Biodiversity Management through Compensation Payments for Landscape Elements: On Spatial Aspects in Bio-Economic Modelling to Get Cost Effectiveness

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Abstract

This contribution proposes opportunities to integrate ecological objectives and compensation payments for waivers on ecologically unfavourable land use practices into landscape modelling. It is based on a new approach using the ecological insight that heterogeneity in land use and less capital intensive farming positively impacts on bio-diversity and that diverse landscapes are a prerequisite to maintain inherited bio-diversity in cultural landscapes. In contrast, modern farm practices prefer homogeneity in land use and cropping; for instance, ever larger fields, monocultures, and substitution of pesticides for labour are today's common practice. We discuss the basic question, of how an integrated modelling combining both, ecological and economic objectives of nature production and compensation payments, can be obtained, resulting in a cost effective payment scheme where property rights are with farmers.

Geometrical interpretation of land use is a helpful approach for the definition of an interface between farming, landscape modelling, and ecological concerns. This interface is used to model a principal agent approach, in which farmers act as agents and the respective government as principal. It equally combines the economic rationale to have competitive incomes of farmers with the ecological rationale to design a most favourable landscape to preserve biodiversity. In order to integrate ecological oriented nature components into landscape planning, a proper payment scheme based on economic incentives has to be introduced. Such payment schemes become part of the farmers' objective functions in a non-linear model. Core decision variables are the longitudinal stretch of field sizes and the transversal stretch of farm sizes. Ultimately, given various natural frames within an overarching subdivision of field parcels, farms and landscapes are optimised. The suggested approach is sequentially solved, taking natural conditions and behaviour into consideration. Essential elements are fields and their patterns. A central focus is directed to policy instruments: 1. Impacts of price policies on landscape structure (farm size) and ecology (field size) are taken into consideration. The growth of field sizes as a consequence of imposed price pressure, applications of modern technology, and income aspirations are depicted. 2. The ecological impacts of this process, directly related to intensity of farming, are addressed and measured as a diversity index. 3. Policies are selected that maintain farm income and correct for negative ecological effects of field size changes.

Keywords: landscape modelling, compensation payments, bio-diversity, principal-agent

1 Introduction

This paper provides a unified approach on economic and ecological modelling of field sizes, farming intensities, landscape patterns and nature elements. The approach aims to facilitate government specifications of goal functions for bio-diversity and landscape management. These goal functions include ecologically retrievable criteria for payments, consider the farmers' concerns to capture economies of scale to sustain competitiveness and help governments to determine payments. 1. We outline why this is a problem. 2. We show how a geometrical presentation of land use helps us to specify interfaces between economic and ecological units. 3. We elaborate on a nature production functions linked to landscape elements that farmers can be paid for. 4. We show how farm modelling can be directed to landscape design. 5. We demonstrate how the deliberations can be used for principal agent specifications with objective functions for farmers seeking to maximise income from land and a government intending to optimise bio-diversity. A special reference is made to farm size and the question how diversity in land use and landscapes relates to numbers of farmers, field sizes, and main-

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tenance of diversity. The approach seeks a maximum of flexibility in nature provision, and may prove as a valuable preservation tool for cultural landscapes under economic pressure.

There are deliberations that nature services can be provided if farmers care about landscapes, for instance, they do not convert land into a purely production oriented cultural steppe of large fields, but rather recognise ecological concerns. The provision of diverse landscapes has become an economic rational where payments for services are widely accepted by ecologists (Johst et al., 2002). But there are conflicts and problems. Agriculture is confronted with the problem of being identified as less multi-functional – a savage species – that endangers bio-diversity and conscienceless tries to reshape cultural landscapes solely modern agronomic rationales of mass production. For this economic pressures are ubiquitous. In contrast, farmer's ambitions to economise landscapes with growing prevalence of large fields and monotonic cropping patterns are objected by a majority of citizens. It is important to acknowledge that the farmer's behaviour results from the great pressure of international commodity markets forcing them to minimise costs. Cost minimising, in particular, is achieved by increasing field sizes and further use of economies of scale. Yet, the public's pressure on agriculture to adhere to the provision of nature services is still weak and most payment projects are too costly.

A question is, do we have a solution? The conflict may seem artificial, if money is available, but it is also real because a lack of money and low effectiveness of money exists. This leads to the more important question: How can payments be more efficient and targeted towards bio-diversity? One solution for the farmers might be to maximise revenues from real goods (wheat) as well as ecological goods (i.e. species: storks) if they simultaneously receive sufficient compensation. The forthright problem is, that no clear criteria exist for which service farmers should be paid for, how payments should be organised, and if, as much as the product, a landscape, is concerned, how the fact of multiple users of a countryside should be addressed. This paper proposes solutions how landscape oriented payments can be introduced covering ecological concerns addressed by: 1. field sizes, 2. buffer strips, and 3. nature elements.

We examine novel approaches to model the provision of a landscape characterised by diversity and nature elements. The intensity of farming is limited to an extent that provides for bio-diversity. The objective is directed to frequently asked questions, such as where to pay, for what to pay, and how participation can be promoted. The approach is innovative, as it addresses heterogeneity in landscapes and shows how to use non-linear programming for landscape modelling. The model provides three interfaces to bio-diversity in landscapes. 1. The size of a field as an edge driven delineation is modelled by the longitudinal and transversal stretch of a field. Farm size is transversal and dependents on price policies. In this case, cropping patterns determine longitudinal field sizes on existing farms. This way of treating land is similar to a vector presentation. Then we particularly want to show how price policies impact on field sizes. 2. The farming intensity on a field can be geared by labour and optional strategies for input use. Hence, it additionally depends on labour costs and chemical input prices. Payments need to consider this aspect. Normally there are two types of intensification: Either the use of modern inputs such as chemical fertiliser, pesticides and machinery is intensified, or more labour is implied. The economic factors behind such strategies have to be clearly understood and depicted in models using the flexibility of quadratic programming. Otherwise payment schemes are ineffective, i.e. rent seeking, only, or address the wrong farmer. Generally speaking, the definition of labour costs, modern inputs costs, and substitution elasticities between modern input and labour is important. 3. We introduce nature elements such as buffer strips and determine strip sizes in relation to the field size. The intention is to acknowledge farmers' income concerns and behaviour with respect to in/decreases in field size, as ecologically warranted, and compensate losses by payments, i.e. for unfarmed strips. Increases in field sizes seem to be necessary to uphold competitiveness in farming with economies of scale; buffer strips can be adjusted to field size increases and then compensate ecological losses in habitats.

There is a strong need for joint landscape planning with farmers, because they have primarily shaped landscapes by designing field patterns according to economic criteria. The farmers property rights limit the ecologist's desires for diverse landscapes. Consequently, ecologists must be willing to compensate farmers. It has to be noted, that we currently undergo a transition form a more traditional to a modern or even post modern "design" of landscapes. In Europe, farmers will most likely expand field sizes to survive; the numbers of farmers will decline even further. These developments will ultimately result in more uniform landscapes. Simply speaking, a former village of thirty or forty farmers can today be farmed by one farmer. If ecologists intend to counteract, a planned compensation needs to be installed on the long sight. The society may compensate according to presented criteria equally approved by farmers. This paper contributes by outlining conflicting interests in adjusted landscape patterns.

2 Outline of the approach

2.1 General frame

Normally, farms and eco-systems, and also their interactions, are self-organised systems (Naveh, 2000). They may be related to governments who want to maximise bio-diversity at reasonable costs through instruments that influence established behaviour patterns. To model these interactions, system compartments have to be related by explicitly defining interfaces and instruments have to be specified in order to define intervention options. We begin with considerations about land use (Figure 1). Note, specific natural and agronomic conditions matter dealing with specific eco-systems, administrative units, and local conditions. We show how these specifics can be integrated into a land use model, but also accredit needed compromises in complexity. A central problem is to maintain a balance between complexity and operation. In general all models should be capable to depict scenarios of future landscape developments as realistic as possible. However, the integration of heterogeneity in natural conditions, especially in local, ecologically sensitive areas, are difficult to simulate. For instance, if ecological losses are anticipated, they must be noticeable in a mathematical structure suitable for payments to counteract. These losses accrue, if farmers are not addressing heterogeneity in agronomic conditions and field sizes as well as specific ecological concerns in land use. To avoid this we use the concept of nature production function. Additionally, all policies, even if those specifically designed to tackle complex, local problems, must remain operational. A compromise is needed. In this respect the paper suggests a geographical presentation and provides a realistic approach for interventions on field level. Payments and regulations relate to land use.

