# Preservation of Bio-Diversity, Heterogeneity of Farm Practices and Payments for Cultural Landscapes under Inhomogeneous Natural Conditions

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Abstract:

The paper explores the question of diversity in agricultural practice as related to bio-diversity and landscape appearance. It starts with the observation that, in the past, diverse natural conditions have considerably impacted on adapted modes of agricultural production, more than today, and that previously performed farm practices were strongly affiliated with specific natural conditions. These practices positively contributed to a modified, diverse and man-made environment which is frequently considered a beautiful landscape. This has changed dramatically. Particularly, where the European countryside is regarded a natural heritage, today, the public seems to be worried about modern farm practices. After the adoption of modern techniques, farmers prefer to apply unified production technologies and tend to set-up uniform farm structures and product mixes as well as land cultivation practices based on purchased inputs. Farm operations equalise natural conditions and contribute to uniform land rents.

However, a rising public concern for the preservation of bio-diversity is asking for change and new measures. Additional to regulations on farm practices governments seek to compensate farmers for nature preservation and production of bio-diversity. Presuming that high bio-diversity is dependent on diversity in agricultural practice and landscape appearance due to preserved natural conditions, the paper develops a model that links payments to diversity in farm practice and natural conditions. The applied model is landscape-oriented and classifies farm behaviour according to agronomic conditions. A reference system for a unified technology is presented and implications for payments are discussed using a behavioural approach. This behavioural approach focuses on regional dynamics in natural condition as major determinants for bio-diversity and payments as determinants for farm practices. Payments are directed to re-establish diversity in farm practices, counteract current technology dominance, and assure a new exposure to nature, though only partly. Diversity becomes prevalent; notably according to an economic calculus of costs and benefits from taxpayers' point of view.

Keywords: bio-diversity, natural conditions, diversity in farming and payments for nature

# Preservation of Bio-Diversity, Heterogeneity of Farm Practices and Payments for Cultural Landscapes under Inhomogeneous Natural Conditions

## 1 Introduction

Until the middle of the last century the countryside of most European countries was characterised by a huge heterogeneity in farm operations as based on variation in natural conditions, based on corresponding heterogeneity in farm technologies, and based on a deliberately preserved, not accidental, remaining nature. However, an identified recent loss of nature and inherited quality of landscape has raised public concern (van Hylenbroeck et al., 1999). Many authors have stressed the fact that farmers have contributed, in the past, to increases of bio-diversity, in particular, by selection of technologies, i.e. plants, practices, etc. (van Mansveld, 1997). Until that time these diverse types of countryside appearance posed no public concern and the countryside had experienced long periods of deliberate positive land development, land consolidation as well as regulated exploitation of natural resources. Also various types of a biological foundation of agriculture and practical management schemes of diversity were implicitly prevalent. Some authors even stress the fact that peculiarly adapted farming systems ingeniously contributed to an up-graded, locally very special, and unique landscape as well as bio-diversity. This diversity would never be found or experienced under pure natural conditions and that the establishment was path dependent and regional distinct (Bonnieux and Goffe, 1998). Also, it seemed that the poorest farmers were most concerned with high biological activity in their communities, since this was the foundation for a livelihood strategy. For instance, up-grading or cultivation of poor soils by enrichment of organic matter, controlled grazing of sheep and goats to combat bush encroachment, establishment of special hedges to combat erosion, etc. contributed to new types of soils, natural-cultural habitats, and micro bio-spheres. As a result, farming was a foundation for a survival of many species as "inherited" from nature and exposed to humans. But this seems to be no longer relevant.

The question is, what has changed so dramatically over the last fifty years (Parry et al., 1992)? As a first hint: In particular, where bio-diversity initially was highest and natural conditions for farming were lowest, nature appearance strongly reserved; so to day: it changed its role from a prerequisite to an obstacle in agriculture. Though agriculture was the most powerful actor in shaping landscapes, it never reduced bio-diversity to such levels as currently experienced in these countrysides. What is the reason? We argue that technologies have changed so strongly that it seems farmers do not need a really sound nature anymore; at least as previously prevalent. In modern words, bio-diversity has lost attraction, because it is only a vague criteria and nowadays its previous functions are taken over by chemical inputs. Though this explanation might be only partly true. Perhaps we really don't know long-term interdependencies and should care about option values. Just think about pesticide substituted natural prey-predatory relationships and log term resistance! However, we compare an initially situation of strong dependency of food production on a diverse nature with almost no dependency.

On the economic side, over the last decades, farmers, with the assistance of modern technologies, reduced heterogeneity in natural conditions. In particular, thanks to technologies offered by input industries, those farmers that lived under less favourable natural conditions were most successful in improving the quality of land from a user's perspective; not the perspective of nature. On the road of industrialising agriculture, evidently, nature lost its functions (which is not only confined to Europe, see Troughton, 1992). Farmers have improved soils with artificial fertiliser, combat weeds with herbicides, act against pests with pesticides, etc. In general farm practices have become uniform and thanks to the benefit of increased productivity, profits in the agricultural sector have also increased tremendously; again, this is more pronounced in the initially lower segment of incomes. Profits and land rents have equalised between regions, natural habitats, and social groups such as peasants and large landowners. In contrast, on the ecological side, as field appearance is concerned (i.e. the mix of a natural remaining vegetation at edges, crop density, and adjacent weeds), this is nowadays nearly the same wherever one goes. This counteracts bio-diversity for which cropping patterns matter (i.e. the number of distinct crops; mono-cultures versus diversity in cultivation). Moroever, crop rotations are relevant now (i.e. length of crop cycles, special sequence of crops and fallow). For good reason, i.e. the income of farmers, operations have been simplified to reap economies of scale and to have a unified production. Such things as large fields, big machinery, easy application rules of pesticides and minimal labour involvement dominate.

