Ohl, Cornelia; Drechsler, Martin; Johst, Karin; Wätzold, Frank

Working Paper

Managing land use and land cover change in the biodiversity context with regard to efficiency, equality and ecological effectiveness

UFZ-Diskussionspapiere, No. 3/2006

Provided in cooperation with:
Helmholtz-Zentrum für Umweltforschung (UFZ)

UFZ-Discussion Papers

Department of Economics

3/2006

Managing Land Use and Land Cover Change *in the biodiversity context* with regard to Efficiency, Equality and Ecological Effectiveness

Cornelia Ohl[a], Martin Drechsler[b], Karin Johst[b], Frank Wätzold[a]

February 2006

[a] UFZ-Centre for Environmental Research
Departments of Economics
Permoserstr. 15, 04318 Leipzig, Germany
e-mail: cornelia.ohl@ufz.de, frank.wätzold@ufz.de

[b] UFZ-Centre for Environmental Research
Departments of Ecological Modelling
Permoserstr. 15, 04318 Leipzig, Germany
e-mail: martin.drechsler@ufz.de, karin.johst@ufz.de

Managing Land Use and Land Cover Change *in the biodiversity context* with regard to Efficiency, Equality and Ecological Effectiveness

Ohl, C.[1], Drechsler, M.[2], Johst, K.[2], Wätzold, F.[1]

[1] Department of Economics, UFZ Centre for Environmental Research Leipzig-Halle in the Helmholtz Association, Permoser Str. 15, 04318 Leipzig, P.O. Box 500 136, 04301 Leipzig, Germany
[2] Department of Ecological Modelling, UFZ Centre for Environmental Research Leipzig-Halle in the Helmholtz Association, Permoser Str. 15, 04318 Leipzig, P.O. Box 500 136, 04301 Leipzig, Germany

Abstract

The introduction of conservation-friendly farming measures is an important tool for biodiversity conservation. Recently, a debate has started whether this money is spent effectively, i.e. whether it successfully contributes to conserve biodiversity in agricultural landscapes. Several types of criticism have been raised that are adequately responded by environmental policies leading to spatially and temporally heterogeneous habitats. However existing policies for species conservation are still designed to support one conservation measure only by paying an equal amount of compensation to all land-users carrying out the corresponding measure.

Regarding ecological findings we firstly point out in which cases environmental policies have to be differentiated in space and time. Secondly, we analyse the necessary and sufficient conditions for transfer schemes to exist that are able to introduce a spatio-temporally heterogeneous land use and land cover type. Thirdly, we reveal that strategic considerations of land-owners limit efficiency and fairness considerations of the policy makers when determining the ecologically accurate payment scheme. However – surprisingly – if policy makers seek to minimise their budget required for implementing the desired policy goal, this at the same time guarantees that the individual profits of the land-owners (when performing with the desired policy goal) are as equal as feasible.

Managing Land Use and Land Cover Change *in the biodiversity context* with regard to Efficiency, Equality and Ecological Effectiveness

Ohl, C., Drechsler, M., Johst, K., Wätzold, F.

1. Introduction

A major part of European biodiversity depends on certain types of agricultural land use which are often not anymore economically viable (e.g. Bignal and McCracken 2000, Mac Donald et al. 2000). The introduction of agro-environmental policies for supporting conservation-friendly farming measures is therefore an important tool for biodiversity conservation. In Europe billion Euros are spent on such programmes each year (European Commission 2005). Recently, a debate has started whether this money is spent effectively, i.e. whether it successfully contributes to conserve biodiversity in agricultural landscapes. Several types of criticism have been raised. First, due to insufficient knowledge about the effects of conservation measures on species, programmes impose the risk of failing to create a suitable habitat for this species (e.g. Kleijn et al. 2001). Second, programmes are often directed at one or a few species but do not cover all relevant species in an area (e.g. Benton et al. 2003). Third, the successful conservation of a particular species may require spatio-temporally differentiated conservation measures due to time dependent habitat quality (e.g. Johst et al. 2001).

Adequate responses to these criticisms are agro-environmental schemes that lead to spatially and temporally heterogeneous habitats (cf. Benton et al. 2003). But still, existing policies for species conservation are designed to support one conservation measure only - e.g. mowing a habitat not before the 15th of June – and to pay an equal amount of compensation to all land-users for carrying out the corresponding measure (e.g. Wätzold and Drechsler 2005). Arguments in favour of this kind of policy design are firstly, that it comes up with less transaction costs than a differentiated policy design and secondly, that equal compensation payment is considered as fair with regard to the equality principle of justice and therefore fosters the willingness of land-owners to participate in a conservation programme. However Whitby and Saunders (1996) found that paying an equal amount of compensation to all land-users for certain conservation practices not always lead to lower transaction costs that are sufficient to offset the higher transfers needed to introduce the policy goal (i.e. uniform payments may increase the public expenditure). Moreover in the case of heterogeneous opportunity costs it is doubtful whether uniform payment satisfies land-owners' fairness considerations. Considering the equity principle of justice it could also be perceived as fair if land-owners with higher opportunity costs receive a higher compensation payment.[1] Moreover such policy design may help to conserve some species but it does not create a heterogeneous landscape with e.g. a mosaic of meadows in different stages of succession where all grassland species would find a suitable habitat. Consequently uniform environmental policy design in a biodiversity context in general is neither ecologically effective nor economically efficient; and it is moreover an open question whether this kind of policy design meets the subjective fairness considerations of the land-owners.

In the following *section two* we lay out in which cases habitat heterogeneity is desirable for biodiversity conservation. *Section three* elaborates on the problems of introducing habitat heterogeneity by a numerical example. *Section four* derives the necessary and sufficient conditions for payment schemes to exist that foster spatially and temporally heterogeneous landscape types. In *section five* we analyse the quality of the existing payment schemes with regard to efficiency and fairness considerations in order to select among the set of feasible payment schemes. Finally, in *section six* we summarise our findings and draw conclusions for further research.

2. Why is habitat heterogeneity desirable for biodiversity conservation in agricultural landscapes?

In the face of insufficient knowledge about which habitat is suitable for an endangered species, spatially and temporally heterogeneous habitats are best to satisfy the needs of endangered species and are naturally, the best approaches to protect the variety of different species. As Benton et al. (2003, p.187) strikingly put it „if the environment is sufficiently heterogeneous (?…), different taxa will find their own habitats". However, nowadays, intensification processes in the primary sector as well as uniform design of species conservation measures lead to a monotony of landscapes that is ineffective or even detrimental for species conservation, at least for three reasons:

[1] For different models of justice e.g. see Clayton, 2000; Deutsch, 1985, Montada, 2003.

2.1. Uncertainty - a major problem in species conservation

Knowledge about the effects of a conservation measure on a particular species is often insufficient. Although field investigations, experiments and ecological modelling can serve as tools to estimate the impact of conservation measures on the species under consideration (Frank 2004; Grimm & Storch 2000; Johst, Brandl & Pfeifer 2001; Kramer-Schadt, Revilla & Wiegand 2005), these approaches have shortcomings. Research has shown that management prescriptions that have proved to be effective under experimental conditions do not have the desired effect or have unexpected adverse side effects when implemented on farms (Kleijn et al. 2001). As a consequence, a programme may fail to provide habitat suitable for the targeted species (Berendse *et al.* 2004; Kleijn & Sutherland 2003). Moreover conservation measures suitable for certain landscapes might not be appropriate for other landscapes due to e.g. climatic or soil differences (i.e. differing habitat quality) or interactions with different ecological and/or economic processes. As a consequence, the impact of conservation measures can vary from landscape to landscape (e.g. Johst et al. 2005). Thus, information from the field or by means of experiments is often context-dependent and highly variable. In consequence, complex ecological or coupled ecological-economic interactions are hard to assess. Establishing a heterogeneous landscape with many different habitat types (*habitat mosaic*) is therefore an adequate measure to meet the shortcomings regarding the knowledge of the species requirements. It increases the chance to randomly cover those habitat types which support the species of interest. In other words, if we have insufficient knowledge about which habitat is suitable for an endangered species in the corresponding landscape, this species will survive with the highest probability in an area with sufficient habitat heterogeneity.