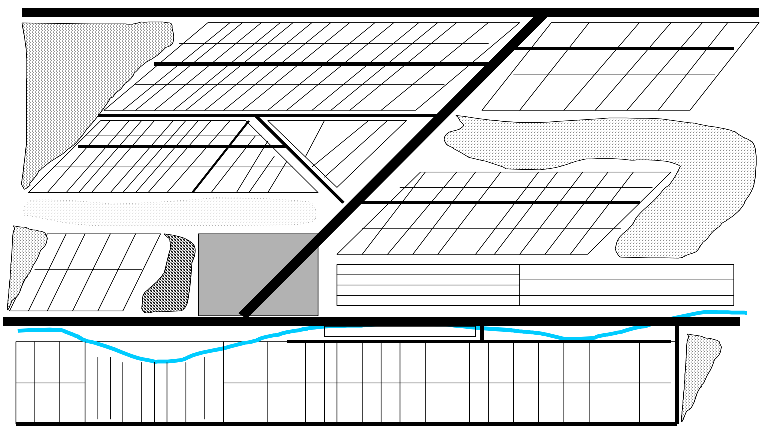
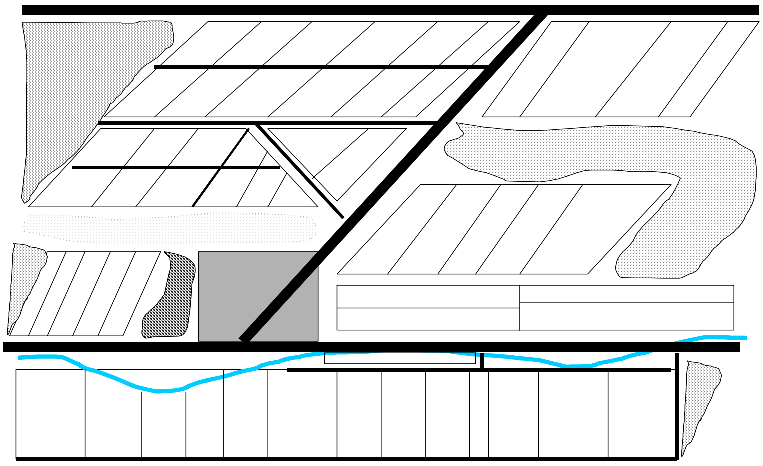


Fig. 1a: Traditional land use structure

For illustration, we begin with a stylised landscape as shown in Fig. 1a, which has so far not been transferred into a "modern landscape". The landscape depicted is composed of sub-units (sub-parishes) with fields organised around agronomic suitable entities in order to serve a large number of farms. Modernization implies a (Fig. 1b) radical switch with only a few farms surviving and field sizes increasing (land consolidation). But, it is difficult to depict and draw a single diagrammatical presentation taking the diversity of crops, rotation, intensity, labour as input, etc. into full account as these are affluent phenomena. Fig. 1 gives an oversight addressing heterogeneity, fragmentation, etc. A threat is that Fig. 1a disappears; we



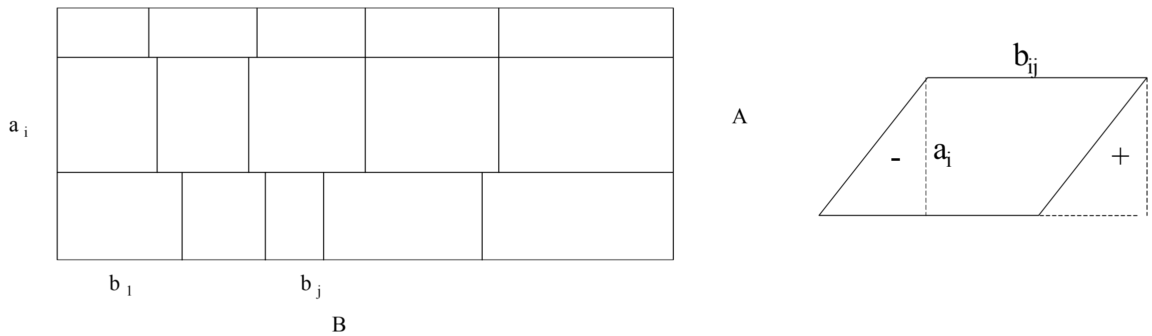
compromise on field structure. As a novel approach for an appropriate analysis we suggest to identify farm sizes, i.e. the number of segments, on the transversal “y”-axis and field sizes, i.e. cropping, on the longitudinal “x”-axis. In case of Fig. 1a we included 24 farms. In Fig. 1b we assumed that 8 farms survived with generally larger fields. As structuring elements we maintained only roads.

Fig. 1b: Modern land use structure

The question arises of how can we model such changes effectively. Our approach suggests to consider landscapes as chess boards: Decisions on size and field organisation become visible and mathematically treatable. We separate land in the spread of farms and their sizes by “y“ and “x”. This geometrically oriented calculation of field sizes can systematically, with some approximation, be redefined as in Fig. 2. Variables such as farm and field size are defined by a_i ,b_{ij} components. Numbers of farms follow vertical and numbers of fields horizontal axes.

The presentation implies a transformation procedure to translate and explain land use as land-quantity and -scape: 1. by map and 2. by mathematics. Vice versa mathematics shall be trans-

a: stylised for mathematical presentation b: calculation of area



where: a_i = transversal stretch of a field (farm size) b_{ij} = longitudinal stretch of a field (cropping pattern)

Fig. 2: Stylised structure of landscape

lated into landscapes. Interfacing farm land and landscape management (fields) we determine the foundation for ecological performance. Such transformation fosters our understanding of interactions in matters. The further approach will be discussed sequentially. It is our declared focus to ultimately achieve an integrated presentation of ecological quality and payments!

2.2 Mathematical presentation of farm land use, landscape planning and ecology

Land, as a spatial entity, is a prerequisite for farming. Harvest is defined as yields multiplied by hectare (later). We address field size as $l_i=a_i \cdot b_i$ and use a Taylor expansion of second order around a reference point to investigate changes in land use. This requires a double sided optimisation (later). For the moment, we aim to linearise as much as possible. Equation (1) express land use in terms of farm “a_i” and field size “b_j” distinguishing them from the start.

$$l_{i,j} = a_i \cdot b_{ij} \cong a_{i,0} \cdot b_{j,0} + a_{i,0} \cdot b_j + b_{j,0} \cdot a_i = A/n \cdot B/m + A/n \cdot (b_j - B/m) + B/m \cdot (a_i - A/n) \quad (1)$$

In doing so, we obtain a function, linear in grid lengths, for further steps.

$$l_{i,j} = \kappa_o + \kappa_1 \cdot (b_j - b_{j,0}) + \kappa_2 \cdot (a_i - a_{i,0}) \quad (1')$$

However, before advancing to an integrated approach of farm behaviour, we have to consider ecological components. We will adhere to a set of ecological criteria, retrievable for farmers. An imminent problem, which we will be addressed in the following text, is associated with the mathematical background of the ecological criteria for payment. Since the later model of farm behaviour with respect to land is quadratic and flexible with field sizes, determined by the rectangular edges, an interface problem emerges. In principle, to have too many non-linearities is dangerous. We solved this problem in our paper by working with the size of a farm first and consecutively deciding on the field structures. This procedure explains, why we firstly optimize along "a", in order to determine the width of the strips to be farmed, and secondly recognise the length of a field by determining "b"; i.e. the final structure of a landscape is due to an iteration. In this context the intermediary is the production or cropping pattern expressed in ecologically conform fields. To achieve this, we need incentives to change the farmers attitude. They are offered by governments to alter field and farm structure.

