

Spatially Uniform *versus* Spatially Heterogeneous Compensation Payments for Biodiversity-Enhancing Land-Use Measures

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Abstract. The importance of compensation payments for biodiversity-enhancing land-use measures has grown over the past decade, particularly in connection with agri-environmental policy. Given that both the costs and the benefits of biodiversity-enhancing land-use measures are subject to spatial variation, the criterion of cost-effectiveness calls for spatially heterogeneous compensation payments. However, when deciding whether to implement uniform or heterogeneous compensation payments, the regulator has to compare the disadvantage of uniform payments in terms of cost-effectiveness with the disadvantages of spatially heterogeneous payments. To help resolve this issue, this paper provides a simple ecological-economic model that allows the reduced cost-effectiveness associated with uniform payments for biodiversity-enhancing land-use measures to be assessed for different types of benefit and cost functions.

Key words: agri-environmental policy, biodiversity, compensation payments, conservation, cost-effectiveness, ecological-economic modelling, land use

JEL classification: Q20

1. Introduction

Whereas some endangered species require reserves to survive, others depend on particular types of human land use. For example, many species in Western Europe can only survive in agricultural landscapes provided that landowners carry out biodiversity-enhancing land-use measures (Hampicke and Roth 2000). However, such measures are usually costly. Since the political will often exists that landowners and in particular farmers should not be forced to carry them out, compensation has to be paid (Bromley and Hodge 1990, Hanley et al. 1998). Furthermore, experience with the USA Endangered Species Act has shown that compelling owners of land containing endangered species to undertake conservation measures may be counterproductive as it

might encourage them to try and eradicate the species concerned in order to escape burden of conservation costs (Brown and Shogren 1998; Innes et al. 1998; Innes 2000). Over the past decade, compensation payment schemes for biodiversity-enhancing land-use measures have become increasingly important in Europe, particularly in the context of agri-environmental policy. Examples of such schemes include the Countryside Stewardship and the Moorland schemes in the UK, and the nature protection contract schemes (“Vertragsnaturschutzprogramme”) in various German states (Hanley and Oglethorpe 1999; Hampicke and Roth 2000).

If compensation payments are to be designed cost-effectively (i.e. such that the conservation benefit is maximised for a certain amount of financial resources), it has to be borne in mind that both the costs and the benefits of biodiversity-enhancing land-use measures are subject to spatial variation. The reasons for cost differences include variations in soil quality, opportunity costs for labour, opportunity costs for land, and the availability of equipment to carry out biodiversity-enhancing land-use measures, while different levels of benefit may be due to different habitat quality.

Given the spatial differences in costs and benefits, the criterion of cost-effectiveness calls for spatially heterogeneous biodiversity-enhancing land-use measures, and, hence, spatially heterogeneous compensation payments. However, the administrative costs of such differentiation may be significant, and objections based on equity or legal concerns may cause political problems in implementing heterogeneous payments. Thus, when deciding whether to implement spatially uniform or heterogeneous compensation payments, the regulator has to compare a possibly low level of cost-effectiveness on the one hand with administrative costs as well as equity and legal concerns on the other.

Cost-effectiveness may also be achieved by paying compensation for *results* rather than *measures*. Under this approach, for instance, a farmer would not be paid for creating a suitable habitat for an endangered plant but only for the actual presence of the plant on his fields. Compensation payments for results lead to a cost-effective allocation of biodiversity-enhancing land-use measures because they encourage the farmers to produce the desired ecological effects who can do so at the least cost. Although being cost-effective, compensation payments for results have other potential disadvantages such as the high administrative costs of verifying whether the ecological results have actually been achieved.

In both types of decision – spatially uniform *versus* spatially heterogeneous payments and payments for measures *versus* payments for results – the regulator has to weigh up the various advantages and disadvantages of both alternatives, including the issue of the cost-effective allocation of biodiversity-enhancing land-use measures. The aim of this paper is to increase our understanding of this issue. For this purpose, a conceptual framework is developed that allows the cost-effectiveness of spatially uniform payments to

be evaluated under different circumstances, i.e. for different cost and benefit structures.