2.2. Habitat suitability is time dependent

Another aspect that calls for habitat heterogeneity is that habitat suitability is sometimes not permanent but time dependent, i.e. transient. For example think of growing grass after cutting a meadow (e.g. Johst, Brandl & Pfeifer 2001) or succession sequences in plant or forest communities (e.g. see Johst & Huth 2005 and references therein). Such transient habitats show time dependent habitat suitability for many species. Although these species can cope with the resulting landscape dynamics by specific traits, like high mobility (e.g. Johst, Brandl & Eber 2002; Keymer *et al.* 2000), they need spatial-temporally heterogeneity in form of a shifting mosaic in habitat quality (of suitable habitat). As habitat quality is transient and thus dependent on the point in time e.g. farming activities (like mowing) take place, a mosaic of shifting qualities can only be generated by spatial-temporally differentiated conservation measures.

2.3. Conservation of biodiversity involves the consideration of many-species

Regarding ecological effectiveness, conservation programmes should be directed to more than one - if not all - endangered species in a region (Benton, Vickery & Wilson 2003; Tews *et al.* 2004; Drechsler et al. 2005). Naturally this requires a heterogeneous landscape matching the different species-specific requirements in time and/or space so that each species can find its own habitat (e.g. Benton et al. 2003). For example in the Landau region in Germany various animal species that need grassland habitat - whinchat (*Saxicola rubetra*), and butterfly species, such as the Large Copper, *Lycaena dispar*, and the Large Blue, *Maculinea teleius* - are endangered and protected by the EU Habitats Directive. These species require quite different mowing dates to ensure high breeding success of the birds as well as successful egg deposition of the two butterfly species. Meeting the needs of these three species requires diversified mowing activities that are not covered by the existing uniform payment scheme that call farmers to not mow before the 15th of June (Drechsler et al. 2005).

Our arguments given above (in points 1 and 2) are of course superimposed in the multi-species context. For example it is much more difficult to gain knowledge about the requirements of multiple species to be conserved than on one species only. Above that species interactions arise that are often not well understood. Hence, confessing *firstly*, that uncertainties regarding the desired type of habitat exist and *secondly*, that habitat quality is time dependent, a reasonable suggestion for biodiversity protection is, to establish a spatial-temporally heterogeneous land use and land cover pattern.

3. Protecting endangered species by a spatial-temporally heterogeneous landscape: A numerical example

To protect a diversity of species with different requirements regarding the type and the quality of habitat, agro-environmental policies have to be differentiated in space and time. This calls for a non-uniform design of compensation payment as will be shown with the help of a simple numerical example:

We focus on two land-owners (i=1, 2) and three time periods respectively conservation measures (t=0, a, b). Assume the costs [$C_i(t)$] when switching from t=0 to t=a to be $C_1(a)$=2 for land-owner 1 and $C_2(a)$=3 for land-owner 2; switching from t=0 to t=b may lead to C_1(b)=3 and C_2(b)=3,5; i.e.:

Table 1: Opportunity costs

Opportunity costs / Land-owners	Land-owner 1	Land-owner 2
C_i(0)	0	0
C_i(a)	2	3
C_i(b)	3	3,5

We here assume a case where land-owners' opportunity costs increase with time. The underlying reason for example are that the later the crops are harvested or meadows are mowed the lower is usually their energy content and hence the yields of the land-owners. Additionally the risk of adverse weather conditions increases with the delay of activity and thus decreases the yield expectations of the land-owners. Hence policy design faces the problem that with one uniform payment *all* but not just one desired group of land-owners attempts to shift their measures as close to the status quo period (t=0) as is possible within the time range specified in the payment scheme (case 1, below).[2]

Case 1:

To show that the objective of creating a spatio-temporally diversified landscape is not met by a uniform compensation payment [p_t], assume $p_a = p_b$=4 for delaying activities from t=0 to t=a respectively t=b.

With the offer of p_t=4 it is attractive for both land-owners to switch from t=0 to t=a; they gain 4-2=2 and 4-3=1 respectively. In comparison, a switch to t=b yields a lower profit (4-3=1 and 4-3,5=0,5 respectively). Thus, the offer of one uniform subsidy is unable to diversify the

[2] In section 4., below, we drop the assumption of increasing opportunity costs and show that our results hold for a variety of cost functions. Moreover notice that the focus here could also be on three different conservation measures that should be performed within one or different time periods.

landscape since both land-owners shift their activities simultaneously to the time period closest to the status quo (t=0).

Moreover it can be shown that even this shift is not guaranteed in face of insufficient information on the individual opportunity costs of the farmer: If policy makers due to lacks in knowledge follow a trial and error procedure and start to offer a subsidy p_t<2 the land-owners prefer the stay in the status quo. Consequently to guarantee right from the start that at least one of the land-owners is willing to participate in the conservation program information on the individual opportunity costs of the land-owners is required.

Case 2:

Now the policy maker diversifies the payment scheme and offers a differing subsidy p_a and p_b. We first point out that even a diversified payment scheme (i.e. $p_a \neq p_b$) does not automatically avoid the problem of simultaneous moves. The determination of ecologically adequate payment schemes is thus a challenge for environmental research. To show this we assume p_a=4 as before and p_b=6.

As was the case before, *both* land-owners like to switch simultaneously – now, to t=b. Land-owner 1 gains 6-3=3 and land-owner 2 gains 6-3,5=2,5 which makes both better off than performing activities in t=0 respectively t=a.

Lets assume budget constraints were not given and the policy maker increases the budget for t=a to p_a=4,5 while p_b remains at a value of 6. Still, both land-owners prefer to perform their activities in one and the same time period, i.e. here, t=b. For land-owner 1 the gains from switching to period a: 4,5-2=2,5 are still less than the profit in t=b that amounts to 6-3-=3. For land-owner 2 the considerations are alike, 4,5-3=1,5<6-3,5=2,5. Hence increasing the budget not necessarily solves the problem. Payment schemes that allow to separate the activities of the land-owners have to lie in the range p_b>3,5 and p_b-1<p_a<p_b-0,5 (e.g. p_a=4,7 and p_b=5,5) as will be proofed in section 4, below.

Before we turn to the derivation of conditions that assure the existence of payment schemes, able to introduce a diversified land use and land cover type, we keep in mind that first, in order to avoid adaptations of p_t (a process of trial and error) knowledge about the land-owners' cost functions is already needed to guarantee the implementation of *one* specific conservation measure (e.g. the delay of a mowing activity to one further period); and second, that there is only a certain range of payment schemes that deliver incentives for a group of land-owners to diversify their activities in space and time.

4. The existence of ecologically accurate payment schemes

In the following we derive the necessary and sufficient conditions for transfer schemes to exist those are able to introduce a spatial-temporally heterogeneous land use and land cover type.