However, the prime ecological concern remains the field size pattern (Daubert et al., 2003). Changing sizes of fields on the "a" axis (reduce number of farms) apparently increases field numbers already, and it is possible to determine farm numbers as a balance between farming and ecology. Notify, with the knowledge about farm sizes, we can determine the length b_{ij} of fields. A determination of field length by "b" is equally important., Addressing the heterogeneity of fields we provide the background in the following, that a great number of fields is <u>the</u> intermediary. Mathematically the procedure requires firstly a determination towards "a", and then, given "a" an optimisation towards "b". Finally we will iterate solutions. The economic <u>and</u> ecological challenge of land use planning is to understand reasons for modifying length <u>and</u> width. From a farmers perspective with land, just perceived as a homogonous entity, it would be perfect to have just one big field eventually. In contrast, we work with a determination of field sizes and crops by addressing the problem of heterogeneity and ecology.

2.3 Ecological aspects

In this section we specify ecological improvements based on a deliberate planning for ecosystem services and associated with changes in field structure of landscapes. This argument needs to be discussed first, because we will link it to land use and concrete payment schemes for achievements later in the course of further deliberations on farm behaviour. In order to retrieve a transparent payment scheme, services have to be defined. A delineation of payments based on ecological goals rather than mere intermediaries like farm practices has the advantage to increase multidisciplinary communication. It does not obscure ecological objectives with income objectives. However, an immediate problem emerges. From an economic point of view, in modelling we need an ecological goal function related to activities; i.e. we need a "production function for nature", though that is not an easy task. Compared to agricultural production "nature production" is a risky endeavour. For instance, since nature is a self-organising system, it does not seem worthwhile to pay farmers for actual appearance of storks (Johs et al. 2002), rare plants, amphibians, etc. It rather makes sense to look at quasi-goals and to be flexible. It is easier to presume a probabilistic approach and see contributions of fields to habitats as key element and interface. The assertion is done in two steps: First we assume a conversion of land into habitats and second of habitats into species. An important question is how to set specific objectives and to specify an overarching objective. We think, if biodiversity is a goal, one can start with a Shannon Index "D_b" (Lichtenstein and Mongomery, 2003):

$$D_b = s' \ln(s) \tag{2}$$

where: s = species vector

Given such measurement, where "s" is a species vector, a further revelation is inevitable. We relate it to spatial organisations of habitats. Including habitats means to address landscape appearance by exploring field structures, specifically and interactively. As habitats may relate to a probability matrix of an appearance of species, habitats translate into species and vice versa

$$s = \Xi h \qquad (3)$$

where: h = habitat vector

Then habitats may decompose into fields "b". For this delineation we consider interactions as necessary. Approximating, we represent species in (4) by 1. the areas set aside "c", i.e. buffer strips, 2. a new landscape structure, i.e. deviations from economically optimal field sizes, and 3. an indicator of yields in farming that reflects the intensity, i.e. use of inputs, all as function:

$$s = \Xi_1[a_0 \cdot c + u \cdot a_0 \cdot c_0] + \Xi_2/A/B[a_0 \cdot (b-b_0) + (a-a_0) \cdot b_0] + \xi_3[1'a_0[1'b] + 1'a[1'b_0]] + \Xi_4(y-y_0) \qquad (4)$$

where: u = additional labour vector for controlling vegetation on buffer strips
c = buffer strip width measured at longitudinal exposure

Some remarks on the capability to get function (4) are necessary: For an accurate depiction of different species scenarios and a calibration of the above ecological relationship, we need observations and experiments. The structure is very close to a structure of cellular automats and simulation methods can be used to calibrate relationships (Steiner and Köhler, 2003). But elements are only attainable with a certain likelihood. We can either take the initial situation as a reference or artificially simulate reference situations. An artificial reference situation might be a situation of no interventions in favour of the cultural landscape. Furthermore we have to explain each element in the above formula: 1. For the first segment we argue that an increase of buffer strip "c" (notice again a vector as for fields j on farm i) augments the possibility of suitable habitats for "s". 2. We may consider current strips c_0 and ask how nature improves if labour "u" is added to improve strips (to come up with nature elements, i.e. planting hedgerows etc.). Labour is proportional on strips. Accordingly, strip sizes can be reduced if farmers work for nature. It has to be noted, that "strips" may currently exist in landscapes and it is a most simple strategy to take them as a reference. Nevertheless, for convenience purposes, we work with linear formulations, because they allow for substitution between strips and labour. The strategy is simple: Labour creates costs and must be paid too. It is now up to the farmers to decide: They either prefer to give up labour or land. This matters very much under different scarcity conditions. 3. Investigating the size of fields, we take important notifications from landscape ecology on habitat structures into account and acknowledge the fact that with an increase of the number of fields (a decline in size) an increase in numbers of edges occurs. A maximum of edges serves as a reference for high diversity of fields and cropping pattern (Dauber et al., 2003). We are modelling this on a micro and a macro scale. Ξ_2 gives the micro (field) impact. ξ_3 gives the macro (length of edges) impact. Again, we might use different, artificially created scenarios as a reference for calibration. 4. We include a measure for yields as a reference for intensity. By this we assume a negative correlation. The increased competition for space within a field and high yields will reduce the number of herbs. In general, for modelling, an immediate mathematical solution is to "redesign" nature in a sense that an image of prevailing interactions can be retrieved. For this purpose we use the Shannon Index as goal function with "s" as a measure of relative species richness. Inserting the species/nature "production" function and looking for constraints on the availability of ecological "input" variables, equation (4) basically delivers interfaces. Land constraints, labour and, hence, finance constraints can be reasons for limitations to nature development and, more importantly, influence competition to and in farming. Alternatively, merely richness "s" is possible.

It is also challenging to address scales of investigation correctly (Dabbert et al, 1999). 1. A landscape is comprised of fields <u>and</u> farmers. Modelling of landscapes with respect to field margins should reveal the number of farms and "a_i" is dependent on the prevalent price levels for products and inputs. 2. If we want to increase or maintain the numbers of farmers concurrent to an ecological friendly farming by adopting practices according to payment schemes, we have to specify the number of farms simultaneously with the structure. 3. Programming this requires that an algorithm between the not filling of slots (potential farms a_i=0) and the payment exists, or, alternatively, we look how payments result in survival of farms. The same applies to the ecology. We have to find algorithms where habitats and fields exist and define their contribution to bio-diversity. We pursue this idea by optional payment schemes, addressing payments to fields and farms. For the ecology, however, the problem that species' prevalence and richness only counts on the landscape level remains. Hence, it is important to notice how vectors are specified and linked. We specify vectors on farm "i" level and field "j" level. In equation (4) vectors appear without index. It means, for instance, b is a vector of

$$b = [b_{1,1},\ldots,b_{1,j},\ \ldots,b_{1,m},\ b_{2,1},\ldots,b_{2,j},\ \ldots,b_{2,m},\ \ldots b_{i,j},\ \ldots,\ b_{n,1},\ldots,b_{n,j},\ \ldots,b_{n,m}]' \tag{5}$$

and where "a_i" is unequal zero, also "b_{ij}" is unequal zero; otherwise zero applies. Logic suggests us to look for necessary "b_{ij}"s from an ecological point of view. Equation (5) represents a spectrum of activities in a landscape necessary for the design of fields and thus contributing to a desired species vector. Similar, vectors are introduced for labour, strips, and farms. But slots can be empty. All depends on ecological substitution possibilities for habitats. The question is, to what extent one can substitute a habitat on farm 1 with a habitat on farm 2. With respect to farm size we have to be cautious and reconsider the physical geographic structure of our landscape. Conclusively, a field can be identified as being owned by a farmer and "owned" by a species. As a final remark on farm organisation: The sum of fields determines farm locations; farmers have transportation costs tending their fields. It is critical to link fields to farms as if they were in their "backyards". To simplify matters, contrary to ownership fragmentation, we assume not every farmer can share a strip in a particular sub-landscape division, a meadow, parish, or village. For instance under these circumstances it is possible to have 12 land parcels per farm. Historically, ownership of land parcels may be traced back to medieval land use and rotation; but we ignore that having consolidated farms.