However, public awareness on bio-diversity losses has created a situation where governments nowadays seek to pay farmers for re-introducing bio-diversity. With respect to this aim it is our objective to study how payments can be designed so that they support bio-diversity based on farming heterogeneity, not only generally, but location-specifically, and how to address questions of heterogeneity in habitat conditions and farm practices simultaneously (Wood et al., 2000). Location-specific payments mean to reckon prevalent agronomic conditions, i.e. include diversity of conditions into a functional approach on payments. Payments should reflect ecological criteria, being bound to agronomic pre-conditions and farm practices, i.e. to bring pre-conditional agronomic practices into a bio-diversity management concept. Payments for bio-diversity provision have to be verified according to the contribution of farmers to habitat diversity and response to changes in natural conditions. Payments to farmers are discretionary and the size of payments per hectare might discriminate according to the willingness of farmers to abandon techniques that have contributed to uniform practices.

## 2 Background on farm behaviour and programs

As said before, from a farmer's point of view bio-diversity matters little or not at all. In contrast, not only ecologist but also the general public and governments are now very much concerned with preserving bio-diversity (Chapin III, 2000). There is an emerging conflict between how bio-diversity is recognised and how it is connected to heterogeneity in farm operation. Disputes have come to a point where the questions are now: how to preserve a biologically active and most suitable countryside, how to accommodate farmers' needs for fair incomes, how to maximise impacts on diversity of the countryside and minimise distortions, as well as how to establish concise projects on ecosystem preservation. A central focus is the question how a diverse nature can be preserved at minimal cost and how it can be linked to heterogeneity in local farm operation. The countryside, its diversity and ecology are man-made and a joint basis existed between natural and cultural landscapes. For this unstructured problem we need a concise analysis or a reference to bio-diversity and the payment mode.

We believe, that currently many programs which seek to preserve bio-diversity in cultural landscapes are not explicitly oriented to an exploration of diversity in natural conditions, proper instrument design and prevalence of actual land use patterns. Rather, most programs only seem to support special features of agriculture considered ecological sound. The increasingly asked question, whether uniform propagation of environmentally "sound" or sustainable practices is sufficient for achieving increased bio-diversity, is not addressed. In general, a concept is missing that integrates features of heterogeneity, location, potential of farm practice, etc. and responds to ecological systems in a more unified diversity optimisation concept.

A concept that seeks to optimise bio-diversity in an initially heterogeneous natural environment, which is now confronted with a farm management that reduces habitat heterogeneity, has to recognise explicitly the tendency of modern technologies and farmers' will for homogeneity and increased income from uniform operation. Pursuing the idea that voluntary farmer participation is pivotal for the success of programs and corresponding instruments of bio-diversity preservation, the design of programs must go along with income compensation for cross compliance criteria and incentive compatibility. Furthermore, if we want to achieve an active involvement of farmers, a most flexible scheme should be envisaged. In principle, an appropriate methodological concept that offers highest flexibility can be seen in a modified principal-agent scheme where the public, the principal, wants bio-diversity as a response to payments to farmers, the agents. This principal-agent scheme should include a behavioural component oriented towards agents' objectives, i.e. maximise profits from operation. This profit orientation (for farmers) may offer a sound basis for participation of agents in a principal's program of achieving public objectives. The question is how to deal with whole regions? From an ecological point of view we face the problem how to achieve a link between a farmer's behaviour on the one side and diversity in land use on the other side. In order to manage the provision of habitats for biological activities we need an explicit link. Also, from a methodological point of view we have to ask how to achieve a calculus that enables us to determine needed financial support under certain eco-conditions in order to change the agricultural practice, especially with respect to cropping patterns, and cater for several farmers simultaneously in a broader eco-system. Apparently, such an approach can be based on linking spatial economic models with ecological models. The prime link will be established by land use.

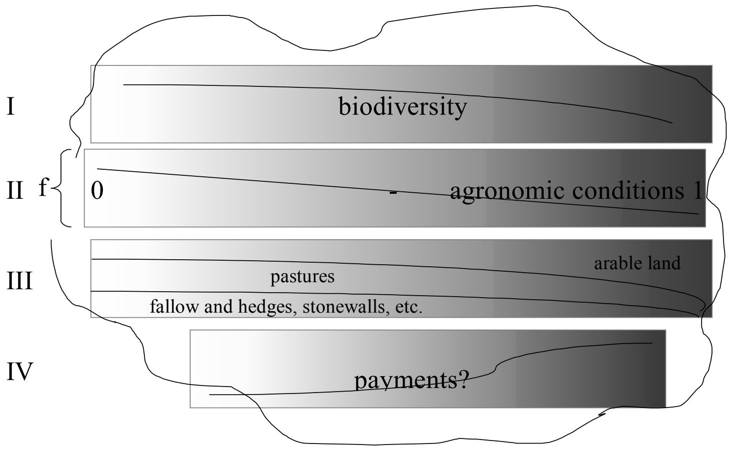
Land use serves as an interface with respect to the provision of an indicator of diversity in farming practices and an indicator of habitat diversity. Land use will comprise at least three categories. First, we will look at ordinary crop land that is, for instance, planted with rye, wheat, rape, etc. Second, we will include pastures and meadows as an alternative with higher biodiversity, notably interactions with crops. Third, crop rotation includes a fallow component, and fourth, we will look at land designated to landscape elements such as hedges, etc. In this context we will deal with a range of farmers. Since diversity in natural conditions is the focus of the study we will build our model along a range of natural conditions that characterise farm land. We will design policy instruments as contingent on natural conditions and practice.