4.1. Introduction of the model

To illustrate the coherences mentioned above, we introduce three land-owners numbered i=1, 2, 3 and three activities t=0, a, b. Each land-owner represents a group of land-owners with roughly the same costs for switching their business as usual activities (t=0) to more conservation-friendly ones (a or b). Each representative land-owner controls a certain land area. The objective of the conservation manager is that each of the three measures of concern (t=0, a, b) is carried out by exactly one representative land-owner (i.e. in one of the three spatial areas).

A land-owner i carrying out the measure t achieves a certain profit $\pi_i(t)$. Without loss of generality we scale these profits with regard to t=0, which is achieved by setting $\pi_i(0)=0$ (i=1, 2, 3). The costs of the measures vary. Without policy intervention each land-owner has an incentive to perform activity t=0 (business as usual). In this setting the landscape is not diversified because each land-owner performs the same activity (t=0). If a land-owner switches to activity a or b this leads to opportunity costs (foregone profits) as given by

$$C_i(t) = -\pi_i(t) \qquad (1)$$

We assume each land-owner to carry out the measure that maximises his/her total profit. Given positive opportunity costs for all i=1, 2, 3 and t=a, b, inducing a spatial-temporally heterogeneous landscape requires compensation payments p_t (t=a, b). For a land-owner who switches from t=0 to another activity the profit becomes

$$\pi_i(t) = p_t - C_i(t) \qquad (i = 1,2,3; \quad t = \mathrm{a}, \mathrm{b}) \tag{2}$$

The payments p_{a} and p_{b} have two functions. First they have to induce land-owners to switch from t=0 to another activity. Second, they have to ensure that no activity is performed more than once to implement the portfolio of (here, three) measures. The proper determination of the payments is crucial for the implementation of a spatial-temporally heterogeneous land use and land cover type; it decides on the success of the policy measure, i.e. on whether a pre-specified subsidy scheme is able to avoid similar moves (uniform choices) of the land-owners and to introduce a heterogeneous landscape.

4.2. Existence of payment schemes introducing a spatial-temporally heterogeneous land use and cover type

The design of an ecologically accurate transfer scheme is a challenge for the policy maker. The payments have to be determined such that profit is maximised for one land-owner by carrying out the measure t=0, for another land-owner by carrying out t=a, and for the third land-owner by carrying out t=b. Below such a payment scheme will be called an “ecologically accurate payment scheme”. Initially we do not know which of the three land-owner is willing to switch from t=0 to t=a, and t=b respectively. There are six possible ways of how the land-owners could allocate their activities. Without loss of generality we consider the following sequence: land-owner 1 chooses t=0, land-owner 2 performs with t=a and land-owner 3 with t=b, and investigate whether a payment scheme (p_{a}, p_{b}) exists that achieves this particular sequence. To achieve the assumed sequence we need to fulfil the following inequalities:

$$\begin{aligned} &\pi_1(0) > \max\{\pi_1(\mathrm{a}), \pi_1(\mathrm{b})\} \\ &\pi_2(\mathrm{a}) > \max\{\pi_2(0), \pi_2(\mathrm{b})\} \\ &\pi_3(\mathrm{b}) > \max\{\pi_3(0), \pi_3(\mathrm{a})\} \end{aligned} \tag{3}$$

With eq. (2), fulfilling eq. (3) is equivalent to fulfilling

$$\begin{aligned}
&\text{(a)}\quad C_2(\mathrm{a}) < p_\mathrm{a} < C_1(\mathrm{a})\\
&\text{(b)}\quad C_3(\mathrm{b}) < p_\mathrm{b} < C_1(\mathrm{b})\\
&\text{(c)}\quad C_3(\mathrm{b}) - C_3(\mathrm{a}) < p_\mathrm{b} - p_\mathrm{a} < C_2(\mathrm{b}) - C_2(\mathrm{a})
\end{aligned} \qquad (4)$$

To fulfil eq. (4), three necessary conditions have to be fulfilled:

$$\begin{aligned}
&\text{(a)}\quad C_2(\mathrm{a}) < C_1(\mathrm{a})\\
&\text{(b)}\quad C_3(\mathrm{b}) < C_1(\mathrm{b})\\
&\text{(c)}\quad C_3(\mathrm{b}) - C_3(\mathrm{a}) < C_2(\mathrm{b}) - C_2(\mathrm{a})
\end{aligned} \qquad (5)$$

We now assume that eq. (5) holds and focus on the sufficient conditions for an ecologically accurate payment scheme to exist. To do this we reformulate eq. (4c) into

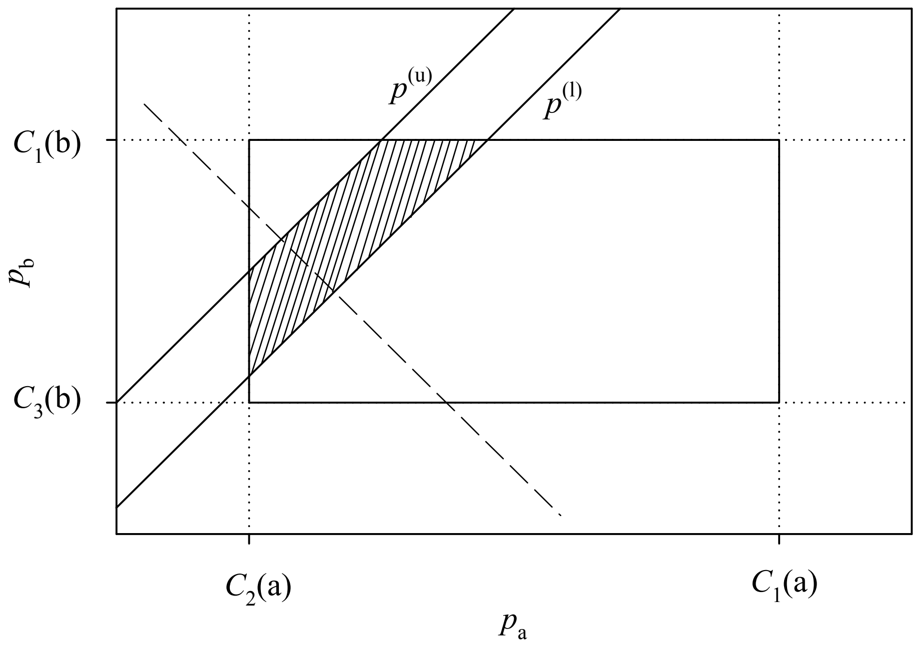
$$p^{(\mathrm{l})} < p_\mathrm{b} < p^{(\mathrm{u})} \qquad \text{with} \qquad (6)$$

$$\begin{aligned}
&\text{(a)}\quad p^{(\mathrm{u})} = p_\mathrm{a} + C_2(\mathrm{b}) - C_2(\mathrm{a}) \quad \text{and}\\
&\text{(b)}\quad p^{(\mathrm{l})} = p_\mathrm{a} + C_3(\mathrm{b}) - C_3(\mathrm{a})
\end{aligned} \qquad (7)$$

Equations (4a, b) and (6) are the necessary and sufficient constraints on the existence of an accurate payment scheme (p_a, p_b). If we identify combinations (p_a, p_b) as points in two-dimensional space and plot p_a from left to right and p_b from bottom to top, then eqs. (4a, b) tell that (p_a, p_b) must lie within a rectangle with left and right bounds given by C_2(a) and C_1(a) and upper and lower bounds given by C_1(b) and C_3(b), respectively (Fig. 1, below).