3 Land use modelling at farm level

Farmers have a certain degree of freedom do decide on the size of their fields. Currently they expand field sizes due to price and cost pressure and this endangers biodiversity (see above). However, many projects and landscape modelling approaches have worked with quasi fixed farm structures (also number of farms) and they did not majorly influence the physical organisation of farms, fields and meadows (Dabbert et al.,1999). The management of farms with respect to landscapes and biodiversity conservation, however, seems to depend crucially on the size, organisation, and composition of fields. The ecological quality of a landscape can be majorly influenced by a decent design of field structure (Daubert, et al., 2003). To address this problem the agricultural economics literature offers two depart modes of analysis. On the one side we have models that initially ignored organisational components of farms. They are purely spatial models of agronomic practices. The methodological background is a raster point; only in a second step, raster are recombined to fields (Kuhlmann et al., 2002). Here a major focus is directed to diversity of agro-ecological conditions and models work by addressing pixels and structural elements. On the other side we have, though modified, but still farm enterprise oriented models (Röhm and Dabbert, 1999), limited in actions with respect to sizes and change of land use; for instance to integrate economics of scale effects under price pressure.

3.1 Basics and Problems on Modelling and Programming

3.1.1 Available tools

To solve some of the analytical problems in land use modelling we suggest the following modifications. We start with the usual objective of farmers to maximise profits. However, a first decision on how to approach profits has to be done with respect to the specification of revenue minus costs, addressing land needs in specific. There are several approaches to include land aspects into revenues and costs. A very simplified mode is to identify gross margins of equal quality land. This approach was traditionally elaborated in the linear programming literature where gross margins were maximized given certain constraints on homogenous factors such as labour, land, capital, etc. This approach is similar to the first step of a linear programming compartment in positive mathematical programming (PMP, Howitt 1995, Paris and Howitt, 2001); though land quality varies and a dual solution has to be calculated that complements the linear approach, achieving continuous supply functions. It has to be critically noted,, that those, who are familiar with programming tools, established in practice since decades, now have trained their minds according to the logic of linear programming (LP) in such manners that reality becomes a construct to fit LP logic. However, recent debates criticise major simplifications in LPs. As a result, PMP has emerged, showing the superiority of quadratic programming. Critical elements are substitution elasticities and limitations to factor availability. For instance, a LP assumes perfect land substitution on farms within an absolute limit of farm size; though land purchases may change this, it still remains a limiting problem. In LP framing very strict criteria exist for decision making, and difficulties emerge with economies of scale, primarily in field size. These limitations of LPs also apply to landscape modelling with LPs. It is critical to model landscapes within a given set up or numbers of farmers, because field structure and labour availability replicate the past. Some experts even argue that land use modelling in LPs is restricted to decision making on crop composition (more ore less rape seed: Kleinhanß, et al. 2002). We think, landscape diversity can not be classified by an inclusion of more or less rape seed to make fields yellow, rather, the topic of heterogeneity in field design is essential. Here PMP is helpful already used for price effects. But our focus is not directed to relative price changes impacting on crop appearance. We seek to model absolute price changes. To further simplify our approach, we use standard technologies; this might imply crop rotation and constraints that normally guarantee a certain visual diversity of fields. Furthermore, a PMP technique can easily be extended to dynamic models.

3.1.2 Search for a new tool

However, taking into consideration the current developments of increases in farm and field sizes in many European regions, especially in peripheral regions with high bio-diversity, a very immediate question arises: How can such developments be modelled in order to identify driving forces beyond the changes in relative prices of crops? Moreover, what are potential steady states, reached after structural changes eliminating nature elements, habitats, etc. occurred? The immediate political question is, will we have and do we want to have landscapes observable in other industrialised agriculture countries, where large farms with large fields dominate landscapes. An analytical tool to answer such global questions is a challenge, since it requires high flexibility on one side and a new type of decision making for landscape provision on the other side. As said, this requires a direction of research, that does not ignore institutional and socio-economic backgrounds, assuming that large parts of land are farmed according to highest land rents (Kuhlmann et al., 2002). In this case, obviously any preservation of small farms would mean compensation payments for ecological reasons. The reason is: Realizing certain types of economies of scale would immediately result in a preferred landscape offering farmers large fields. Any restrictions on fields impact negatively on land rents and will ultimately lead to a request for compensation. But if there is a societal and political will for other reasons than maximising land rents, we have to specify those types of landscapes that work with small fields and/or with buffer strips. How can this be programmed?

Also farming can be very much driven by natural conditions and farmers receive a maximum of yield selecting the right crops at the right place, given agronomic conditions such as water availability, temperature, etc. This would mean small fields or precision farming. It also sounds beneficial for biodiversity. But by any means this type of modelling would majorly reduce substitution capability of land. Large profitable farms need uniform lands. Hence, for practical applicability with due respect to farm management, if hundred percent precision farming is not guaranteed, these models range far away from reality. This creates problems in applying models in landscape planning for payment; one is confronted with numerous farmers who seek compensation for interventions in numerous field size decisions. But making public interferences for getting diversity of landscapes, is a prerequisite for nature production.

3.1.3 New tool

In this paper we suggest a compromise between a very strict farm oriented approach with all the temporary constraints of farm size, labour, machinery, etc. as modelled in LPs, and an agronomic condition oriented landscape modelling approach, abstracting from any socio-economic conditions. The basic idea is to return to the above mentioned spatial concept that includes limited substitution possibilities, but leaves room for model improvements at the level of meadows and decomposed landscape compartments. The approach combines two aims: 1. to develop a tool that can predict changes in farm and landscape composition along current trends of completely implementing economies of scale driven by cost pressure as a consequence of agricultural price policies and decoupled income payments on the one side, and 2. to develop a tool that enables landscape planners to determine compensation payments for ecological services on the other side if financial budgets are limited . Both aspects are equally important, if a certain diversity of landscapes is the common consensus.

We consider the optimisation of tools and instruments that create landscapes with "suitable" field sizes, field and crop diversity, and with the necessary agronomic differentiation of behaviour on plots (fields), etc, as very important. Consequently, we head for a mixture of a quadratic cost approach and yield determination. This approach can be realized using GAMS (Brooke et. al. 1995). We start with one farmer "i", but already keep in mind that we want to extend the approach to potentially multiple farmers "m" and their interactions. Furthermore, we have to decide on the appropriate selection of variables and the relationship between these variables (A list of variables will follow). Most variables of farm modelling adhere to the standard theory of cost function approaches, although a special recognition for production, land and yields is needed. As mentioned before, in a natural science oriented approach, yields for a particular plot are considered as partly fixed. As definition may serve the following rule: the quantity produced is yield times land for the respective crop. Thus, we can reduce the problem to land use. It is notable that yields depend on intensity.

$$q_{ij} = y_{ij} l_{ij} = [y_{ij,o} + \Theta^1_{ij} i_{i,j}] l_{ij} \qquad (6)$$

where: q_{ij} := production on farm i and field j of farm i
y_{ij} := yield on farm i and field j of farm i
i_i = input use vector as intensity
l_{ij} := size of field j on farm i

Using a combination of "natural" yields partly determined by site specific conditions and partly by the use of inputs (intensity), we can profit from detailed field specific agronomic information such as water availability, evaporation, soil fertility, etc., derived from raster models (Kuhlmann et al., 2002). It is crucial to enter this information in payment schemes in the manner described below. In a next mathematical step, land in field "ij" is considered an interior constraint to a cost function. Costs are defined on production levels, starting with crop production. Note, the approach can easily be extended to animal production including the interactions between crop and animals (incl. manure, labour, etc.). For the moment, we assume fodder crops have been defined by internal prices using opportunity costs. Furthermore, right from the beginning of our calculations we use a vector approach, qualifying the summation of items as vector products. Accordingly the total revenue on farm i is:

$$R_i = \sum_j p_{ij} q_{ij} = p_i^{'} q_i \qquad (7)$$

where: $q_i=[q_{i,1},q_{i,2},\ldots,q_{i,m1}]'$ = quantity vector
$p_i=[p_{i,1},p_{i,2},\ldots,p_{i,m1}]'$ = gross margin vector p = p* - c* with p*= crop price c*= unit costs

