Biodiversity Conservation through Public Management in Cultural Landscapes: Integrating Economic and Ecological Evaluation of Species by Shadow Prices

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Abstract— **The paper deals with the problem of finding relative values for species in the case of biodiversity conservation in a cultural landscape. We use the concept of shadow prices to derive flexible functional forms that allow us to conduct an interactive and internal valuation process. The paper is organized such as that (1) the theory of shadow price derivation is presented in a framework of programming. (2) We obtain quadratic objective functions for participant in the valuation process. (3) Quasi demand and supply functions are derived from which we can simulate a market. (5) The special role of ecologists as experts and potential managers of a landscape is addressed and (6), or finally, a balanced solution on values, value oriented management, and species prevalence is provided.**

Keywords— **Valuation, cultural landscape, species composition and nature provision by farms.**

I. INTRODUCTION

This paper makes a contribution to the problem of cost effective integration of ecological and economic concerns in landscape management. A concise and more realistic theoretical background for biodiversity management in cultural landscapes, which is value oriented, nature favouring, and less conflicting, has not been obtained so far. Especially because of dissents in thinking of value and valuation [1] problems exist. Problems with the willingness to pay approach [2], which gives, usually, only vague priority settings [3], are manifold and new approaches are needed. Economists [4] prefer individualistic approaches of cost-benefit-analyses and they see limited tasks for experts (ecologists), though reality is different. Ecologists criticize economists to be to narrow on values [5].

It is the aim of this paper to find a better approach which allows detailed valuation of species. The problem is specified as landscape management problem for biodiversity conservation in farm lands using the knowledge of experts, i.e. real managers. Ecological experts are considered managers of biodiversity on behalf of citizens, though they face financial constraints if farmers want money for compliance with regulations. Then paper is organized along a general outline of shadow price, behavior and equilibrium finding.

II. GENERAL OUTLINE OF SHADOW PRICES

In this section we deal with the general economic problem of minimizing costs given physical objectives to be fulfilled. Physical objectives become value oriented and measured in costs. The target is a vector, biodiversity "s". The issue is how to measure a value "λ_e" of target "s" and get "$\lambda_e \cdot s$", i.e. revenue type of value function given costs/constraints. Note "λ_e" depends on structures how we set up "ecologically motivated" activities "e". Presumably "e" is a control variable that is influenced by a government. Through "c", pursuing ecological objectives "s", costs are transparent; where "c" is cost and "p" is financial gain. Then:

$$\text{Min } c^{'}e \; - p_p^{'}e \qquad (1)$$

where:
e : = efforts or activities
c : = unit costs
p : = prices per unit or gross margins

Objective (1) and constraint (2) constitute the programming. The ecological demand "s", as a set of criteria (constraint) and prescribed by a vector of species (2), is accomplished in a territory. We use the notation of Paris and Howitt [6] to make the point clear. In our case a species vector "s" is linked to a control variable "e" by a linear system (see later on aspects).

$$s \geq A\ e \qquad (2)$$

where:
s : = target, i.e. species vectors

And for calibration, also according to [6], we use $s \geq \underline{s}$.

The next step is to find a primal and dual solution for the technology (2). A dual solution provides a function of shadow prices, i.e. values. Continuing with the notation of dual solution, (3) maximizes the sum of shadow prices for constraints giving a value function

$$\text{Max} \quad r's + \lambda_e' e \tag{3}$$

where:
λ_e : = shadow price

Now we can specify prices "c" and "λ_e", which follows a linear rule and, note, "λ_e"s are constrained in the dual optimization. The dual pricing includes (finds) the shadow price λ_e that correspond to the costs

$$c \le A'\lambda_e + r + p \tag{4}$$

Shadow prices are flexible with "demand vector: s". The issue, for calibration, is that shadow prices of species can not exceed a willingness to pay information, gathered through a survey and expressed as support for preservation of wildlife in agro-ecosystems: $\underline{w} \ge r$

To briefly explain the benefit of the approach: the reader may imagine that shadow prices stand for a species vector portraying the desired (weighted) biodiversity. Knowing symmetric properties of functions, we can retrieve coefficients in objective functions either from estimating corresponding dual or primal behavioural functions. Value units are costs "c", but values λ_e stand also for "s". In case of a quadratic utility function, we get a quadratic benefit function. Costs in this context might be opportunity costs of foregone profits due to interventions, which control farm behaviour.