Equations (6) and (7) tell that (p_a, p_b) must lie within a strip with upper and lower bounds $p^{(\mathrm{u})}$ and $p^{(\mathrm{l})}$, respectively. Altogether, feasible payment schemes lie in the intersection of the rectangle (eqs. 4a, b) and the strip (eqs. 6, 7). Fig. 1 clearly demonstrates the necessity of eq. (5): Without fulfilment of equation (5a, b) a rectangle with non-zero area does not exist and without fulfilment of eq. (5c) a strip with non-zero area does not exist.

Figure 1: Feasible payment schemes (p_a, p_b)



Feasible payment schemes (p_a, p_b) lie in the shaded area (excluding the boundaries) which is the intersection of the rectangle (with bounds C_2(a), C_1(a), C_3(b) and C_1(b)) and the strip with bounds $p^{(l)}$ and $p^{(u)}$.[3]

If an intersection between strip and rectangle exists, policy makers are thus given the opportunity to induce a spatial-temporally differentiated land use and land cover type by a pre-specified subsidy scheme. This transfer scheme has to be designed such that on the one hand it covers the opportunity costs of delay, i.e. the costs of switching from t=0 - the most desired activity from each land-owners' point of view in case of no governmental intervention - to an activity a or b, and on the other hand such, that no activity is chosen by more than one land-owner. Figure 1 shows that such a design is feasible if the strip lies neither above nor below the rectangle (i.e. an intersection exists). This is if the left upper corner of the rectangle is above the lower bound (eq. 7b) of the strip, i.e., if

$$C_1(\mathrm{b}) > p^{(l)}(p_\mathrm{a} = C_2(\mathrm{a})) = C_3(\mathrm{b}) - C_3(\mathrm{a}) + C_2(\mathrm{a}) \qquad (8a)$$

The strip does not lie below the rectangle if the lower right corner of the rectangle is below the upper bound (eq. 7a) of the strip, i.e., if

[3] The dashed line marks an iso-budget line (cf. section 5.).

$$C_3(\mathrm{b}) < p^{(\mathrm{u})}(p_{\mathrm{a}} = C_1(\mathrm{a})) = C_2(\mathrm{b}) - C_2(\mathrm{a}) + C_1(\mathrm{a}) \quad (8b)$$

To summarise, ecologically accurate payment schemes exist if and only if a rectangle and a strip with non-zero area exist and overlap, i.e. if and only if eqs. (4) and (8) are fulfilled. Rearranging and combining equations (4) and (8) we obtain the necessary *and* sufficient condition for the existence of ecologically accurate payment schemes:[4]

$$C_2(\mathrm{a}) + C_3(\mathrm{b}) < \min[C_1(\mathrm{a}) + C_3(\mathrm{b}), C_2(\mathrm{a}) + C_1(\mathrm{b}), C_2(\mathrm{b}) + C_3(\mathrm{a}), C_1(\mathrm{b}) + C_3(\mathrm{a}), C_1(\mathrm{a}) + C_2(\mathrm{b})] \quad (9)$$

Generalising from the fixed indices (1, 2, 3) to variable ones, eq. (9) becomes:

$$C_v(\mathrm{a}) + C_w(\mathrm{b}) < \min[C_u(\mathrm{a}) + C_w(\mathrm{b}), C_v(\mathrm{a}) + C_u(\mathrm{b}), C_v(\mathrm{b}) + C_w(\mathrm{a}), C_u(\mathrm{b}) + C_w(\mathrm{a}), C_u(\mathrm{a}) + C_v(\mathrm{b})] \quad (10)$$

with $u, v, w \in \{1,2,3\}$ and $u \neq v$, $u \neq w$, $v \neq w$.

Equation (10) is necessary and sufficient for the existence of a payment scheme that induces land-owner u to carry out the measure a, land-owner v to carry out b and land-owner w to carry out t=0. The selection rule of eq. (10) is: Form all possible combinations of land-owners, calculate each sum of cost and select the combination with the minimal costs.

Two outcomes are possible:[5]

1. There is a unique sequence S of land-owners for which the sum of costs is minimal. This sequence S fulfils eq. (10) so that ecologically accurate payment schemes exist that separate the land-owners such that a spatial-temporally heterogeneous landscape is introduced by a voluntary switch from t=0 to t≠0. These payment schemes introduce a sequence of land-owners S so that no activity is chosen more than once. No other sequence doing this job can be obtained by any payment scheme.

[4] One could also include the cost of the land-owner with activity t=0 which is zero by normalisation (eq. 2).

[5] Although studying the three land-owner case is sufficient to catch the problem it is shown in appendix 1 that our results also hold in the N land-owner case.

2. Several sequences exist that lead to the same minimal sum of costs. Equation (10) cannot be fulfilled and no payment scheme exists that is able to induce any unique sequence. In this case no spatial-temporally heterogeneous land use and land cover type can be obtained by a clearly defined payment scheme. The underlying reason is that in order to make one land-owner shift from t=0 to t=a (b respectively), this land-owner is to compensate such that incentives for a further land-owner arise to choose the same activity as well. With it the problem of similar choices can not be solved.

4.3. Cost functions fostering the existence of feasible payment schemes

We now discuss for which types of cost functions $C_i(t)$ with $i \in \{\text{u, v, w}\}$ an accurate payment scheme exists and specify as follows:

$$C_i(t) = \alpha_i(1+\beta_i) \quad \text{with}$$

$$\alpha_i = C_i(\text{a}) \text{ and}$$

$$\beta_i = \begin{cases} 0 & t = \text{a} \\ \dfrac{C_i(\text{b})}{C_i(\text{a})} - 1 & t = \text{b} \end{cases} \tag{11}$$

In words, α_i gives the cost for t=a and β_i the relative cost change from t=a to t=b. Inserting eq. (11) into equation (10) leads to 5 conditions whose joint fulfilment for some sequence (u, v, w) is necessary and sufficient for the existence of a feasible payment scheme:

$$\begin{aligned} &\text{(a)} \quad \alpha_v < \alpha_u \\ &\text{(b)} \quad \alpha_w\beta_w < \min[\alpha_u\beta_u + \alpha_u - \alpha_w, \alpha_v\beta_v, \alpha_u\beta_u + \alpha_u - \alpha_v, \alpha_v\beta_v + \alpha_u - \alpha_w] \end{aligned} \tag{12}$$

Below we develop a class of cost functions that fulfils eq. (12). First we assume that the costs of all land-owners for t=a differ from each other. Then without loss of generality we can arrange these costs in decreasing order and write

$$\alpha_u > \alpha_v > \alpha_w \tag{13}$$

With some rearrangement, one can show that eq. (12) is implied by eq. (13) and

$$\beta_w\alpha_w < \min[\beta_u\alpha_u, \beta_v\alpha_v] \tag{14}$$

Noting that $\alpha_i\beta_i$ denotes the cost increase of land-owner i regarding activities a and b, eqs. (13) and (14) tell that this increase must be minimal for the land-owner who has the smallest cost for t=a. In our notation this is land-owner w. As a result, this land-owner will carry out the measure t=b (!) while land-owners u and v will choose t=0 and t=a, respectively. Given eq. (13), a special type of cost functions that fulfils eq. (14) are "isomorphic" cost functions which have the same shape, such that the β_i are equal for all i.[6]

It should be emphasized that the joint fulfilment of eqs. (13) and (14) is not necessary for the fulfilment of eq. (10) and the existence of ecologically accurate payment schemes, but it is sufficient. This means that if one can find a sequence (u, v, w) that fulfils eqs. (13) and (14) feasible payment schemes exist, but there exist types of cost functions that do not fulfil eqs. (13) and (14) and still may lead to accurate payment schemes. These cost functions however may be less easily defined and understood. Moreover eqs. (13) and (14) cover a large class of cost functions, so it is likely that a set of cost function either fulfils eqs. (13) and (14) or it does not fulfil eq. (12).