Now, the profit can be defined as:

$$P_i\ (.) = R_i\ (.) - C_i\ (.)$$

having a quadratic cost function and two constraints, land and income expectations,

$$\begin{aligned} P_i\ (.) = {} & p_a^{/} q_i - \psi_i^{/} q_i - 0.5 q_i^{/} \Psi_{i,1} q_i + q_i^{/} \Psi_{i,2} l_i + \psi_i^{/} l_i + 0.5 l_i^{/} \Psi_{i,3} l_i + q_i^{/} \Psi_{i,4} r_i + \psi_i^{/} r_i + 0.5 r_i^{/} \Psi_{i,5} r_i \\ & + q_i^{/} \Psi_{i,6} x_i + l_i^{/} \Psi_{i,6} x_i + q_i^{/} \psi_i z_i + \lambda_{1i} [z_i - 1^{/} l_i] + \lambda_{2i} [m_i - [w_i^i - w_i^o][1'[H_i^f + i_i^{'} \Theta_{i,1}^2] l_i + w_i^o h_i^t] \end{aligned} \tag{8}$$

where additionally: l_i = land vector (land in field ij: $a_{i,0} \cdot b_j$
z_i = size of farm ($B \cdot a_i$)
r_i = input price vector (including labour costs)
o_i = off farm employment
x_i = exogenous factors including fixed labour availability per hectare as total hours h_i^f

Land and additional labour demand/supply conditions prevail explicitly. For Labour a criteria of income, a salary m_i, is assumed, in which hours of off-farm work are valued by wage:

$$\begin{aligned} & m_i \geq w_i h_i = w_i^i 1' h_{i,j} + w_i^0 o_i \\ & m_i = [w_i^i - w_i^o][1'[H_i^f + i_i^{'} \Theta_{i,1}^2] l_i + w_i^o h_i^t \quad whereas \quad o_i = h_i^t - 1' H_i^f l_i \end{aligned} \tag{9}$$

where additionally: w_i^o= off-farm wage, exogenous
w_i^i = returns to labour on the farm, endogenous

The inclusion of labour is essential. Payments are income components and only a proper balance of requests and effective payments makes programs cost effective. The expectation m_i varies individually. A farmer has to work an amount of hours H_i^f per hectare which is internally priced with w_i^i. By changing intensity i, labour can be augmented. Equation (9) requires the calculation of the shadow price of labour per hectare. Labour requirements measured in working hours are proportionally assigned to a single farm. For clarification: A potential salary m_i, as opportunity cost, is given exogenously to a farmer. By definition it must at least be obtained by farming. Optimising wage earnings on a per hour basis "w_i" the respective farmer is able to adjust labour for income on a labour market and therefore counteract tendencies for chemical intensive framing. Normally we have off-farm labour o_i as balancing income expectations (positive o_i). The concept spells out for all family labour, though sales and purchases may occur. To assure their income, farmers consider changing intensity on farms (augment labour by investment), that is why i (intensity) is appearing. The specifications above invite for a discussion on labour used in landscapes: On the one side, a labour-land-combination is an income generating unit. Without land sufficient income from arable farming and pastures is impossible. On the other hand labour is a cost factor. Labour costs, i.e. wages, determine the competitiveness of farms on world markets. In the presented model we consider it as crucial to appreciate income aspirations. The certain flexibility in this formulation enables us to work with different income levels as aspirations including compensation payments, and we are able to assign income constraints as shadow prices. With this approach we do not only maximise land rents (Kuhlmann et al. 2002), we rather consider farm income as a restriction.

Taking these discussions too a higher level, we propose that an income provision level is the result of summing up individual income aspirations in landscapes. This leads immediately to the question of how to get correct levels of income aspirations from individual farmers. One way of dealing with this question is to construct a reference scenario in which the current situation prevails. Then, bio-diversity management depends on information on income aspirations. There are indications that only detailed studies of the socio-economic conditions in landscapes hint on income differentiations. To achieve this, a reference scenario of landscape development may serve as a basis to calculate a set of viable farms under given price scenarios. The scenarios could be randomly selected and consist of farmers, labourers, storks, vascular plants, any other species with a maximum of eco-tones. To plan means to provide bio-scenarios, farmers will demand money, but it is our task to estimate how much. From within our ecological orientation we have to carefully investigate how much income compensation is required per farm <u>and</u> how many farms exist. To set up a reference or "best" ecological scenario, a government planner must prevail and pay. The model outline can only try to solve the conflict between ecological and economic aspirations by reaching a compromise. For starters we suggest iterations that involves mathematical simulations for these scenarios.

3.2 Mathematical solutions

In the postulated model we try to capture the observation that farm sizes "a_i" increase with opportunity costs of labour and the general tendency to increase the field sizes due to income aspirations. Additionally, farm sizes definitely increase due to heavy investment in machinery, etc. In the context of quadratic programming field size determination means that linear response functions can be derived. However, in this paper we only show a general outline as based on the size of fields and farms. We then resemble to spatial representations by a_i's and b_{ij}'s, because this saves space in the logical presentation of our arguments. The objective function (8) is a special case where we seek to depict observations such as:

- if opportunity costs for farming increase, (given as off-farm salaries) farm sizes increase.
- if field sizes increase, although land with different quality is less important than field size.

Technically speaking an objective function can be optimised for quantities and given constraints as shown in equation (10). In this equation the variables are vectors addressing crops "j" on field "j". Again, for the moment we consider a field vector "l_i=a·b" as a land measure.

$$\begin{aligned} P_i(.) = {} & p_a^{/} q_i - \psi_i^{/} q_i - 0.5 q_i^{/} \Psi_{i,1} q_i + q_i^{/} \Psi_{i,2} l_i + \psi_i^{/} l_i + 0.5 l_i^{/} \Psi_{i,3} l_i + q_i^{/} \Psi_{i,4} r_i + \psi_i^{/} r_i + 0.5 r_i^{/} \Psi_{i,5} r_i \\ & + q_i^{/} \Psi_{i,6} x_i + l_i^{/} \Psi_{i,6} x_i + q_i^{/} \psi_i a_i + \lambda_{i,1}[a_i B - 1^{/} l_i] + \lambda_{i,2}[m_i - w_i^i [1'[h_i^f + \Theta_{i,1}^2 i_i] l_i + w_i^o o_i] \end{aligned} \tag{10}$$

It results in a system of first derivatives that is mostly linear. The system is price dependent.

$$\frac{\partial P_i(.)}{\partial q_i} = p_a - \psi_i - \Psi_{i,1} q_i + \Psi_{i,2}(a_{i,0} b_{i,j} + b_{i,j,0} a_i) + \Psi_{i,4} r_i + \Psi_{i,6} x_i + \psi_i a_i = 0 \tag{10a}$$

$$\frac{\partial P_i(.)}{\partial l_i} = \psi_i + \Psi_{i,2} q_i + \Psi_{i,3}(a_{i,0} b_{i,j} + b_{i,j,0} a_i) + \Psi_{i,6} x_i - 1\ \lambda_{i,1} - w_i \Theta_{i,1} \lambda_{i,2} = 0 \tag{10b}$$

$$\frac{\partial P_i(.)}{\partial r_i} = \psi_i^{/} + \Psi_{i,4} q_i + \Psi_{i,5} r_i = i_i \tag{10c}$$

$$\frac{\partial P_i(.)}{\partial a_i} = \psi_i^{/} q_i + B \lambda_{i,1} = 0 \tag{10d}$$

$$\frac{\partial P_i(.)}{\partial h_i^f} = \Psi_{i,6} q_i^{/} + \Psi_{i,6}(a_{i,0} b_{i,j} + b_{i,j,0} a_i) = w_i^i \tag{10e}$$

$$\frac{\partial P_i(.)}{\partial \lambda_{i,1}} = a_i B - 1^{/}(a_{i,0} b_{i,j} + b_{i,j,0} a_i) = 0 \tag{10f}$$

$$\frac{\partial P_i(.)}{\partial \lambda_{i,2}} = m_i - [w_i^j - w_i^o][1'[H_i^f + i_i^{'} \Theta_{i,1}^2](a_{i,0} b_{i,j} + b_{i,j,0} a_i) + w_i^o h_i^t = 0 \tag{10g}$$

A computer simulation will result in the same optimisation (10a to g) which can be used for calibration. For elucidation, we explore the programming aspects linking (10) to a PMP (Howitt, 1995). We find 7 conditions (incl. "b" and "a") of a behavioural system which we can be used as response system, although we still have to include payments. In our considerations we see system (10) as a reference scenario. Endogenous variables are q, a, b, i, w, and λ_1 and λ_2. The variable "i" varies individually as the vector of industrial inputs on the farms, such as fertilizers, pesticides, etc. applied to different crops. Noticeable, the problem has some nonlinear components: the internal valuation of labour. After some mathematical manipulations it can provide a solution. Exogenous variables are agronomic conditions and prices. Prices “p, r” determine the land use. Additionally, concerning landscapes we have to add land constraints or divisions in meadows; land parcelling is acknowledged as illustrated above (Fig.1).