## 3 Formal approach and perspectives for modelling

### 3.1 Concept outline

The starting point is an approach on land use and farm behaviour that reflects the costs of heterogeneity in farm practice. To reflect the different types of approaches to farming with respect to heterogeneity, we opt for a most flexible behavioural function on costs, revenues and profits, and we consider a whole bundle of activities. In Diagram 1 the primary concept is explained along four categories or assumptions. Basically, we assume that landscape can be depicted using strips that are organised along gradients of agro-ecological conditions and that these strips match with ecological conditions and farm behaviour forming territories. Then, towards bio-diversity (category I) we assume, first, that bio-diversity is declining with an increase in agro-ecolgical conditions in a territory (category II). This is supported by observations that ecologist normally are more concerned about less favourable or sensitive areas.

Diagram 1: Concept of modelling and basic assumptions




Second, agro-ecological conditions (category II) are organised on a scale from zero to one and as an assumption, traditionally agro-ecological conditions mix with changes in farming systems (category III). In our context we assume a continuous change. Third, a question is whether modern farming will produce a uniform distribution of farming modes, i.e. more or less independent on linking category II and III. Moreover, another question is what are the empirical effects of II and III on bio-diversity as outlined in category I (see next chapter). Fourth, the policy question is what is a necessary alteration of payments (category IV) to achieve a given bio-diversity by given amounts of money. Making a cost benefit-analysis of a public administrator we will show that curvatures can be determined. Apparently, the whole approach is land use- and territorial-oriented and we assume that we can systemise questions of direction of payments along a gradient approach.

Then we depict a territory or region as the basis for farm production and sum up profits over land in that territory as organisational unit. By that we follow a regional farm concept, for instance, either classified as sub-territories or as numbers of consecutive farms; basically, that needs a ranking according to natural conditions. Natural conditions spread in a unified measurement of information "i". For example, typically, agricultural land is classified between 0 and 100 as a soil fertility index which normally includes slopes, watershed orientation, soil layers, etc. Furthermore, we take a vector on farm produces and land use. This is necessary to establish a continuous farm model. In a second phase we discuss the bio-economic implications for species appearance along a gradient. Note, settings in Diagram 1 serve as an illustration. Any practical application can be organised in a similar way, but needs pre-structuring.

### 3.2 Farm behaviour

For the moment and explicitly, we deal with a very simplified farm operation to make the point of heterogeneity in natural conditions and various links to farm practices and biodiversity. We distinguish two types of farm sales: animal products such as meat and milk at a fixed proportion to land use (as pasture requirements) and production of grains such as wheat, barley, etc. (as arable land requirements). A mixed farm produces both and shows regional response to change in land quality. This impacts on changes in land use, provisionally including fallow, etc. and we opt for a presentation in regional farm model such as

$$P = \sum_j [p_j q_j^s - C(q_j^s, q_j^s - q_j^h, n_j, i)] \qquad (1)$$

where Profits P are determined by:

$p_j$ = farm price (exogenous to farmer)
$q^s_j$ = quantity produced as vector and classified as cropping land (arable land), grassland for animals (pastures), land in fallow (rotations) and land for permanent nature structure ("unused" land)
$q^h_j$ = quantity produced as economic optimal without payment; the difference $q^s_j$ - $q^h_j$ equals zero at first
$n_j$ = non agricultural inputs
$i$ = index on soil and agro-climatic conditions.

Additionally, we may consider an explicit quadratic cost function, as first approximation:

$$C(q_j^s, q_j^s - q_j^h, n_j, i) = \gamma_{10j} q_j^s + \gamma_{20j}[q_j^s - q_j^h] + .5\gamma_1 [q_j^s]^2 + .5\gamma_{2j}[q_j^s - q_j^h]^2 + \gamma_{3j} q_j^s n_j + \gamma_{4c} q_j^s e_j^{\gamma_j^s i} \qquad (1')$$

This follows Chamber's (1988) duality approach using constrained cost functions. In equation (1) a vector of production can most simply be used for explaining the production mix of farmers in conjunction with land use. Farmers' production mix can be directly related to the landscape appearance and habitat formation assuming the existence of a linear relationship between product mix and land allocation such as a given exogenous yields: $\psi_j := q_j /(f\, l_j) \Leftrightarrow q_j = f\, \psi_j\, l_j$ . Yields and carrying capacities per hectare explain land use , i.e. land use "l" can be established in absolute terms or as a percentage of total area "f"; for example, if we define the vertical distance f of a strip in Diagram 1 as "f". "f" is a proportional factor and binds the four types of land use, three types are flexible and the rest is endogenous. In this respect, we assume that farmers have two more types of land beside usual farming: fallow and unused bad lands. Today farmers fallow only because of payments (discussed later and a reason for divergence of q's). Fallow is very important in nature appearance, but in modern farming the function of fallow is substituted by fertiliser and pesticides. Hence, if somebody wants to fallow, for instance, because of a contribution to increased ecological quality, he demands compensations. Second, permanent structures such as hedgerows, ditches, stone walls, etc. are integrated as "un-used bad land". These elements are preferably removed by modern farming because they hamper use of modern machinery. Compensatory payments shall encourage farmers to establish such structures and to prevent them from removal. These changes provide us a land use-oriented representation of regional farm revenues, cost and profits such as:

$$P = \sum_j p_j \Psi_j l_j^s + \sum_j z_i [l_j^s - l_j^h] - \sum_j C(\Psi_j l_j^s, \Psi_j l_j^s - \Psi_j l_j^h, n_j, i) \qquad (2)$$

where additionally:

$l^s_j$ = land allocation with recognition of species or bi-diversity
$l^h_j$ = land allocation of hard core economic decision
$z_i$ = payments

and as an explicit quadratic structure (2')

$$C(l^s_j, l^s_j - l^h_j, n_j, i) = \gamma_{10j}\Psi_j l^s_j + \gamma_{20j}\Psi_j [l^s_j - l^h_j] + .5\gamma_1[\Psi_j l^s_j]^2 + .5\gamma_{2j}\Psi_j [l^s_j - l^h_j]^2 + \gamma_{3j}\Psi_j l^s_j n_j + \gamma_{4c}\Psi_j l^s_j e_j^{\gamma^s_j i}$$

Interactions between land use, farm practice and profits now become directly visible. Again, in equation (2) we can model and recognise "l" as a vector of land use l=[arable land, pastures, fallow, buffer strips]. If no payments occur the region (farm) will optimise according to natural conditions "i" and costs of actively changing farm practices (see below). But, by the inclusion of payments one can gear the direction of change in land use in order to preserve heterogeneity in land use. More general, the allocation of land is reflected in technologies adapted by farmers which is, from an economic point of view, mirrored in the cost function.

### 3.3 Regional farm model and behavioural response

From equation (2) we can derive a convenient linear behavioural response of farmers (to the territory) with respect to payments, technologies and input costs, and can also reckon adjustments in land use with respect to desired changes in landscape appearance. For that we need to include the category of natural conditions in (2) and costs of adjustment. This second aspect is the major theme of this paper. We will explore related aspects in a more enlightening description on the corresponding costs for farmers. So far we just considered farm operations that might be located at a given, well specified, natural condition. However, containing the information "i" on soil quality, etc. (for notification, soil quality might be measured in a point system ranging from 0 to 100 as been widely used in several countries, for instance as in Germany), unit costs per product vary considerably. The hypothesis is: good soils have low unit costs and bad soils are marginal providers because of declining yields. Ordering farm operations according to soil quality we can use a unified approach. A unified and continuous approach offers an integration from highest (land quality categories) to lowest land quality. It is important that we later substitute the sum of profits from individual land parcels by a vector presentation and integral over "i". Then, even important, we add a cost component dependent on changes in land allocation. This component caters for the specific tendency that strong economies of scale (modern technology) in farm production suggest a uniform operation, limit heterogeneity in operation as result of costs of adjustment to location specifics. Again and in principle, in equation (3), the well-known formulation of a contingent farm model is extended to a regional or territorial approach (Chambers, 1988). Additionally, with respect to land use, we only assume that a cost component exists which caters for costs from change of practice reducing adjustment to local conditions. Note, since we have reformulated our analysis in land use categories we find land use and land use change as the relevant category instead of production. For interpretation, if the coefficient in front of the change in land use "Δ" is prohibitive, farmers will have a strong tendency not to alter their production. Technically, as a frequent observation, farmers or regions do not alter production with changes in natural conditions. This is captured as reference in the differential "Δ" in front of land use:

$$\Pi = \sum p_j^* l_j^s + z_i (l_i^h - l_i^s) - \gamma_{10j}^* l_j^s + \gamma_{20j}^* [l_j^s - l_j^h] + .5\gamma_1^* [l_j^s]^2 + .5\gamma_{2j}^* [l_j^s - l_j^h]^2 + \gamma_{3j}^* l_j^s n_j + \gamma_{4c}^* l_j^s e_j^{\gamma_j^s i} - \gamma_{5c}^* [l_j^s - l_j^h] \cdot [\Delta l_j^s - \Delta l_j^{h^2}] \quad (3)$$

In case of equation (3) we still sum-up over soil quality which ranges from lowest agro-ecological conditions to highest in discrete terms. This is most useful for establishing coefficients. Empirically, coefficients that build up the frame can be gathered from econometric analysis. A system of first order derivatives to land use patterns $l^s_j$, the inputs $n_j$, and the deviation $l^s_j$ - $l^h_j$ results in land use revelation. We may use a pooling of farmers at received payments and see reactions. Generalised coefficients become observed and we should find parameters on technologies and practice. Note that agronomic conditions explicitly vary between locations.

$$\partial\Pi / \partial l_j^s = p_j^* - z_i - \gamma_{10j}^* + \gamma_{20j}^* + \gamma_1^* l_j^s + \gamma_{2j}^* [l_j^s - l_j^h] + \gamma_{3j}^* n_j + \gamma_{4c}^* e_j^{\gamma_j^s i} - \gamma_{5c}^* \dot{l}_j^s = 0 \quad (4a)$$

$$\partial\Pi / \partial n_j = \gamma_{20j}^* + \gamma_{2j}^* [l_j^s - l_j^h] + \gamma_{2j}^* \dot{l}_j^s + \gamma_6^* n = 0 \quad (4b)$$

$$\partial\Pi / \partial l_j^h = \gamma_{5c}^* l_j^s - \gamma_{56}^* \dot{l}_j^s + \gamma_{2j}^* [l_j^s - l_j^h] = 0 \quad (4c)$$

As a rule, in case of no payments the presentation follows the criteria that $l^s_j$ equals $l^h_j$, a special case. As a further comment, current payments towards pastures and on types of fallow may be included and serve as measurement basis. Presentation (4) enables us to easily establish a uniform behavioural system in farm sectors, given a frame of agro-ecological conditions.