5. The quality of ecologically accurate payment schemes

In the previous section we have discussed the conditions for the existence of ecologically accurate payment schemes (p_a, p_b). In this section we presuppose that feasible payment schemes exist and from a policy maker's point of view identify the optimal one. Of course there may be different objectives a payment scheme may or should fulfil. One objective could be that the design of the payment scheme should minimise the sum of the costs of the land-owners (criterion of cost-efficiency). A further objective could be to minimise the sum of the subsidies given to the land-owners (criterion of budget-efficiency). Additionally fairness considerations could be in the objective function of the political decision maker. And of course regulators might wish to follow different goals simultaneously. In order to select among the feasible payment schemes we elaborate on these different criteria.

5.1 The criterion of cost-efficiency

In section 4 we have shown that there is only one unique sequence (u, v, w) that fulfils equation (10). The sum of costs is C_v(a)+C_w(b). This sum is independent of the choice of the subsidies p_a and p_b. Consequently individual profit maximisation ensures that each land-

6 See Appendix 2 for the case of N>3 land-owners.

owner gains most if s/he seeks to minimise her/his cost given the subsidy for delay. Hence it is obvious that Pareto-improvement is highest if the policy maker seeks to minimise the subsidies, i.e. if he follows the criterion of budget-efficiency.

5.2 The criterion of budget-efficiency

Budget-efficiency implies that the sum of the subsidies, $B = p_a + p_b$, is minimised. Without loss of generality we again assume that the (unique) sequence that can be induced by the payment schemes is (1, 2, 3), i.e. land-owner 1 carries out the measure t=0 (business as usual; no subsidy is paid), land-owner 2 chooses t=a (stimulated by the payment p_a) and land-owner 3 performs with t=b (due to the offer of p_b). Figure 1 illustrates that iso-budget lines are lines with slope minus one (dashed line). The line representing the smallest budget is:

$$B_{\min} = \min[p_a + p_b] \text{ s.t. eq. (4)} \tag{15}$$

which is the one closest possible to the "origin" of the rectangle, i.e. to the rectangle's lower left corner (C_2(a), C_3(b)).

There are three different cases with feasible payment schemes to distinguish:

a) The lower bound of the strip lies *above* the origin of the rectangle (the case shown in Fig. 1),
b) The upper bound of the strip lies *below* the origin of the rectangle,
c) The origin of the rectangle lies *within* the strip.

Case (a): The lower bound of the strip lies above the origin of the rectangle, i.e.

$$C_3(\mathrm{b}) < p^{(1)}(p_a = C_2(\mathrm{a})) = C_2(\mathrm{a}) + C_3(\mathrm{b}) - C_3(\mathrm{a}) \Leftrightarrow C_2(\mathrm{a}) > C_3(\mathrm{a}) \tag{16}$$

Here the minimum feasible budget is achieved at the point where the lower bound of the strip (eq. 7b) intersects the left border of the rectangle:

$$\begin{aligned} p_a{*} &= C_2(\mathrm{a}) + \delta_a \\ p_b{*} &= p^{(1)}(p_a{*}) + \delta_b = C_2(\mathrm{a}) + C_3(\mathrm{b}) - C_3(\mathrm{a}) + \delta_a + \delta_b \end{aligned} \tag{17}$$

To consider that the boundaries of the shapes in Fig. 1 do not belong to the set of feasible payment schemes we introduced arbitrarily small but positive δ_a and δ_b. To simplify the notation, we write

$$\begin{aligned} &p_a^* \doteqdot C_2(a) \\ &p_b^* = p^{(l)}(p_a^*) + \delta_b \doteqdot C_2(a) + C_3(b) - C_3(a) \end{aligned} \tag{17'}$$

The budget has the magnitude (with $\doteqdot$ pointing out that the budget is arbitrarily higher due to δ_a, δ_b >0)

$$B_{\min} \doteqdot p_a^* + p_b^* = C_2(a) + C_3(b) + [C_2(a) - C_3(a)] \tag{18}$$

Case (b): The upper bound of the strip lies below the origin of the rectangle, i.e.

$$C_3(b) > p^{(u)}(p_a = C_2(a)) = C_2(a) + C_2(b) - C_2(a) \Leftrightarrow C_3(b) > C_2(b) \tag{19}$$

Here the minimum feasible budget is achieved at the point where the upper bound of the strip (eq. 7b) intersects the lower border of the rectangle:

$$\begin{aligned} &p_b^* = C_3(b) \\ &C_3(b) = p^{(u)}(p_a^* - \delta_a) = p_a^* - \delta_a + C_2(b) - C_2(a) \Leftrightarrow p_a^* = C_2(a) + C_3(b) - C_2(b) + \delta_a \end{aligned} \tag{20}$$

or

$$\begin{aligned} &p_b^* = C_3(b) \\ &C_3(b) \doteqdot p^{(u)}(p_a^*) = p_a^* + C_2(b) - C_2(a) \Leftrightarrow p_a^* \doteqdot C_2(a) + C_3(b) - C_2(b) \end{aligned}$$

The budget has magnitude

$$B_{\min} \doteqdot C_2(a) + C_3(b) + [C_3(b) - C_2(b)] \tag{21}$$

Case (c): the origin of the rectangle lies within the strip, i.e.,

$$C_2(\mathrm{a}) < C_3(\mathrm{a}) \wedge C_3(\mathrm{b}) < C_2(\mathrm{b}) \tag{22}$$

Here the minimum feasible budget is given by origin of the rectangle;

$$\begin{aligned} p_{\mathrm{a}}* &\dot{\equiv} C_2(\mathrm{a}) \\ p_{\mathrm{b}}* &\dot{\equiv} C_3(\mathrm{b}) \end{aligned} \tag{23}$$

and has magnitude

$$B_{\min} \dot{\equiv} C_2(\mathrm{a}) + C_3(\mathrm{b}) \tag{24}$$

The general interpretation of the three cases is as follows:

Case (a): The cost of the land-owner 2 who performs with activity t=a [C_2(a)] is higher than the cost land-owner 3 would have if s/he carried out the measure t=a [C_3(a)] by an amount $\varepsilon_{\mathrm{b}}=C_2(\mathrm{a})-C_3(\mathrm{a})>0$. The total profit of land-owner 2 (eq. 2) is $p_{\mathrm{a}}^*-C_2(\mathrm{a})\dot{\equiv}0$ while that of land-owner 3 is $p_{\mathrm{b}}^*-C_3(\mathrm{b})\dot{\equiv}\varepsilon_{\mathrm{b}}$. The quantity ε_{b} is an incentive component that has to be paid to land-owner 3 for not performing with activity t=a [that is subsidised by $p_{\mathrm{a}}^*\dot{\equiv}C_2(\mathrm{a})>C_3(\mathrm{a})$]. Positive ε_{b} implies $p_{\mathrm{b}}*-C_3(\mathrm{b})\dot{\equiv} p_{\mathrm{a}}*-C_3(\mathrm{a})$, which means that for land-owner 3 the choice of t=b is more attractive than the choice of t=a because of $p_{\mathrm{b}}*=C_3(\mathrm{b}) + \varepsilon_{\mathrm{b}} \geq p_{\mathrm{a}}*-C_3(\mathrm{a})$. At the same time it implies [with eq. (5c)] $p_{\mathrm{a}}*-C_2(\mathrm{a}) > p_{\mathrm{b}}*-C_2(\mathrm{b})$. The budget has to cover the costs $C_2(\mathrm{a})+C_3(\mathrm{b})$ plus the incentive component ε_{b}.