Technically, as shown by Paris and Howitt [6], the linear programming approach corresponds to a formulation of cost equivalents incurred by the constraints. This gives a quadratic quasi-revenue function such as:

$$E = [c-p]' e + \pi(\ldots) = [c-p]' e + \lambda_e[Ae - s] = [c-p]' e + x'C'A'[Ae - s] \tag{5}$$

where λ_b=C·s = C·A·e. Since where is this linear relationship between the constraint and the shadow price, we can eliminate the constraint and get a typical well-behaved revenue (cost) function. In general terms, if we expand the problem of finding a revenue function, a quadratic function emerges. It means an evaluation of the desired vector "s" is possible if we use certain technology and costs. For this is:

$$E = [c-p]' e + .5e'Q_1'e + e'Q_2'\lambda + .5\lambda' Q_1'\lambda] \tag{6}$$

In equation (6) matrices Q_i can be obtained by maximum entropy ME [6]. As a follow up, matrices Q_i can be derived by a single observation or more. ME is a quasi statistical procedure, used in cases of limited information [6]. ME is a method that follows a certain strategy of calibrating models [6] along probable sets of coefficients and constraints (set here by ecologists).

III. ECOLOGY, SPACE AND MANAGEMENT

Then entering into a real exercise of valuation, questions, to be solved, are: how to 1. integrate ecological concerns for wildlife into a farming area, 2. evaluate nature in this context, and 3. derive the necessary interface. We work with a spatial "nature production function". The concept is based on a deliberate planning for eco-system services and associates nature primarily with changes in field structures of landscapes [7]. To model interactions, system compartments have to be interactively modelled by explicitly defined interfaces such as spatial units in nature (see soon). We use a stylized spatial representation (Fig. 1 and 2). In this respect the paper makes suggestions how to compromise and provide a realistic approach for management, such as payments and regulations in land use.

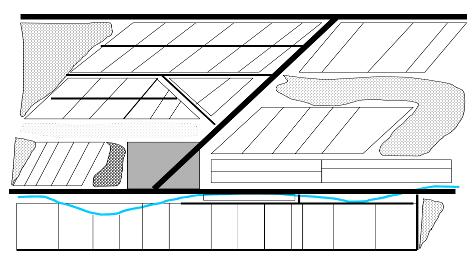

Fig. 1: Modern land use structure

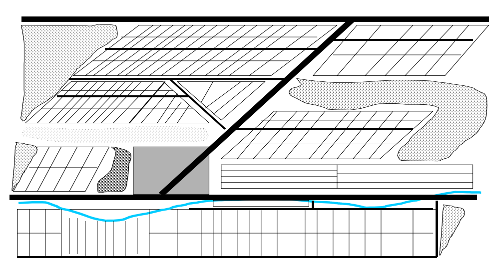

Fig. 2: Traditional land use structure

The corresponding is a spatial outlay of farms and fields (Fig.3); it can be translated into vectors. Vectors can be large. Additionally we need information on current design [7] as a reference and departure. From a

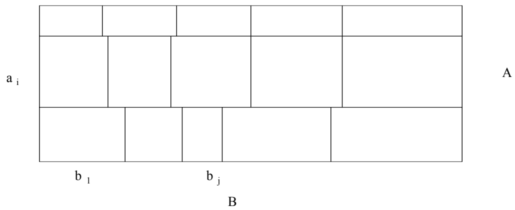

Fig3: Stylized structure of landscape

technical point [7] the above setup fits a mathematical scheme which contains "effort" (activities) of farmers.

$$s \;=\Xi_{e}^{'}e+\Xi_{x}^{'}x \qquad (7)$$

Where: e=[a-a$_0$,b-b$_0$,y-y$_0$,u,l]. Remarks on variables and the possibility to get function (4) are necessary. For a depiction of different species scenarios and a calibration, we either can take an initial situation as a reference or artificially simulate reference situations.

For applications each element in the above formula must be explained. I.e.: 1. For the first segment we introduce "buffer strips: u$_o$" and argue that an increase of strips "u" augments the possibility of suitable habitats for "s". 2. We consider current strips c$_0$ and ask how nature improves if more labour "l" is added. Since labour is proportional to strips, strip sizes can be reduced if farmers work more. 3. Investigating the size of fields (a·b, we take into account the important result of landscape ecology that an increase in the number of fields (a decline in the size: a-a$_0$) increases the number of edges and diversity of fields and cropping patterns increase biodiversity [8]. 4. We include change in intensity (y-y$_0$) as positively correlated with herbs in "s".