The issue of the spatial differentiation of environmental policy instruments received much attention in the 1970s and 1980s, when it was discussed against the background of regional differences in air pollution (see e.g. Tietenberg 1978). On a theoretical level, Kolstad (1987) analyses the extent of efficiency losses with spatially uniform regulation. Among his findings is that efficiency losses increase when the marginal cost and benefit functions are steep. Similarly, Babcock et al. (1997) and Ferraro (2003) analyse efficiency losses if the regulator spatially allocates funds for environmental purposes not according to the cost-effectiveness rule but according to the rules of cost targeting (funds are directed to the least-cost options first) and benefit targeting (funds are directed to the options with the highest benefits first). Their results show that the extent of efficiency losses depends on the relative variability of costs and benefits and the correlation between them. However, the benefit functions considered in Kolstad (1987), Babcock et al. (1997) and Ferraro (2003) encompass only a subset of the possible benefit functions relevant in the context of biodiversity conservation.

To focus on biodiversity conservation, the ecological benefit function has to be based on ecological theory. This requires incorporating ecological and economic knowledge into the evaluation of conservation instruments. So far, only a few studies have explicitly integrated both ecological and economic knowledge into such an evaluation. Recent work using this approach includes analyses of the extent to which efficiency improvements can be achieved by integrating economic costs (land prices) with the selection criteria of conservation sites compared to an approach that only considers ecological parameters, such as the number of endangered species (Ando et al. 1998; Polasky et al. 2001). Similarly, Johst et al. (2002) integrate economic cost data and the results of a species-specific simulation model with a numerical modelling procedure to determine spatiotemporally efficient compensation payments for species conservation. On a more general level, Wu and Bogess (1999) show that the specific shape of the ecological benefit function influences the spatial allocation of conservation funds. For instance, if a threshold in the ecological benefit function exists (i.e. cumulative effects are present), the optimum spatial allocation of limited conservation funds is such that funds should be concentrated in one region in order to exceed the threshold instead of being evenly distributed among regions. Drechsler and Wätzold (2001) systematically examine how the budget size, the shape of the cost function and the shape of the benefit function affect the efficient spatial allocation of conservation funds.

These ecological-economic studies have contributed to our understanding of how best to allocate conservation funds in space. What they have not addressed is the issue that for the reasons outlined above, a cost-effective

allocation of biodiversity-enhancing land-use measures through heterogeneous compensation payments may pose problems, and that in this context it is important to know the extent to which uniform payments lead to reduced cost-effectiveness.

We use a numerical optimisation model which is an extension of the model by Drechsler and Wätzold (2001) to analyse the cost-effectiveness of spatially uniform compensation payments. The model's cost and benefit functions are briefly explained in Section 2. Section 3 describes the model, Section 4 how it is analysed, and Section 5 presents the results. The model assumptions are modified in Section 6 to address the issue of spatially multiplicative benefits. Section 7 discusses the results.

2. Benefit and Cost Functions

This section introduces the benefit and cost functions which are taken from Drechsler and Wätzold (2001) and form the basis of the model. Both functions relate the costs and biodiversity benefits to the area that has been transformed by biodiversity-enhancing land-use measures into land suitable for conservation. The benefit B depends on habitat area A in an algebraic manner:

$$B = \alpha \cdot A^z \quad (1)$$

where A is the habitat area, α is some positive constant, and z an exponent that determines how strongly B increases with A , and in particular whether the marginal benefit increases ($z > 1$) or decreases ($z < 1$) with increasing habitat area (cf. Figure 1). Equation (1) captures a wide spectrum of possible ecological benefit functions, as pointed out in Drechsler and Wätzold (2001) and in the discussion (section 7).