### 3.4 A continuous landscape territory

So far the system was discrete. A discrete system would mean to solve the problem piecewise, i.e. at any point on the soil and agronomic quality index. Numerical optimisation techniques and programming algorithms are appropriate procedure. But, we seek an analytical solution. The piecewise specification allows no general presentation. Our more general presentation suggests to operate with continuous variations and integration. To do so we opt for a formal optimisation based on the Euler-condition in the calculus of variation. This, compared to standard optimisation, extends the concept of finding optimal moves and uses functionals. Instead of functions, functionals, as been outlined, for instance, by Tu (1991), describe behavioural responses in systems. Changes are in "i", our case the space, i.e. we use space instead of time.

$$\Pi = \int_0^I \{p^* l^s + z\ (l^h - l^s) - \gamma_{10}^* l^s + \gamma_{20}^* [l^s - l^h] + .5\gamma_1^* [l^s]^2 + .5\gamma_2^* [l^s - l^h]^2 + \gamma_3^* l^s n\ + \gamma_{4c}^* l^s e^{\gamma_j^s i} - \gamma_{5c}^* [l^s - l^h] \cdot \dot{l}^s - \gamma_{56}^* \dot{l}^{s\,2} + \ldots\} di$$
(5)

Formally speaking, the Euler-condition provides a criterion for an optimality that involves an ordinary first order derivative component and a second order differentiation component Derivations from differential equations become involved. It is a generalisation of the Maximum Principle including derivatives towards classified system parameters (Tu, 1991) as:

$$f_{l^s}(\ldots) + \frac{df_{\dot{l}^s}(\ldots)}{di} = 0 \qquad (6)$$

Criterion (6) applied to the problem specified in (5) provides a behavioural equation such as:

$$p^* - z(i) - \gamma_{10}^* + \gamma_{20}^* + \gamma_1^* l^s(i) + \gamma_{2j}^* [l^s(i) - l^h(i)] + \gamma_3^* n(i) + \gamma_{4c}^* e^{\gamma_j^s i} - \gamma_{5c}^* \dot{l}^s(i) + \gamma_{6c}^* \ddot{l}^s(i) = 0 \qquad (7)$$

Equation (7) can serve as the basis for further deliberations. Essentially, the equation shows how a change in cropping pattern can be initiated by paying subsidies for land under different land use patterns, for instance, fallow and buffer zone strips as dependent on agro-ecological conditions. Further note that this functional is most flexible in recognising as "functional" relationships between natural heterogeneity, farm practice and external economic factors.

$$\ddot{l}^s(i) = \gamma_{11} \dot{l}^s(i) + \gamma_{21} l^s(i) + \gamma_{31}^* l^h + \gamma_{31}[p\ \ - z(i)] - \gamma_{01} + \gamma_{41}^* e^{\gamma_j^s i} \qquad (8)$$

As a benchmark for analysis it further includes the reference of $l^h$ being equal to the alteration (heterogeneity) of farm practices as dependent on agro-ecological conditions given no payments and current technology. Especially, if costs for alteration of technologies are high farmers will pursue a uniform farm practice. This benchmark analysis will be shown next.

## 4 Land use, land appearance and discussion on comparative dynamics

### 4.1 Without payments

As a reference we can model the situation without payments by portraying land use solely by $l^h$. The reference serves as a benchmark for altering the landscape. Technically we have to use

$$\Pi = \int_0^I \{p^* l^h - \gamma_{10}^* l^h + .5\gamma_1^* [l^h]^2 + \gamma_3^* l^s n\ + \gamma_{4c}^* l^h e^{\gamma_j^s i} - \gamma_{56}^* \dot{l}^{h\,2}\} di \qquad (9)$$

Taking a mode of deriving a "behavioural" function over the differential equation as above is:

$$p^* - \gamma_{10}^* + \gamma_1^* l^h(i) + \gamma_3^* n(i) + \gamma_{4c}^* e^{\gamma_j^s i} - \gamma_{5c}^* \dot{l}^h(i) + \gamma_{6c}^* \ddot{l}^h(i) = 0 \qquad (10a)$$

$$\gamma_3^* l^h + \gamma_6^* n + \gamma_{7c}^* e^{\gamma_j^s i} = 0 \qquad (10b)$$