IV. NATURE SUPPLY BY FARMERS

The aim is to get an elaborated necessary payment scheme for activities "e" which are given by "c". If we use a quadratic exposition of the programming of farm behaviour [7], the noticeable change in farm behaviour is compensated on the basis of a deviation from an optimal economic plan. As can be shown [7], a concise depiction of the objective of farmers is again a quadratic function resulting in a modelling approach (8):

$$P(.) = p^{'}q + c^{'}e - \pi_1^{'}q - \pi_2^{'}e + .5[q-e]^{'}\,\Pi_1 [q-e] + .5e^{'}\Pi_3 e + [q-e]^{'}\,\Pi_3^{'}z \qquad (8)$$

Then a supply system for "s" can be derived from the specification if derivatives to e and q, being taken:

$$\partial P/\partial q \;= p-\pi_1^{'}+\Pi_1[q-e]+\Pi_3^{'}z=0 \qquad (9a)$$

$$\partial P/\partial e = c \;-\pi_2-\Pi_1[q-e]+\Pi_3 e-\Pi_3 z=0 \qquad (9b)$$

Eliminating "q" gives is a linear representation of the behaviour a farm community with respect to incentives "c". Note "c" is a now payment (structure); but "c·e" is also costs of pursuing ecologist's interests

$$e \;=\pi_f+\Pi_{f,1}c+\Pi_{f,2}z \qquad (10)$$

This relationship specifies interaction of "q" and "e" whereas "e" is determining "q". Additionally we can summarize all exogenous variables to x$_f$, incl. output prices, etc.; i.e. exogenous variables x$_f$ include farm "economics", and we can match farm behaviour in:

$$s \;=\Xi_{e}^{'}[\pi_f+\Pi_{f,1}c+\Pi_{f,2}z]+\Xi_{x}^{'}x \qquad (11)$$

Similarly solving in (9b) for "q" gives a, by ecologists and citizens moderated and preferred, farming system (or supply of farm produces) which matches with references of citizens. For instance, it may include meadows. If this is of concern it has implication for the landscape since policy changes cropping patterns, for example introducing grass land; we see that later.

V. MARGINAL WILLINGNESS TO PAY

To be consistent with the above approach we presume that a certain overall willingness to pay exists, though it has now to be derived from a "constructed" consumer. The basic idea is that a consumer or visitor appreciates a certain set of species appearing as been designed by ecologists. For instance a willingness to pay may have been detected for a nice landscape, though this can not be directly attributed to species and design. Rather researchers have to infer the evaluation from observation. To construct such a decision framework of citizens we presume that a preference order for utility is given be by a certain *wish* criterion "a": for example, an index of satisfaction with a walk. It can be constructed and is composed of a component of 1. private goods, delivered by tourist industry "z", 2. species or nature appearance "s", delivered by nature conservation units, and 3. landscape quality "q", delivered by farms; "q" is included as farming system.

$$\Theta_{cz} z + \Theta_{cs} s + \Theta_{cx} q \geq a \qquad (12)$$

Visitors minimize costs (primal) given the constraint of index of achievements by their visit to be met.

$$\text{Min !} \{ p' z \} \qquad (13a)$$

$$\text{s.t. } \{ [a - \Theta_{cz} z + \Theta_{cs} s + \Theta_{cx} q]' \tau + \zeta' z \}$$

and the corresponding dual is

$$\text{Max ! } \{ [a - \Theta_{cz} z + \Theta_{cs} s + \Theta_{cx} q]' \tau + \zeta' z \} \qquad (13b)$$

$$\text{s.t. } \Theta'_{cz} \tau \leq p$$

After solving the problem, a corresponding utility function which follows the above concept of constructing quadratic benefit functions is obtained depending on shadow prices. Activity levels of a constrained vector of index "a" are obtainable. "τ" provides marginal values and demand function "z". Both are dependent on levels of species as well as landscape appearance.

$$V(z, \tau) = .5\tau' \Psi_1 \tau + \tau' \Psi_2 z + .5 z' \Psi_3 z \qquad (14)$$

Subtracting marginal equations after optimisation gives a solution for a demand function of "s". As dependent on the shadow price, index, and type of agriculture, it can be calculated as residual response

$$\Psi_1^* \tau = \Psi_2^* a + \Psi_3^* s + \Psi_3^* q + \Psi_5^* x_z \qquad (15)$$

By representation (15) a "derived demand" for species (and landscape) can be established. It depicts payments of citizens as dependent on internal pricing of shadow prices τ for constraint "s"; i.e. design matters.

VI. ECOLOGISTS AS MANAGERS

Now, the objective of a manager has to be integrated. By integration we intend to get a "balanced" biodiversity between farmers as suppliers, citizens as users and ecologists as mediators; though there are conflicting interests. Citizens want to pay few for big results showing their preferences. Farmers want to change little but receive high payments. Ecologists want to have a nature that is following their science based knowledge. They want to spend much but normally may receive small money. However, the difficulty is to match the different perspectives in a desired vector of species as valuation problem. As shown, the expert's preference function can be expressed in terms of unit costs "c" and the stated objective "s".