Case (b): The cost of the land-owner 3 carrying out t=b [C_3(b)] is higher than the cost land-owner 2 would have if s/he carried out the measure t=b [C_2(b)] by an amount $\varepsilon_{\mathrm{a}}=C_3(\mathrm{b})-C_2(\mathrm{b})>0$. The total profit of land-owner 3 is (just above) zero while that of land-owner 2 is just above ε_{a}. The quantity ε_{a} is an incentive component that has to be paid to land-owner 2 for not performing with activity t=b [that is subsidised by $p_{\mathrm{b}}*\dot{\equiv}C_3(\mathrm{b})>C_2(\mathrm{b})$]. Thus, with arguments analogous to case (a), offering the incentive component ε_{a} ensures that for land-owner 2 the choice of t=a is more attractive than t=b while for land-owner 3 the choice of t=b is more attractive than t=a.

Case (c): Neither case (a) nor case (b) is observed (note that due to eq. (5c) case (a) excludes case (b) and vice versa, so all three cases are mutually exclusive). The total profits of both land-owners are just above zero, i.e. $p_a \gtrsim C_2(a)$ and $p_b \gtrsim C_3(b)$. In this case there are no incentives for similar choices - i.e., no additional incentives have to be set by the design of the payment scheme (the incentive components ε_a and ε_b equal zero) so that the budget has to cover the opportunity costs $C_2(a)+C_3(b)$ only.

5.3 The fairness criterion

Fairness can be specified according to different criteria. If opportunity costs are heterogeneous it could be perceived as fair if each land-owner is compensated according to his efforts for inducing the desired management goal. The efforts of each land-owner are reflected in the land-owner specific costs of delay, i.e. $C_2(a)$ and $C_3(b)$. Above, we have shown that the subsidy equals the land-owners' specific costs of delay if and only if case c (see section 4, above) is observed. If cases a or b are found, there is one land-owner who is able to improve his/her profits by switching to an already chosen activity. This strategic incentive has to be compensated by the payment scheme. Hence there is no scope for meeting the equity criterion if land-owners impose their strategic power, i.e., if they follow individual profit maximisation only.

In the following we therefore seek for a distribution of subsidies ensuring that the total profits of the land-owners with choices a and b are as equal as possible, i.e. the payment scheme that minimises: $|p_a - C_v(a) - [p_b - C_w(b)]|$.

Considering the fairness objective

$$F = | p_a - p_b + C_w(b) - C_v(a) | \tag{25}$$

we find that "Even-fairness-lines" (where the objective function F has the same value) are those lines where the difference p_a-p_b is constant. These are lines with slope +1 in the (p_a, p_b)–space. Fairness is thus maximised (F is minimal) by the line closest to the one that runs through the origin of the rectangle. Setting u=1, v=2 and w=3 without loss of generality this line is given by

$$p_b = p_a + C_3(b) - C_2(a) \tag{26}$$

Now consider the three cases (a), (b), and (c) of section 4.

In case (a) (Fig. 1), highest fairness is achieved if the payment scheme is located just above the lower bound. As that lower bound is given by

$$p^{(l)} = p_{\mathrm{a}} + C_3(\mathrm{b}) - C_3(\mathrm{a}) \tag{27}$$

the set of feasible points maximising fairness includes the point $(p_{\mathrm{a}}, p_{\mathrm{b}})=[C_2(\mathrm{a})+\delta_{\mathrm{a}}, C_2(\mathrm{a})+C_3(\mathrm{b})-C_3(\mathrm{a})+\delta_{\mathrm{a}}+\delta_{\mathrm{b}}]$ which was also found to minimise the budget (eq. 17).

In case (b) highest fairness is achieved if the payment scheme is located just below the upper bound of the strip. As that upper bound is given by

$$p^{(u)} = p_{\mathrm{a}} + C_2(\mathrm{b}) - C_2(\mathrm{a}) \tag{28}$$

the set of feasible points maximising fairness includes the point $(p_{\mathrm{a}}, p_{\mathrm{b}})=[C_2(\mathrm{a}) +C_3(\mathrm{b})-C_2(\mathrm{b})+\delta_{\mathrm{a}}, C_3(\mathrm{b})]$ which was found to minimise the budget (eq. 20), too.

In case (c) highest fairness is achieved if the payment scheme is located on the line through the rectangle's origin (eq. 26). This line includes the point $(p_{\mathrm{a}}, p_{\mathrm{b}})=[C_2(\mathrm{a})+\delta_{\mathrm{a}}, C_3(\mathrm{b}) +\delta_{\mathrm{b}}]$ which again was found to minimise the budget (eq. 23) as well.
We are thus able to conclude that budget-efficiency in all three cases is equivalent to maximising fairness, in a sense that the subsidy scheme introduces the desired ecological goal – a spatial-temporally heterogeneous land use and land cover type – by compensation payments that are as equal as feasible.[7]

6. Summary and conclusions

Our analysis points out that first, spatio-temporally heterogeneous landscapes for species protection are required in the face of uncertainty, transient resources and in cases where biodiversity (i.e., multi-species) protection is under consideration. Second, the paper reveals

[7] Of course if we allow for a higher compensation budget than needed for the introduction of the ecological goal we might also derive at more even compensation payments. However one should keep in mind that within a group of heterogeneous land-owners different subjective fairness appraisals might be made that are not necessarily in line with the equality principle. Hence policy makers should carefully consider whether a departure from the criterion of budget efficiency is justified by the argument of fairness.

that spatio-temporally heterogeneous land use and land cover types may not be introduced by uniform subsidy design but rather by differentiated compensation payments for a selection of different measures. Such transfer schemes not necessarily exist. Though there might be incentives for the land-owners to switch form the business as usual to a more conservation-friendly activity, all land-owners (dependent on their opportunity costs) might like to perform with one and the same activity. With that the policy goal – the implementation of a set of differing conservation measures – is not met.

On the other hand there might be more than one feasible payment scheme so that policy makers have to select an optimal one. A common starting point of research on this selection process is that each land-owner should be compensated according to the individual conservation costs. The argument for tailoring payments to each land-owner's opportunity costs is that with higher payments land-owners earn a producer surplus which has to be financed by a higher budget than actually needed for achieving the desired level of conservation. A higher budget, in turn, leads to a welfare loss as the taxation required to finance public funds has a distortion effect on consumption or production (Innes 2000). However we have shown that compensation of the opportunity costs is not necessarily sufficient for the introduction of a diversified land use and land cover type. To separate the land-owners it might be necessary to also compensate their incentives for similar choices. The freedom of the land-owners to choose the most desired conservation measure poses strategic power to the land-owners that limits efficiency and fairness considerations. However – surprisingly – if policy makers seek to minimise their budget required for implementing the desired policy goal, this at the same time guarantees that the individual profits of the land-owners are as equal as possible[8].