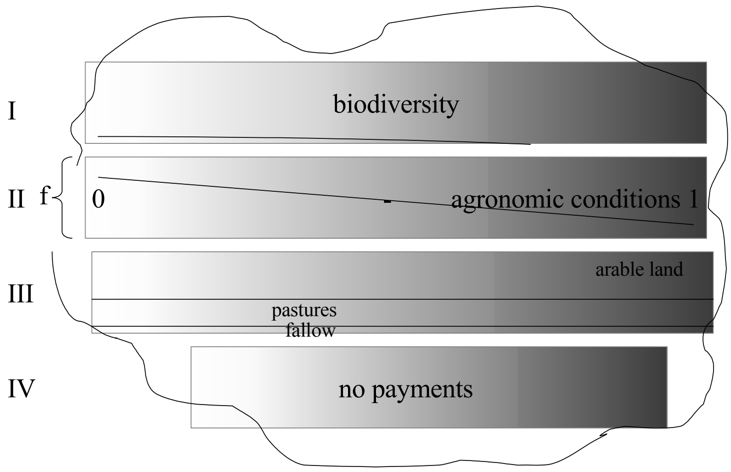
Then subtracting the second equation from the first reduces the problem to a second order differential equation. For interpretation equation (11) offers a solution for land use adjustments over agro-ecological conditions in a generalised mode. A first evaluation of the property of equation (10a) draws on the importance of coefficients in front of the second order derivative. If coefficient $\gamma_{6c}$ is large, costs of adjustment are high. A stylised presentation is like

$$\ddot{l}^h(i) + c_1 \dot{l}^h(i) + c_2 l^h(i) + c_0 + c_3 e^{\gamma_j^s i} = 0 \tag{11}$$

It reveals that, if the coefficient $c_1$ is small (Tu, 1991), a small $c_1$ is equivalent to low values in an exponential equation; i.e. farmers' choice for land use is homogenous of a formal like

$$l^h(i) = +a_0 + a_1 e^{b_j^s i} + a_2 e^{b_j^s i} \quad \text{with} \quad b_1, b_2 = c_1 \pm \sqrt{c_1^2 \cdot c_2} \tag{12}$$

Diagram 2: Expected system behaviour without payments




The theoretical background can be observed in Diagram 2 and Appendix I provides the general concept of solving equations. In consequence, no differentiation of landscapes is the result and this means that bio-diversity will be low (to be shown soon). The more the coefficient $b_1$ equals zero; i.e. the constant is only relevant, indicators show increasing homogeneity. However, to make a reference to bio-diversity, we must be clear about measurement and mechanisms for diversity.

## 4.2 Bio-economic modelling and territorial species appearance

The strongest argument for heterogeneity in farm management stems from the important contribution of heterogeneity in land use to species' appearance. Though it is not the intention of this paper to provide deeper insight into ecological deliberations (Chapin III, 2000) and criteria for the need of heterogeneity, we briefly have to touch upon the link of heterogeneity in farm operation and bio-diversity. At least from empirical observation two aspects need to be mentioned. First, ecological science has proved that the variability of cropping patterns (offer of habitats) plays a major role in bio-diversity preservation. The worst thing that could happen from an ecological point of view (frequently portrait as doomsday scenario in ecology), is a uniform farm operation at every locations ignorant to locality. This implies that species at location i are dependent on agro-ecological conditions "i", local pattern of land use "l" and, most importantly, if one caters for the non-homogeneity, prevalent changes "dl" in land use:

$$s(i) = \gamma^*_{12} \dot{l}^s(i) + \gamma^*_{22} l^s(i) + \gamma^*_{32} n(i) + \gamma^*_{42} e_j^{\gamma_2^s i} \tag{13}$$

where additionally:
s(i) = vector of species' composition under natural conditions i

Equation (13) captures these aspects. It needs some further explanation and comments. First, we assume a probable relationship. Coefficients are based on probabilities. Second, an empirical foundation may focus on key species or specifically rare species. Third, the inclusion of inputs "n" (for instance nitrogen or fertilisation per hectare) recognises an instrument farmers use to manipulate natural agro-ecological conditions. This is important, if as a second a benchmark artificial inputs are included for simulation. The two effects of artificial inputs: equalisation of natural conditions and direct negative externalities can be simulated. To make the approach on species in equation (13) compatible with the land change in equation (8) we take the first derivative of species "ds/di" and focus on an equilibrium between both systems.

$$\dot{s}(i) = \gamma_{12}\ddot{l}^{s}(i) + \gamma_{22}\dot{l}^{s}(i) + \gamma^{*}_{32}n(i) + \gamma^{*}_{42}/\gamma^{s}_{j}e_{j}^{\gamma^{s}_{j}i} \qquad (13')$$

Inserting and elimination (Appendix II) of differential $dl^S/di$ gives a structural equation (14):

$$\dot{s}(i) = \gamma_0 + \gamma_1 s(i) + \gamma_2 l^s + \gamma_3 l^h + \gamma_4[p - z(i)] + \gamma_5 n + \gamma_6 e_j^{\gamma^{s}_{5j}i} \qquad (14)$$

(Note that in this context another strategy would be to tax the input use, not pursued here). Finally, to match land use with bio-diversity we alter the presentation of species' change and references for habitats in equation (15). Land use and species are given in one formula:

$$l^s(i) = \gamma_2^{-1}[\dot{s}(i) - \gamma_0 + \gamma_1 s(i) + \gamma_3 l^h + \gamma_4[p - z(i)] + \gamma_5 n + \gamma_6 e_j^{\gamma^{s}_{5j}i}] \qquad (15)$$

which gives the basis for the economic problem for a regional planner facing society wishes.

## 5 Objective functions and payments

### 5.1 Public interest in bio-diversity and model solution

In the previous chapters we have dealt with modelling of farm behaviour with respect to non-homogenous natural conditions and the modelling of species occurrence with respect to changes in land use pattern. In this chapter we focus on the optimisation of government projects that are supposed to preserve bio-diversity. We assume an existing positive relationship between species diversity and landscape evaluation and welfare. To use indices we apply a Shannon-Viener Index for measuring bio-diversity and attribute a positive value to this index.

$$B = \beta\int_0^I s(i)\cdot \ln s(i)\ di = \beta\int_0^I s(i)\cdot \dot{s}(i)\ di \qquad (16)$$

In the equation (16) the logarithm is substituted by the first derivative which holds for small changes. Alternatively one could think of a more complex benefit function; however, that would not alter the argument substantially. Next we have to consider the costs of a society.