For this we start modifying the analysis and think there is a deviation between ecologists' perspective s_n and citizens perspective s_c. An ecologist's preference function is based on s_n; it can be expressed in terms of unit costs "c" for measures and stated vector becoming:

$$N = .5 s_n' \Phi_{b1}' s_n + s_n' \Phi_{b2}' c + .5 c' \Phi_{b3}' c + s_n' \Phi_{b2}' x_e + c' \Phi_{b2}' x_e \qquad (16)$$

The ecologist is the citizens' agent, though he wants to do more. His decisive problem is to determine the "correct" s and c along an "equilibrium" or balance. As said, we may distinguish the provision of biodiversity through experts, who follow the nature driven concept "s_n", and consumer/ citizen concept "s_c". For a compromise we see the expert following the approach to get money by offering "s_c" and immolating "s_d", a deviation, in his preference function. Though he maintains his knowledge, he pretends. The question is always how approaches are linked to the costs "c". We introduced vectors that enable us to depict the conducted pursue of wishes from a preference function. $s_n = s_c + s_d$.

Note it expresses the species vector of the nature expert as citizens' preference plus deviation. As an assumption the citizens' preference is exogenous to the ecologist. He gets information from the willingness to pay which is quantity "s_c" multiplied by (shadow) price "τ". The decisive thing is that the agency (ecologist) conducts the final, now quadratic, version of a flexible benefit function as an agency that should pursue a "public" task, though by deviation it ("she") follows expert knowledge. Remember, the benefit function contains already knowledge of the ecological expert. Then we supplement the preference by two aspects: (a) labour costs and (b) a profit or surplus.

A surplus element C(ι,l) is considered as a bonus for working in nature conservation. Benefits shall marginally succeed costs. Now let us assume the ecological expert has to pursue a different vector of preferred nature vector s_c due to budget constraints to be met. It traverses s_c, "preferred", into the ecologists' frame s_n, “needed”. Inserting this measurement for a citizen oriented governance is equivalent to a biodiversity index. The wished ecologist’s governance is:

$$G = .5s_c^{'}\Phi_{b1}^{'}s_c + .5s_d^{'}\Phi_{b1}^{'}[2s_c + s_d] + [s_c + s_d]^{'}\ \Phi_{b2}^{'}c$$
$$+ .5c^{'}\Phi_{b3}^{'}c_n - d^{'}l \ + [s_c + s_d]^{'}\ \Phi_{b4}^{'}x_e + c^{'}\Phi_{b5}^{'}x_e$$
$$+ \lambda_f[\tau_c s_c - [c^{'} - p^{'}]A\,e \ - d^{'}l\ ] + C(\iota, l) \quad (17)$$

The amended objective function (17) contains financial aspects as a budget constraint. We get an expert objective function which is the ecologist’s interest function, but conveys public welfare. It recognizes the requested delivery for citizens as exogenous. Function (17) can be optimized to s_d and λ_f which means that the deviation is minimized. This gives the stake of the nature experts as marginal objective (interest) function.

$$\partial G/\partial s_d = \Phi_{b1}^{'}[s_c + s_d] + \Phi_{b2}^{'}c + \Phi_{b4}^{'}x_e - [c^{'} - p^{'}]\lambda_f = 0 \quad (18a)$$
$$\partial G/\partial \lambda_f = \tau_c s_c - [c^{'} - p^{'}]A\,[s_c + s_d] - d^{'}l\ ] = 0 \quad (18b)$$

In this system the second equations is multiplicative in “$\tau \cdot s_c$” and $[c' - p']A[s_c+s_d]]$; it is non-linear. But we can approximate it using a reference and Taylor approximation, because we look for deviations. Then

$$\Phi_{b1}^{*'}s_c + \Phi_{b2}^{*}c \ + \Phi_{b2}^{*}\tau + \Phi_{b4}^{*}x_e = 0 \qquad (19)$$

is the behaviour of the ecologist as being the coordinating and designing agency following its expertise.

VII. EQULIBRIUM

Finally we can use the equations as tool to derive a simulated equilibrium for valuation of shadow prices. In the above outline we derived a system of five equation with c, λ_e, τ, s_d and s_c as endogenous variables. For the derivation of variables a matrix algebra is can be used or the equations are inserted to each other.

VIII. CONCLUSIONS AND OUTLOOK

In the above outline we derived objective (interest) functions of participants in a landscape design to be publicly managed. The objectives have to be integrated. Hereby we intend to get a “balanced” biodiversity and evaluation as jointly done by farmers as suppliers, citizens as users and, importantly, ecologists as managers. Therefore we applied shadow prices adjustments based on scarcity. Note there are conflicting interests. Citizens want to pay few for big results showing their preferences. Farmers want to change little but receive high payments. Ecologists want to have a nature following their science based concept of ecological knowledge and spent little money, even having money at all. The difficulty is to match different aspirations discerning the “equilibrium” of species. We suggested doing matching by shadow price analysis.

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