Remember, we have inserted orthogonal grid lengths at specific cost function as starting point. Optimisation is along a_i and b_i. Alternatively we could have started with $l_{i,j} = a_i\, b_{i,j}$. However, this may lead to further non-linearities. In numerical research, it is advisable to work with programming software only slightly better than linear programming (quadratic programming: GAMS) which avoids too complicated structures in the constraints. There is a great danger of getting off numerical algorithms for optimisation. We suggest, as an anchor, to either choose a current field structure or normalise the spatial organisation by starting with a certain qualitatively justifiable number of farms or fields according to a general description of respective landscapes. For instance, if we investigate a certain number of farms, i.e. thirty, we may divide the distance A by this number. This results in equally sized farms as a reference point and, perhaps, leads to acceptable ways of calibration. Then we re-iterate. Iteration means that, in a first step, we sequentially keep either the grid length or width constant and, then in a second step, we proceed vice versa. This final step is repeated several times.

4 Compensation payments, financial costs and scenarios

Our concurrent problem is to specify payments. A payment specification requires three aspects: 1. the payment criteria, 2. the determination of the contribution size per criteria, and 3. the volume of an overall payment. Equation (11) gives a set of criteria that are derived from previous modelling, i.e. change in field size, size of buffer strips, labour, and yields.

$$g_{i,k}=g_{0,i,k}+ g_{1,i,k}a_{j,i}(b_{j,i,k}-b_{j,0,i,k})+ g_{2,i,k}a_{,i,}c_{j,i}+ g_{2,i,k}(y_{j,i,k}-y_{j,0,i,k})+ g_{3,i,k}u_{j,i,k}+ g_{4,i,k}b_{j,0,i,k}a_i \qquad (11)$$

Basically this means that both, farm and landscape modelling, provide a reference scenario and payments are made according to behaviour changes desired by a government. Furthermore, we suggest to test whether it makes sense to pay beyond field level, i.e. on farm level. From an ecological point of view it would make sense to address fields or parcels of land individually, but farmers depend on money as a basis for their existence. To combine the prevalence of special habitats and their importance in species appearance with farm income we use a mixed scheme. Payments specifically for fields may represent an <u>ecological approach</u>, but fail to assure participation. A <u>farm approach</u>, measured by size “a_i“, should have a strong impact on the ecology, if ecologists prefer small farms and farmers want to be compensated!

The advantage of the above specification is that payments can be individually addressed, though maybe not completely on field and farm level as completely distinguishable amount. Some generalisation is needed. We must remain realistic and test the issue of farm land allocation as well as the issue of fair payments in communities respectively. A major criteria might be that payments within “equal” meadows are the same, otherwise there will be protests from farmers. The question remains what can be differentiated and how can equal payments for equal services be realized. It seems crucial to aggregate payments. By designing payments according to the above payment criteria, we can direct payments to farms and towards ecological goals. In the process we can also summarise and balance payments to ensure participation in schemes and carefully analyse bargaining positions of individual farmers. This is especially important, since we have to show that the product “bio-diversity” can only be realized by addressing strong requests of farmers under consideration of ecological goals.

An immediate step in this direction is to include payments in the income participation constraint (i.e. for m_i, see above). From the side of modelling and programming of farm behaviour the inclusion means that, in order to receive nature services for the society, farmers have to work for nature and devote land to nature consequently losing money from farm products. In exchange they will request money for doing the work. In terms of exchange, reciprocity emerges: Farmers are paid by money and nature receives labour and land as service. Two problems are associated with this paradigm. 1. Who controls and coordinates this exchange? And 2. What is it's objective function? Concerning the first aspect a spatially and ecologically landscape planning unit (a principal) must balance costs and benefits and try to solve conflicts. But, according to what rules, what costs and what benefits should this unit (principal) operate? Furthermore, which responsibilities should be predefined? Concerning the second aspect, from an economic point of view, any interference with a competitive, world market price oriented determination of landscapes implies economic losses. These losses have to be either minimised, if a certain level of ecological goals shall be obtained, or the ecological goals realized with monetary values eventually become competitive. Additionally, we have to be cautious on price policies, i.e. to what extent are variables such as prices really exogenous and payments endogenous. Payment levels are linked to price levels. As reference may serve the competitive pricing according to world market prices. But only the recognition of output price policies and payments may enable us to reconstruct an overall policy that favours more diverse landscapes and that sustain bio-diversity. In this context, the amount of money spent is not an adequate measure of social costs, because it contains a transfer element. Payments are merely financial costs. The actual costs can be calculated in an economically "ideal situation" with no interferences and exact knowledge about value addition. Careful procedural investigations of the situation reveal best policies. But still, procedural questions remain open about the most effective installation of financial benefits for the farmers. It seems feasible to understand them as tools in the process rather than a exact mere measure of actual costs.

A correct system investigation depends on the development of scenarios without interventions. Pure economic optimisation will provide us with a systematic reference. Employing this systematic reference we are able to show how farming under given conditions is optimal, i.e. we receive: $b_{j,0,i,k}$ and $y_{j,0,i,k}$. By farming we understand the spatial organisation of fields. Deviations from the economically optimal field structure through payments j_{uju} lead to value reductions and therefore, we need to define a loss function (12). However, yet another problem has to be taken into consideration: What is the goal of landscape design? In the above setting we were looking for a public good D_b. In this respect goals are exogenous. Alternatively, we can reckon that ecological functions of landscapes are beneficial for farmers. Ecological functions of landscapes can either be appreciated purely by the public or the public <u>and</u> farmers. Unfortunately today's farmers seem unwilling to recognise any ecological functions other than the straight productivity of their soils/ fields and demand compensations. They are hesitant to join into general ecological activities. However, there are indications that farmers understanding of nature services is yet incomplete. If the farmers are oblivious about the profitable impacts of a decent environment in an intact landscape, allowing them, for example, to reduce chemical inputs, they have no incentive to contribute to landscape provision. Consequently, a government has to pay for <u>all</u> services provided. The low recognition of a potential for profit enhancing functions of landscapes is an important issue that has to be clarified with respect to the reference systems. With elevated levels of awareness and understanding a reduction of compensatory payments can be achieved. Nevertheless, we can technically model reference scenarios including the beneficial effects of ecosystems, i.e. "s", on cost functions and substitute eco-system services for chemicals. Technically or mathematically such reference scenarios are possible and should include a species vector "s" dependent on landscape provisions in cost functions of individual farmers.