There are many deliberations on the appropriate way to specify costs. In practice it has been argued that costs of distorting allocation should be taken. However, this depends strongly on the problem defined and on who is addressed doing the job of bio-diversity optimisation. One immediate way to approach the problem is to choose a manager who perceives the costs as expenditures. With respect to expenditure we assume that a excess burden ρ exists that enables a discounting of tax payers money. We further can think of accelerating the importance of bio-diversity with declining agro-ecological quality. Hence we could put forward different modes of responsibility for costs. However, we might start with the most simple proposition that costs are equal to payments for increasing the heterogeneity of land use. This is admittedly a narrow focus of a bureaucracy maximising either bio-diversity, given payments, or minimising expenditures, given bio-diversity. Notably, if the general objective is cash flows and if a market or willingness to pay exists for bio-diversity, the various points would be equal to a production of bio-diversity in a spectrum of agro-ecological conditions.

The problem can be easily solved as difference between willingness to pay and expenditures in monetary terms. The substance of the argument would be that citizens prefer bio-diversity from different landscapes at varying agro-ecological quality. Anyhow, a simple mode is to state a differential functional similar to equation (17) offering a continuous cost-benefit ratio:

$$H = \int_0^I \{\beta s(i) \cdot \dot{s}(i) \; - (1+\rho) z(i) l^s(i)\} di \tag{17}$$

Then inserting equation (15) in equation (17) provides the final problem for the planner:

$$H = \int_0^I \{\beta s(i) \cdot \dot{s}(i) \; - (1+\rho) z(i) [\gamma_2^* \dot{s}(i) - \gamma_0^* + \gamma_1^* s(i) + \gamma_3^* l^h + \gamma_4^* [p \; - z(i)] + \gamma_5^* n \; + \gamma_6^* e_j^{\gamma_{5j}^s i}]\} di \tag{17'}$$

Equation (17') provides a function dependent on species. Again it can be solved using the Euler condition from above. Note that this is a dynamic (spatial) principal agent approach

$$f_s(\ldots) + \frac{df_{\dot{s}}(\ldots)}{di} = 0 \qquad (18a) \qquad \text{and} \qquad f_z(\ldots) + \frac{df_{\dot{z}}(\ldots)}{di} = 0 \qquad (18b)$$

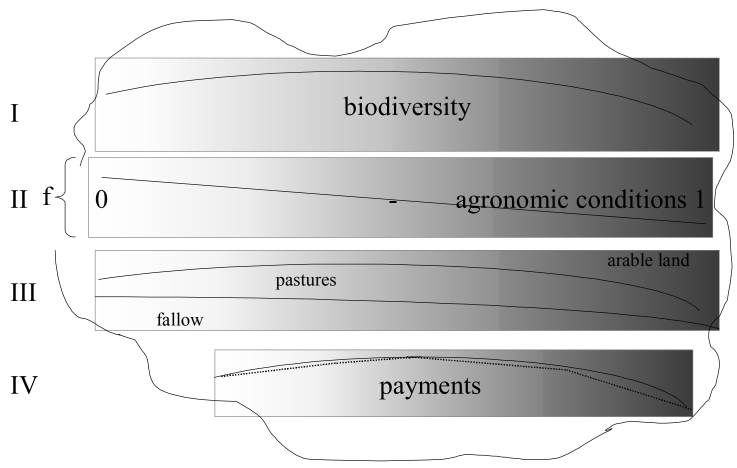
Applying the criteria to policy variables s(i) and z(i) a system of optimal response appears:

$$(1+\rho)[\gamma_1^* z(i) + \gamma_2^* \dot{z}(i)] = 0 \tag{19a}$$

$$\gamma_2^* \dot{s}(i) - \gamma_0^* + \gamma_1^* s(i) + \gamma_3^* l^h + \gamma_4^* [p \; - z(i)] + \gamma_5^* n \; + \gamma_6^* e_j^{\gamma_{5j}^s i} = 0 \tag{19b}$$

Since this is a recursive system of two differential equations, it can be solved quite easily (Tu, 1991). However, note that the analytics are based on vectors and require some special mathematical treatment (Tu, 1991). Essentially, the curvature of the contingent payment is not trivial. For practical reasons a recommended payment scheme, see Diagram 3, can be linearised into sections. Diagram 3 shows the potential of deriving systematic changes and categorise payments according to agroecological conditions; also in line with landscape heterogeneity.

Diagram 3: Bio-diversity with Optimal Payments




For interpretation: First, the payment along the index of agro-ecological conditions z(i) is a differential equation. Second, the inserting of results will provide the achievable total change in species composition (For simulation purpose the system (19) can be analytically and provides a contingent solution to payments). Third, the main argument is that farmers are willing to give up the use of external inputs that equalise the agro-ecological conditions and that species can resettle decent habitats that depend on the interaction of different farm types and land use patterns.

