + u_i$$

Where cost and exogenous variables are logarithmically transformed and α_0, α_{1n}, α_{3mj}, α_{4l} are the parameters to be estimated.

The final model where insignificant parameters have been deleted is written and can be written

$$\begin{aligned} cost_i &= \alpha_0 + \alpha_{tim}tim_i + \alpha_{ntim}ntim_i + \alpha_{carb}carb_i + \alpha_{dead}dead_i \\ &+ \tfrac{1}{2}\alpha_{timtim}tim_i * tim_i + \alpha_{carbtim}carb_i * tim_i + \alpha_{deadntim}deadw_i * ntim_i \\ &+ \alpha_{carbntim}carb_i * ntim_i \\ &+ \alpha_{forha}forha_i + \alpha_{ownl}ownl_i + \alpha_{wage}wage_i + \varepsilon_i \end{aligned}$$

where

$$\varepsilon_i = v_i + u_i \text{ and } u_i \sim N^{+}(\mu_i, \sigma_u^2),\ v_i \sim N(0, \sigma_v^2), \text{ and}$$

$$\mu_i = \varphi_0 + \varphi_{privm}privm_i + \varphi_{headd}headd_i + \varphi_{educ}educ_i$$

The two equations are estimated simultaneously with maximum likelihood methods[3] and the data is decribed in table 1. The costs variable *cost*, is interviewed households' stated total direct costs associated with managering their forest. This includes direct costs of planting, stand treatments, harvesting, and road maintaince during the last three years. The cost estimate does not include costs of land and opportunity cost of household labor. Instead, we have included the variables *forha* and *ownl*, representing forest size and hours the household members have spent working in the forest, respectively. The output variables considered include harvested timber volume, *tim*, 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, *ntim* and the second the number of dead trees in the forest *deadw*. We have included an indicator of the wage rate of hired labour, wage. We did not have the hourly salary for hired workers. However, we used an estimate of the alternative costs of household labour which is estimated as the non-forest income devided with the number of hours not working in their own forest. In the final model we use three variables to explain the mean of the inefficiency distribution in a truncated normal distribution. These include the number of years of education, *educ*, a dumy variable which equals one if it is the household that carries out most of the work in the forest *privem*, and whether it is the

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[3] We use the « frontier » procedure in STATA (Belotti et al. 2012).

household head that is the main decision maker with respect to forest activities in the forest, *headd*. In the estimation we used 176 quationnaires.

Table 1 descriptive statistics (176 observtions)

Variable		Mean	Std. Dev.	Min	Max
cost	Total costs of forest management (Dong/3 years)	4.76E+07	3.25E+07	1.20E+07	2.65E+08
tim	Harvested timber volume (cbm/3 years)	80.70	33.14	24	190
deadw	Number of dead trees	8.98	4.17	1	23
ntim	Number of non-timber forest products	4.38	1.18	2	7
carb	Carbon stock (tons)	8.77	5.68	1	24.7
wage	Wage rate (Dong/hour)	16692	31577	1455	272187
forha	Forest size (ha)	3.16	1.15	1	7
ownl	Household labour (hour/year)	1000	842	30	2904
privm	*privm*=1 if private management, otherwise *privm*=0	0.40	0.49	0	1
headd	*headd*=1 if forest owner main decision maker , otherwise *headd*=0	0.54	0.50	0	1
educ	Number of years of education	12.90	3.30	10	18

Results

All variables in the cost function are logarithmically transformed after having been mean-scaled. The estimated coefficients can therefore be interpreted as elasticities at the sample mean values. All variables in the cost function, except the forest size (*forha*), are significant. The cost increases with increasing timber production and number of non-timber products produced in the forest. On the other hand, the results indicate that the costs are decreasing with higher level of carbon storage and number of deadwood. The cost increases with the number of non-timber forest products produced in the forest.

Table 2 Stochastic cost frontier. Estimation results.

variable	Coefficient	Std. Err.	z	P>z
tim	0.197	0.063	3.110	0.002
*tim*tim*	0.244	0.087	2.790	0.005
ntim	0.215	0.129	1.660	0.097
carb	-0.073	0.034	-2.140	0.032
deadw	-0.155	0.063	-2.460	0.014
*tim*carb*	-0.175	0.073	-2.390	0.017
*Ntim*carb*	-0.285	0.139	-2.050	0.041
*ntim*deadw*	-0.692	0.237	-2.920	0.004
Price of input and fixed input				
wage	0.335	0.025	13.310	0.000
forha	-0.020	0.061	-0.330	0.738
ownl	-0.135	0.031	-4.420	0.000
constant	-0.596	0.062	-9.590	0.000
Determinants of in-efficiency				
privm	0.208	0.126	1.650	0.099
headd	-0.163	0.116	-1.410	0.159
educ	-0.056	0.023	-2.460	0.014
constant	1.048	0.218	4.810	0.000
$ln(\sigma_u^2+\sigma_v^2)$	-1.476	0.275	-5.370	0.000
$Ln(\gamma/(1-\gamma))$	3.359	0.988	3.400	0.001
$\sigma_u^2+\sigma_v^2$	0.228	0.063		
$\gamma=\sigma_u^2/(\sigma_u^2+\sigma_v^2)$	0.966	0.032		
σ_u^2	0.221	0.062		
σ_v^2	0.008	0.007		
likelihood = -56.762056				

We use the marginal cost of outputs in order to investigate the concept of jointness in production of carbon as discussed above (equation 1). That is, we evaluate how the marginal cost of timber harvest and number of non-timber products changes when the amount of carbon sequestration changes (table 3). We find that there is a complementarity between carbon storage and timber production and between carbon storage and number of non-timber forest products. However, presence of dead wood in the forest is showing a competitive relationship with carbon storage. On the other hand there is a complementary relationship between presence of dead wood in the forest and timber production as well as the number of non-timber products. Finally we also find a competitive relationship between timber and non-timber production.

Table 3 Jointness in production (+ : competitive, - : complementarity)

Outputs	*ntim*	*carb*	*deadw*
tim	+	-	-
ntim		-	-
carb			+

As expected we find that the cost increases with the wage rate and decreases with the labour input from the household. The impact of forest size is not significant. However, indicates that intensification of the timber production does not increase the production costs per cubic meter of timber.

We find that private management has a positive effect on the mean of the cost inefficiency distribution while number of years of education decreases the inefficiency.

5. 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. The results of this study indicate that increasing carbon sequestration in the forest is complementary production (timber and non-timber products) but competitive to the biodiversity indicator (presence of dead wood in the forest). This indicates that production-oriented forests may not have negative impact on carbon storage as well as on presence of deadwood in the forest. Interestingly, we find that the competitive relationship is between the two market outputs (timber and non-timber products) and between the two non-market services (dead wood and carbon storage)

One of limits of the present study is that it does not take into account the dynamic nature of timber production, i.e. that low harvest of timber may be associated with growing timber stock and can be considered as an investment. Present study, implicitly assumes that the forest are in a steady state where timber harvest is in equilibrium. This will probably not be the case, but over the sample we may think that the forest is, in average, in equilibrium.

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