Above that there are cases were neither uniform nor differentiated payment schemes exist to foster a heterogeneous landscape type. In these cases policy makers either fail to comply with the ecological goal or have to rethink the chosen subsidy approach with pre-specified compensation payments and seek for other forms of regulation.

[8] This agreement between budget-efficiency and fairness consideration will change, however, if a different fairness criterion is considered. This may be e.g., to make the payments as equal as possible: min $|p_b - p_a|$. Analysis of this fairness criterion and the trade-offs with budget-efficiency will be subject to future analysis.

References

Benton, T.G., Vickery, J.A., Wilson, J.D. (2003): Farmland biodiversity: is habitat heterogeneity the key? *Trends in Ecology and Evolution, 18/4*, 182-188.

Berendse, F., Chamberlain, D., Kleijn, D. & Schekkerman, H. (2004): Declining biodiversity in agricultural landscapes and the effectiveness of agri-environment schemes. *Ambio* 33, 499-502.

Bignal, E. M., McCracken, D. I., (2000): The conservation value of European traditional framing systems. *Environmental Reviews 8*, 149-171.

Clayton, S. (2000): Models of justice in the environmental debate. *Journal of Social Issues, 56* (3), 459-474.

Deutsch, M. (1985). *Distributive justice: A social-psychological perspective*. New Haven: Yale University Press.

European Commission (2005): Agri-environment Measures: Overview on General Principles, Types of Measures, and Application. Study of the European Commission Directorate General for Agriculture and Rural Development, Unit G-4 - Evaluation of Measures applied to Agriculture, March 2005 (URL: http://europa.eu.int/comm/agriculture/publi/reports/agrienv/rep_en.pdf; (22. October 2005).

Frank, K. (2004): Ecologically differentiated rules of thumb for habitat network design - lessons from a formula. *Biodiversity and Conservation* 13, 189-206.

Grimm, V. & Storch, I. (2000): Minimum viable population size of capercaillie *Tetrao urogallus*: results from a stochastic model. *Wildlife Biology* 6, 219-225.

Innes, R. (2000): The Economics of Takings and Compensation When Land and Its Public Use Values are in Private Hands. *Land Economics 76*, 195-212.

Johst K, Brandl R, Pfeifer, R (2001): Foraging in a patchy and dynamic landscape: human land use and the White Stork. *Ecological Applications, 11*, 60-69.

Johst, K., Brandl, R. & Eber, S. (2002): Metapopulation persistence in dynamic landscapes: the role of dispersal distance. *Oikos* 98, 263-270.

Johst, K., Drechsler, M., Wätzold, F. (2002): An ecological-economic modelling procedure to design compensation payments for the efficient spatio-temporal allocation of species protection measures. *Ecological Economics 41*, 37–49.

Johst, K. & Huth, A. (2005): Testing the intermediate disturbance hypothesis: When will there be two peaks of diversity?, *Diversity and Distributions 11*, 111-120.

Keymer, J.E., Marquet, P.A., Velasco-Hernandez, J.X. & Levin, S.A. (2000): Extinction thresholds and metapopulation persistence in dynamic landscapes. *American Naturalist* 156, 478-494.

Kleijn, D. & Sutherland, W.J. (2003): How effective are European agri-environment schemes in conserving and promoting biodiversity? *Journal of Applied Ecology* 40, 947-969.

Kleijn, D., Berendse, F., Smit, R., Gilissen, N. (2001): Agri-environment schemes do not effectively protect biodiversity in Dutch agricultural landscapes. *Nature 413*, 723–725.

Kramer-Schadt, S., Revilla, E. & Wiegand, T. (2005): Lynx reintroductions in fragmented landscapes of Germany: Projects with a future or misunderstood wildlife conservation? *Biological Conservation* 125, 169-182.

MacDonald, D., Crabtree, J. R., Wiesinger, G., Dax, T., Stamou, N., Fleury, P. Gutierrez Lazpita, J., Gibon, A. (2000): Agricultural abandonment in mountain areas of Europe: Environmental consequences and policy response, *Journal of Environmental Management 59*, 47-69.

Montada, L. (2003): Justice, equity, and fairness in human relations. In I. Weiner (Ed.), *Handbook of Psychology, Vol. 5*, New York: Wiley, pp 537-568.

Tews, J., Brose, U., Grimm, V., Tielbörger, K., Wichmann, M.C., Schwager, M. & Jeltsch, F. (2004): Animal species diversity driven by habitat heterogeneity/diversity: the importance of keystone structures. *Journal of Biogeography* 31, 79-92.

Wätzold F, Drechsler M. (2005): Spatially Uniform versus Spatially Heterogeneous Compensation Payments for Biodiversity-enhancing Land-use Measures, *Environmental and Resource Economics,* 31, 73-93.

Whitby, M., Saunders, C. (1996): Estimating the supply of conservation goods in Britain, *Land Economics, 72*, 313–325.

Appendix A:

The N land-owner case

Now turn to the problem of allocating N>3 land-owners to three different activites. Similar to the case of N=3, we start considering a particular sequence of land-owners: Let land-owners i with $i \in I_a = \{1,\ldots,n_a\}$ choose activity a, land-owners $i \in I_b = \{n_a+1\ldots n_a+n_b\}$ activity b and the remaining land-owners $i \in I_0 = \{n_a+n_b+1\ldots N)$ activity 0.

Similar to above, for a payment scheme to exist that induces just this sequence, the total profit of land-owners $i=1\ldots n_a$ must be maximal for choosing activity a, the total profit of land-owners $i=n_a+1\ldots n_a+n_b$ must be maximal for b and that of the remaining land-owners $i=n_a+n_b+1\ldots N$ must be maximal for activity 0. From this we can derive bounds on the feasible payments p_a and p_b in a straight forward manner:

$$
\begin{array}{ll}
\text{(a)} & \overline{C}_{\mathrm{a}}(\mathrm{a}) < p_{\mathrm{a}} < \underline{C}_0(\mathrm{a}) \\
\text{(b)} & \overline{C}_{\mathrm{b}}(\mathrm{b}) < p_{\mathrm{b}} < \underline{C}_0(\mathrm{b}) \\
\text{(c)} & \overline{C}_{\mathrm{b}}(\mathrm{b},\mathrm{a}) < p_{\mathrm{b}} - p_{\mathrm{a}} < \underline{C}_a(\mathrm{b},\mathrm{a})
\end{array}
\qquad \text{(A1)}
$$