5.2 Merging public and farmers' interests in bio-diversity and alternative models

In the above specification farmers basically were not interested in bio-diversity besides for payments. Because bio-diversity was not entering their immediate objective function provision of land use changes subject to bio-diversity was of no concerns to farmers. However, more recent research and literature on the impacts of bio-diversity has confirmed that increased bio-diversity might also play a crucial role in yields and can be used as an instrument to improve cost efficiency of farming (Sala, 2001). This would mean that bio-diversity should be recognised in farm cost function, apparently, as a shift factor that reduces costs. Moreover the interactions between bio-diversity and, for instance, the use of pesticide should be more explicitly recognised. Assuming that substitution effects between bio-diversity (focusing on the predatory function for pests) exist the costs of chemical pest control will matter. In equation (20) we pursue this idea by introducing bio-diversity as a cost factor in an objective function of farmers. In principle that means the objective function of farmers reappears as

$$\Pi = \int_0^I \{p^* l^s + z\ (l^h - l^s) - \gamma^*_{10} l^s + \gamma^*_{20}[l^s - l^h] + .5\gamma^*_1[l^s]^2 + .5\gamma^*_2[l^s - l^h]^2 + \gamma^*_3 l^s n + \gamma^*_{4c} l^s e^{\gamma^s_j i}$$
$$- \gamma^*_{5c}[l^s - l^h]\cdot \dot{l}^s - \gamma^*_{56}\dot{l}^{s^2} + \gamma^*_{6c} l^s \cdot s + 0.5\gamma^*_{7c} s^2 + \gamma^*_{8c} s\cdot n + \ldots\} di \qquad (20)$$

Consecutively, all functions, outlined above, have to be modified and new behavioural equations have to be derived. Technically, i.e. from a mathematical point of view, this may be an easy extension to be shown as procedure. But it involves an additional environmental economics component. It has to be discussed what role farmers play in public interest from an institutional point of view. If they are purely providers of bio-diversity in landscapes, one can limit the question of farmers' interests to a common public good by applying a principal agent approach. A principal agent approach maintains the response or incentive component as outlined above and public interest still remains with the economic benefits from bio-diversity. Citizens preferences are measured by willingness to pay minus taxpayers money spend on obtaining the delighted bio-diversity.

Alternatively, a benevolent government might also be interested in the distortions created in the farm sector. Distortions in allocative efficiency due to selected payments for "unproductive" land use reduce the land rents to be obtainable from narrow optimisation. That approach is still purely economic-oriented and farmers need not have a special ecological interest. For deriving a measurement for this distortion we can use the benchmark analysis from chapter 3.4 and specify a farm related second part in the government objective function. However, this new analysis would involve a measurement of the relative importance of declining welfare created from distortive activities as compared with benefits from increased bio-diversity. This approach could be build around the presented outline, but goes beyond this paper.

## 6 Summary

In this paper on bio-diversity, heterogeneity of farm practices and natural conditions in landscapes we focused on a model that integrates spatial components and prerequisites of nature provision. First, an overview on the need to integrate spatial aspects in farm behaviour was provided which brought up the idea of a representation of landscapes as differential equations. The basis for such a differentiation was seen in varying agronomic conditions as dependent, for instance, on a soil quality index. Second, we showed how farm or regional optimisation can be used to answer why farmers do no longer care about responses to natural conditions in their farm practices rather use modern technologies to unify farm practices. Third, within this given framework, a payment oriented approach reveals a deviation from such behaviour. Payments are directed to counteract farmers tendencies for unified practices. Fourth, the behavioural approach was used to show, by government optimisation, how costs and benefits of bio-diversity can be balanced in a spatial approach, comfortably and universally.

In the paper we further touched upon the question of an appropriate objective function which integrates public or citizens' and private or farmers' interest. Basic mathematical tools, such as calculus of variation and procedure to solve differential equations, are used in a spatial framework to show that analytical models are able to cater for such things as diversity in species' appearance and heterogeneity in farm practice as well as quality landscapes, simultaneously, the paper provided a solution for an integrated approach. The integrated approach showed its analytical potential. It is important that we can use it for comparative dynamics of payments, reference to output and input prices, and technology shifts which frequently are required.

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## 8 Appendix I:

A solution procedure for exponential equations (Tu, 1991) using reversion of integration is

$$\frac{d}{di} y e^{p\cdot i} = e^{p\cdot i}[\dot{y} + p \cdot y] = 0 \Leftrightarrow \text{integrating}: y e^{-p\cdot i} = c \Leftrightarrow y = c e^{-p\cdot i}$$

It applies to differential equations of first order; it can be extended to higher orders (Tu, 1991)

## 9 Appendix II:

$$\ddot{l}^s(i) - \gamma_{11}\dot{l}^s(i) = \gamma_{21} l^s(i) + \gamma^*_{31} l^h + \gamma_{31}[p \quad - z(i)] - \gamma_{01} + \gamma^*_{41} e^{\gamma^s_j i}$$

$$\gamma_{12}\ddot{l}^s(i) + \gamma_{22}\dot{l}^s(i) = +\dot{s}(i) + \gamma^*_{32}\dot{n}(i) + \gamma^*_{42}/\gamma^s_j e_j^{\gamma^s_j i}$$

which can be solved for:

$$\ddot{l}^s(i) = \gamma^{01} + \gamma^{11} l^s(i) + \gamma^{12} l^h + \gamma^{31}[p \quad - z(i)] + \gamma^{41} n \quad + \gamma^{51} e^{\gamma^s_j i}$$

$$\dot{l}^s(i) = \gamma^{02} + \gamma^{12} l^s(i) + \gamma^{22} l^h + \gamma^{32}[p \quad - z(i)] + \gamma^{42} n \quad + \gamma^{52} e^{\gamma^s_j i}$$