5 New objective function

5.1 Single farm, constraints and up-scaling

Introducing above deliberations on landscape structure and payments as key elements we modified objective function (10) accordingly including the payment scheme (11). In approaching a concise representation, we focus on depiction of farm size, change in field size, buffer strips, yields, and labour due to ecological concerns. The trade-off for farmers presents as follows: 1. to lose in production, because they comply with regulations set up by planners limiting their field sizes, introducing buffer strips, and therefore increasing work; 2. to gain on the ecological side because they receive compensatory payments; and 3. to maintain flexibility in decision processes with ecological concerns because a variable incentive structure exists. Finally, we use a farm objective function (12) as much as possible by defining objectives relating to length and width of fields. We rewrite the above specification (10) using the new two-dimensional expression in (11):

$$\begin{aligned} P_i\,(.)=&[p_a^{/}y_{ij}^{o}-\psi_i^{/}y_{ij}^{o}+\psi_i^{/}-[\kappa_{0,i}+\kappa_{1,i}a_i+\kappa_{2,i}b_i]y_{ij}^{/}[.5\Psi_{i,1}y_{ij}+\Psi_{i,2}+.5\Psi_{i,3}]+r_i^{/}\Psi_{i,4}y_{ij}^{o}\\ &+r_i^{/}\psi_i^{/}+x_i^{/}\Psi_{i,6}y_{ij}^{o}+x_i^{/}\Psi_{i,6}+z_i^{/}\psi_i][\kappa_{0,i}+\kappa_{1,i}a_i+\kappa_{2,i}b_i]+0.5r_i^{/}\Psi_{i,5}r+\lambda_{i,1}[a_iB-1^{/}[\kappa_{0,i}\\ &+\kappa_{1,i}a_i+\kappa_{2,i}b_i]]+\lambda_{i,2}[m_i-[w_i^{i}-w_i^{o}][1'[H_i^{f}+i_i'\Theta_{i,1}^{2}][\kappa_{0,i}+\kappa_{1,i}a_i+\kappa_{2,i}b_i]+w_i^{o}[h_i^{t}-u_i] \end{aligned} \tag{11}$$

In the new equation we have included payments and a reduction in profits (see 12) compensated within payment criteria. Again we use a step-by-step optimisation. Like before, we start with a fixed (i.e. zero) payment. Then using our knowledge about landscape structures we introduce payments for departure from the initial optimality. Departures are indicated by Δ.

$$\begin{aligned} P_i\,(.)=&[p_a^{/}y_{ij}^{o}-\psi_i^{/}y_{ij}^{o}+\psi_i^{/}-[\kappa_{0,i}+\kappa_{1,i}a_i+\kappa_{2,i}[b_i-\Delta b_i]y_{ij}^{/}[.5\Psi_{i,1}y_{ij}+\Psi_{i,2}+.5\Psi_{i,3}]+r_i^{/}\Psi_{i,4}y_{ij}^{o}\\ &+r_i^{/}\psi_i^{/}+x_i^{/}\Psi_{i,6}y_{ij}^{o}+x_i^{/}\Psi_{i,6}+z_i^{/}\psi_i][\kappa_{0,i}+\kappa_{1,i}a_i+\kappa_{2,i}[b_i-\Delta b_i]]+0.5r_i^{/}\Psi_{i,5}r_i-w_i\Delta u_i\\ &+g_{i,0}+g_{i,1}a_{i,0}\Delta b_i+g_{i,2}a_{i,0}c_i+g_{i,3}\Delta i_i+g_{i,4}\Delta u_i+g_{i,5}b_{i,0}a_i+\lambda_{i,1}[a_iB-1^{/}[\kappa_{0,i}+\kappa_{1,i}a_i\\ &+\kappa_{2,i}[[b_i-\Delta b_i]+c_i]]+\lambda_{i,2}[m_i-[w_i^{j}-w_i^{o}][1'[H_i^{f}+i_i'\Theta_{i,1}^{2}][\kappa_{0,i}+\kappa_{1,i}a_i+\kappa_{2,i}b_i]+w_i^{o}[h_i^{t}-u_i]] \end{aligned} \tag{12}$$

As a new strategic element we include a vector “c” for buffer strips. Up to this point the discussion was limited to farm levels. In the next step we broaden our perspective and investigate whole landscapes. This leads to a summing up of higher order vectors of numerous farmers. It additionally implies that we have to include the size of the landscape as a further constraint. The terms “summing up” and constraints refers to the fact that individual farm sizes have to fit into the landscape. Looking at equation (12) the reader may notice that for sizes of farms “a_i“ payments do not reflect changes but rather absolute terms. Doing so, we aim to control the number of farms and their labour. Only this approach leads to a joint optimisation. For that the considerations above outlined the importance of economic and ecological interactions between farms and their fields. A simple approach of one unified optimisation is difficult to obtain. The resulting mathematical representation already works with vectors. For a mathematically and technically oriented approach, we suggest to work with a complete presentation in vector and matrix form. This furthermore enables us to drop suffixes. As similarly suggested for landscape interactions vectors such as the angles of the fields in “b” can be used systematically. If adding up applies, a long vector “b” in a consecutive manner is:

$$b=[b_{1,1},\ldots,b_{1,j},\ldots,b_{1,m},b_{2,1},\ldots,b_{2,j},\ldots,b_{2,m},\ldots b_{i,j},\ldots,b_{n,1},\ldots,b_{n,j},\ldots,b_{n,m}]' \tag{9'}$$

With this notation we receive double summaries of $B=\Sigma_j^{n}B_i=\Sigma_j^{n}\Sigma_i^{m}b_{ij}=1'$(m-lines and n-lines) b.

5.2 Landscape level planning

Following the above notation, three further and major aspects re-emerge. 1. Reformulation of landscapes for profit maximisation. For those who are farming under market conditions and receiving compensation payments this simultaneously means that the outcome is a “desired” or planned landscape: A landscape, that is equally influenced by ecological and economic goals. Planning means that farmers do what they usually do following the individual and collective rationale. Planning does not mean to impede farmers’ wills! Naturally farmers would object to cooperation, if they lose money as a result of planning. 2. The prices “p”, for crops “q”, and the money “g” paid for services are considered exogenous. Nevertheless, “g” is accepted: I.e.. "g_1" as service "Δb" (change in length), "g_2" as service "c" (buffer strip), "g_3" as service "Δi" (reduction in intensity), "g_4" as service "Δu" (plus labour), and "g_5" as service "a" (small farms) have to be calculated and are dependent on "p". The integration of ecological goals has not been accomplished yet. It means a way has to be found to specify "g". At this point we have to decide which factors of the system are considered to be exogenous and endogenous. At least a decision about payments on landscape level has to be made under anticipation of limited budgets. 3. Whence, what happens to "p"? High "p"s may reduce "g". Optimisation with respect to ecological efficacy will solve the problem only partly.

Finally, for a complete optimisation of instruments two approaches are feasible: Firstly, a full integration of ecological and economic goals into one unified objective function for a landscape can be attempted in which case both quantitative interactions as well as price and payment are endogenous. The second approach is a principal agent approach (Richter and Forobutn,1997). We favour the second one assuming that a landscape provides services according to incentives. In this approach farmers act as agents "A" and the government as principal "P".

6 A principal agent approach on nature elements provision

6.1 Farm goals and response functions for compensation payments in landscapes

To solve the problem in a principal agent (PA) framework, we already modelled farm behaviour. We now suggest to exemplify a functional approach building along quadratic programming and matrices as demonstrated in equation (13). In order to keep the interchange active and practical, a vector presentation fulfils the argument to capture structural and numerical components. With the basic argument of a complete vector presentation of fields in "b", farm sizes in "a", buffer strips "c", "i" intensity (yields) "y", and labours "u", we receive

$A(p,g,a,b,i,\Delta b,\Delta u,\Delta i)=p\cdot y + g\cdot e - \pi' y - 0.5[y'+e]\Pi\,[y-e] + z'\Omega[y-e] + \lambda'\,[\Phi[y+e] + g' I\, e + Zx]=$

$$\begin{bmatrix} p \\ \psi \\ y_o \end{bmatrix}'\begin{bmatrix} a \\ b \\ i \end{bmatrix} + \begin{bmatrix} g_5 \\ g_1 \\ g_3 \\ g_4 \\ g_2 \end{bmatrix}'\begin{bmatrix} a \\ \Lambda b \\ \Lambda i \\ u \\ c \end{bmatrix} -.5\begin{bmatrix} a \\ b+\Lambda b \\ i+\Lambda i \end{bmatrix}'\left[\begin{bmatrix} \pi^{1,1}{}_{1,1} & \pi^{11}{}_{1,2} & \pi^{1,1}{}_{1,3} \\ \pi^{1,1}{}_{2,1} & \pi^{1,1}{}_{2,2} & \pi^{1,1}{}_{2,3} \\ \pi^{1,1}{}_{3,1} & \pi^{1,1}{}_{3,2} & \pi^{1,1}{}_{3,3} \end{bmatrix}\begin{bmatrix} a \\ b-\Lambda b \\ i-\Lambda i \end{bmatrix} + Z^1 x_1\right] + \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \end{bmatrix}'$$