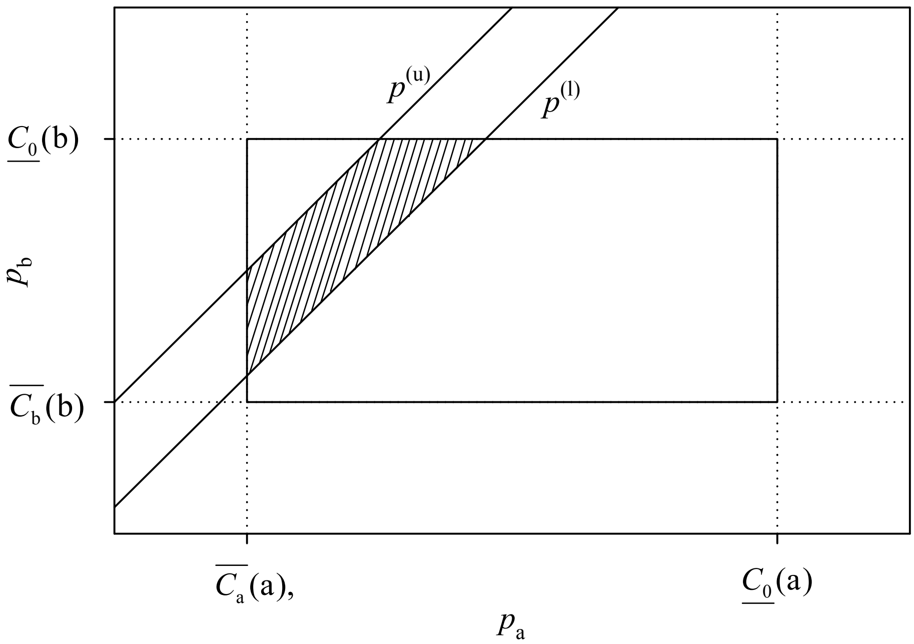
with

$$
\begin{aligned}
&\overline{C}_x(t) = \max_{i \in I_x} C_i(t), \\
&\underline{C}_x(t) = \min_{i \in I_x} C_i(t) \\
&\overline{C}_x(\mathrm{b},\mathrm{a}) = \max_{i \in I_x}[C_i(\mathrm{b}) - C_i(\mathrm{a})] \\
&\underline{C}_x(\mathrm{b},\mathrm{a}) = \min_{i \in I_x}[C_i(\mathrm{b}) - C_i(\mathrm{a})] \quad (t = \mathrm{a},\mathrm{b};\ x = 0,\mathrm{a},\mathrm{b})
\end{aligned}
\qquad \text{(A2)}
$$

Equation (A2) in words: $\overline{C}_x(t)$ is the maximum of all costs $C_i(t)$ in period t where the maximum is taken over all land-owners $i \in I_x$ that are allocated to activity x. The same applies for $\underline{C}_x(t)$, except that the minimum is taken. $\overline{C}_x(\mathrm{b},\mathrm{a})$ and $\underline{C}_x(\mathrm{b},\mathrm{a})$ are the maximum/minimum of the cost differences between choices a and b, taken over all land-owners allocated to activity x. Equation (A1.a), e.g., then means that considering the costs of activity a, the maximum cost of the land-owners allocated to this activity must be smaller than the minimum cost of the land-owners allocated to activity 0. This is plausible, because otherwise some land-owners would prefer to switch from 0 to a (cf. eq. 4a). Similar to the N=3 case, eqs. (A1.a,b) describe a rectangle and eq. (A1.c) a strip with upper and lower bounds

$$\begin{aligned} &\text{(a)} \quad p^{(\mathrm{u})} = p_{\mathrm{a}} + \underline{C}_a(\mathrm{b},\mathrm{a}) \quad \text{and} \\ &\text{(b)} \quad p^{(\mathrm{l})} = p_{\mathrm{a}} + \overline{C}_{\mathrm{b}}(\mathrm{b},\mathrm{a}) \end{aligned} \qquad \text{(A3)}$$

Figure 2: Feasible payment schemes (p_{a}, p_{b}) in the N land-owner case



Following the same procedure as in section 4.2 we can now derive a set of necessary and sufficient conditions for the existence of feasible payment schemes:

$$\begin{aligned} &\text{(a)} \quad \overline{C}_{\mathrm{a}}(\mathrm{a}) < \underline{C}_0(\mathrm{a}) \\ &\text{(b)} \quad \overline{C}_{\mathrm{b}}(\mathrm{b}) < \underline{C}_0(\mathrm{b}) \\ &\text{(c)} \quad \overline{C}_{\mathrm{b}}(\mathrm{b},\mathrm{a}) < \underline{C}_a(\mathrm{b},\mathrm{a}) \\ &\text{(d)} \quad \overline{C}_{\mathrm{b}}(\mathrm{b},\mathrm{a}) + \overline{C}_{\mathrm{a}}(\mathrm{a}) < \underline{C}_0(\mathrm{b}) \\ &\text{(e)} \quad \overline{C}_{\mathrm{b}}(\mathrm{b}) < \underline{C}_a(\mathrm{b},\mathrm{a}) + \underline{C}_0(\mathrm{a}) \end{aligned} \qquad \text{(A4)}$$

Appendix B:

Critical Cost functions in the *N*>3 land-owner case

Similar to the *N*=3 case one may derive a class of cost functions that fulfils eq. (A4) in Appendix A. Inserting eq. (11) into eq. (A4) we obtain

$$
\begin{aligned}
&\text{(a)} \quad \overline{\alpha_\mathrm{a}} < \underline{\alpha_0} \\
&\text{(b)} \quad \overline{\alpha_\mathrm{b} + \alpha_\mathrm{b}\beta_\mathrm{b}} < \underline{\alpha_0 + \alpha_0\beta_0} \\
&\text{(c)} \quad \overline{\alpha_\mathrm{b}\beta_\mathrm{b}} < \underline{\alpha_\mathrm{a}\beta_\mathrm{a}} \\
&\text{(d)} \quad \overline{\alpha_\mathrm{b}\beta_\mathrm{b}} + \overline{\alpha_\mathrm{a}} < \underline{\alpha_0 + \alpha_0\beta_0} \\
&\text{(e)} \quad \overline{\alpha_\mathrm{b} + \alpha_\mathrm{b}\beta_\mathrm{b}} < \underline{\alpha_\mathrm{a}\beta_\mathrm{a}} + \underline{\alpha_0}
\end{aligned}
\tag{B1}
$$

with

$$
\begin{aligned}
&\overline{\alpha_x} = \max_{i \in I_x} \alpha_i \\
&\underline{\alpha_x} = \min_{i \in I_x} \alpha_i \\
&\overline{\alpha_x\beta_x} = \max_{i \in I_x} \alpha_i\beta_i \\
&\underline{\alpha_x\beta_x} = \min_{i \in I_x} \alpha_i\beta_i \quad (x = 0, \mathrm{a}, \mathrm{b})
\end{aligned}
\tag{B2}
$$

where the interpretation of eq. (B2) is analogue to that of eq. (A2). Similar to the *N*=3 case we assume that we can arrange the costs of all land-owners going for a (α_i) in decreasing order, so we can write

$$
\overline{\alpha_0} > \underline{\alpha_0} > \overline{\alpha_\mathrm{a}} > \underline{\alpha_\mathrm{a}} > \overline{\alpha_\mathrm{b}} > \underline{\alpha_\mathrm{b}}
\tag{B3}
$$

which is the analogon to eq. (13). Using $\overline{\alpha_x + \alpha_x\beta_x} \le \overline{\alpha_x} + \overline{\alpha_x\beta_x}$ and $\underline{\alpha_x} + \underline{\alpha_x\beta_x} \le \underline{\alpha_x + \alpha_x\beta_x}$ (x=0,a,b) and with some straight forward transformations one can find that eq. (B1) is implied by eq. (B3) and

$$
\overline{\alpha_\mathrm{b}\beta_\mathrm{b}} < \min[\underline{\alpha_0\beta_0}, \underline{\alpha_\mathrm{a}\beta_\mathrm{a}}]
\tag{B4}
$$

Analogously to eq. (14), eq. (B4) tells that the maximum cost increase between a shift from a to b taken over all land-owners going for b must be smaller than the cost increases for all other land-owners. Similar to the N=3 case, eq. (B4) is fulfilled by eq. (B3) and the assumption of isomorphic cost functions where β_i are equal among all land-owners. Also note that eqs. (B3) and (B4) are sufficient but not necessary for the fulfilment of eq. (B1).