$$\left[\begin{bmatrix} aB \\ m \\ g \end{bmatrix} - \begin{bmatrix} \pi^{2,1}{}_{1,1} & \pi^{2,1}{}_{1,2} & \pi^{2,1}{}_{1,3} \\ \pi^{2,1}{}_{2,1} & \pi^{2,1}{}_{2,2} & \pi^{2,1}{}_{2,3} \\ \pi^{2,1}{}_{3,1} & \pi^{2,1}{}_{3,2} & \pi^{2,1}{}_{3,3} \end{bmatrix}\begin{bmatrix} a \\ b+\Lambda b \\ i+\Lambda i \end{bmatrix}\right] + [\lambda_4]'\left[\begin{bmatrix} g_5 \\ g_1 \\ g_3 \\ g_4 \\ g_2 \end{bmatrix}'\begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 \end{bmatrix} + \right.$$

$$\left.\begin{bmatrix} \pi^{3,1}{}_{1,1} & \pi^{3,1}{}_{1,2} & \pi^{3,1}{}_{1,3} & \pi^{3,1}{}_{1,3} & \pi^{3,1}{}_{1,3} \\ \pi^{3,1}{}_{2,1} & \pi^{3,1}{}_{2,2} & \pi^{3,1}{}_{2,3} & \pi^{3,1}{}_{1,3} & \pi^{3,1}{}_{1,3} \\ \pi^{3,1}{}_{3,1} & \pi^{3,1}{}_{3,2} & \pi^{3,1}{}_{3,3} & \pi^{3,1}{}_{1,3} & \pi^{3,1}{}_{1,3} \end{bmatrix}\begin{bmatrix} a \\ \Lambda b \\ \Lambda i \\ u \\ c \end{bmatrix} + Z^2 x_2\right] \qquad (13)$$

This mathematical equation is a most comprehensive representation of farmers' objectives in a landscape. As quadratic vector presentation of the objective function of farmers in a landscape it is sufficient to provide goal based responses. But how to set up adequate incentives?

In the representation (13), we have included a restriction on the budget "g" available to provide for the farmer's incomes. This creates a problem with respect to non-linearity. Since g_1, g_2, g_3, g_4, and g_5 are part of the description of the budget as well as multipliers of the instruments in the constraint, they enter the approach in a non-linear fashion. As a consequence, for the first derivative we get a joint term of $\lambda\cdot g$. Starting with a full compensation, i.e. to work without a constraint, and then reiterate the non-linearity with the constraint, might solve this problem. Additionally, we recognise that a combination of production and yield is given by: $\partial P_i(.)/\partial q_i = p_a - \psi_i - \Psi_{i,1}q_i + \Psi_{i,2}(a_{i,0}b_{i,j} + b_{i,j,0}a_i) + \Psi_{i,4}r_i + \Psi_{i,6}x_i + \psi_i z = 0$. This interdependence requires a special treatment, because the combination of production and land essentially depends on yields and yields depend on intensity. In the above specification we have only included "y_0" as an exogenous variable. It is a "natural" yield indicating the agronomic situation on a field in terms of the its natural production capacity. For instance, payment modalities can be adapted towards high or low yielding areas. This creates another non-linearity. However, as a final solution, a linear response system can be constructed and optimised. Being a quadratic function (13), the first derivative is a linear function and we obtain equation (14) as response function. In equation (14) the landscape design criteria, payment and ecosystem goal criteria, are given by "y", "g" and "e", respectively. We might distinguish two cases. 1. Again we consider prices for crops to be exogenous (world markets) and use payments as single instruments. This gives an approximate response function on eco-services:

$$e = [\Pi+\Phi]^{-1}\ [[\lambda_0 I + I]g + \Phi y^* + \Omega z + Zx] \qquad (14)$$

where y* is a function of p: $y^*=\Pi^{-1}[p+\pi+\Omega z']+\ldots$determining landscapes in relation to prices. 2. Alternatively, we optimise "p" and "e". This requires more detailed discussions on objective functions. But it reveals price as a secondary instrument, and prices reappear endogenous.

6.2 A government as principal and its objective function

We simplify and drop "p" as an instrument. In equation (14) we solely receive the willingness to change landscape structures "e" according to payments "g" with price levels functioning as exogenous determinants, i.e. if "p" decreases, the expected payments "g" increase. Furthermore our principal (government) is a pure, ecologically oriented government focusing on biodiversity and payments. To successfully integrate, we specify the objective of the principal by maximising "D_b" with a given budget "g". This is the least complicated and perhaps most easily perceivable delineation of a principal's goal. In function (15) a certain level of biodiversity delivered by a landscape design according to payments (the efficacy problem) is assumed. The following steps have been taken: 1. We set D_b as $D_b = s' \ln [s] \approx [s]'[I+[s]]$ (for small numbers the natural logarithm is 1 plus a %). 2. We split structural and response components in equation (4) to get: $s = \Xi^1 y + \Xi^2 e$. 3. With these expressions we receive biodiversity achievements as a combination of initial landscape structure "y" and responses "e":

$$D_b = [\Xi^1 y+\Xi^2 e]'\ [I+ [\Xi^1 y+\Xi^2 e]] \qquad (15)$$

In a next mathematical step we add the budget constraint in (16) and therefore maximise D_b with a fixed amount of money. In (16) we specify the problem around a fixed budget (vice versa is also possible: a given diversity and flexible budget). A shadow price ρ evaluates both:

$$E = [\Xi^1 y+\Xi^2 e]'\ [I+ [\Xi^1 y+\Xi^2 e]] - \rho'[g_g - g\cdot e] \qquad (16)$$

Vector "ρ" contains shadow prices and vector "e" opens up the flexibility for the principal. After the final insertion the problem can be solved for "g" providing the payment structure.

$$E = [\Xi^1 y+\Xi^2 [\Pi+\Phi]^{-1}[[\lambda_0 I + I]g + \Phi y^* + \Omega z + Zx]]'\ [I+ [\Xi^1 y+\Xi^2 [\Pi+\Phi]^{-1}[[\lambda_0 I + I]g + \Phi y^* + \Omega z + Zx]]]] - \rho'[g_g - [\Pi+\Phi]^{-1}[[\lambda_0 I + I]g + \Phi y^* + \Omega z + Zx]] \qquad (17)$$

This (17) represents an objective function in landscape planning for a government as principal, deciding on incentives "g" at given market prices "p". It is based on the knowledge of the ecological and economic landscape components. As Richter and Furubotn (1997) showed it may include participation constraints. Constraints are spelled out in (13) and (14) with “e” unequal zero. Finally we can provide a solution that grants income concerns and reactions to payments. Mathematically first derivatives for “g” will give the payment scheme. Again that requires a reference calculation of “y*” without payments and knowledge on “p”. Scenarios have to be designed for changing prices. Initially, “y” can be defined where “e=0”, and then provide an iterative optimisation of “y” and “e”. Any results give an indication how many farmers will survive endogenously on expenses of a government that seeks to maintain bio-diversity; the number of farms is not the objective rather farmers are agents and determined.

7 Summary

It was the objective of this paper to show how payments for environmental services can be integrated in landscape planning to facilitate a cost-effective provision of bio-diversity. In particular, a goal function for government use has been derived that captures economic aspects of land user concerns on the one side and ecological aspects of public concerns for bio-diversity conservation on the other side. Only with this approach we are able to obtain a joint planning of used cultural landscape. Our derivation of a model for the planning of cultural landscape was based on a geometrical presentation of farm and field sizes. Payments for the provision of landscape elements where included. We introduced an ecological goal function as a Shannon index measuring diversity. Diversity was delineated by spatial organisation of habitats overlapping with farmers’ fields. Then we consider it necessary, that farmers are sufficiently compensated for interventions in their design of landscapes characterised by ecologically preferred field sizes, buffer strips, nature elements and intensity of farming. For this: 1. We assumed that the property rights remained with farmers, but without full compensation. 2. For the planning we developed a unified modelling approach based on a well-known quadratic programming approach and extended it to a principal-agent approach. Our deliberations showed that such modelling is achievable, however, it requires a certain reduction of complexity.

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