We assume that initially each region contains habitat of an area A_0 corresponding to an initial benefit of $B_0 = \alpha \cdot A_0^z$. If the habitat area is increased by the amount of ΔA to a value of $A = A_0 + \Delta A$, the benefit increases by

$$\Delta B = B - B_0 = \alpha \cdot (A_0 + \Delta A)^z - \alpha \cdot A_0^z = \alpha \cdot A_0^z \cdot [(1 + \Delta A/A_0)^z - 1] \quad (2)$$

Without loss of generality we set the constant $\alpha \cdot A_0^z = 1$ such that $\Delta B = (1 + \Delta A/A_0)^z - 1$. Figure 1 shows ΔB for a range of different z .

This illustrates that functions with a rather small z ($z < 1$) imply that marginal benefits ($d\Delta B/d\Delta A$) decrease with increasing habitat area while a comparatively large z ($z > 1$) leads to increasing marginal benefits.

Regarding the cost function, we assume linearly increasing marginal costs

$$c = c_0 + e \cdot \Delta A. \quad (3)$$

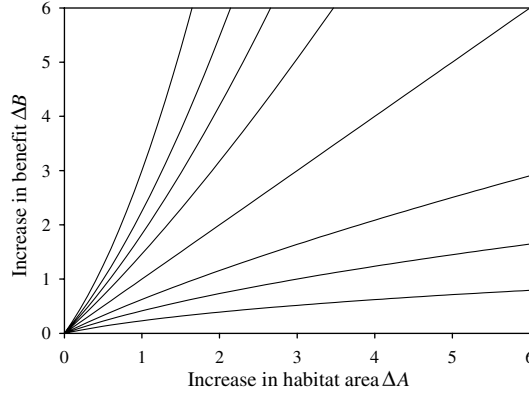


Figure 1. Increase in benefit ΔB as a function of habitat area increase $\Delta A' = \Delta A/A_0$ for various z (from bottom to top: 0.3, 0.5, 0.7, 1, 1.3, 1.5, 1.7, 2).

The slope of the marginal cost curve is given by e . Increasing marginal costs are a reasonable assumption because the cost of biodiversity-enhancing land-use measures may differ from one plot of land to the next (cf. ‘Introduction’). Thus, they range from low to high, implying rising marginal costs with increasing habitat area. A value of $e = 0$ represents constant marginal costs; a value of $e = c_0/A_0$ means that an increase in habitat area by an amount of A_0 increases marginal costs by c_0 , which is regarded as a plausible maximum for the value of e .

3. The Model

The purpose of the model is to assess the cost-effectiveness of spatially uniform compensation payments for biodiversity-enhancing land-use measures under different circumstances. Assuming two different regions, we expect the results to depend on whether the benefit functions as well as the cost functions are identical in both regions or not. Therefore, in contrast to Drechsler and Wätzold (2001), the exponent z of the benefit function and the slope of the marginal costs e may differ between the two regions. They are denoted as z_i and e_i for region i respectively ($i = 1, 2$). Marginal costs prior to biodiversity-enhancing land-use measures (c_0), however, are identical in both regions. We simplify the model by Drechsler and Wätzold (2001) by assuming that both regions have the same initial habitat area A_0 .

We assume that the total benefit increase ΔB_{tot} for the entirety of both regions is given by

$$\Delta B_{\text{tot}} = \Delta B_1 + \Delta B_2 \quad (4)$$

where ΔB_1 and ΔB_2 reflect the increase in benefit in regions 1 and 2, respectively, as derived from the benefit function (Equation 1). In Equation (4) we assume that the benefits in the two regions are additive (this assumption is modified in section 6). The total costs, C_{tot} ,

$$C_{\text{tot}} = C_1 + C_2 \quad (5)$$

are the sum of costs in regions 1 and 2, C_1 , and C_2 , respectively, where the total costs in each region are given by the integral of the corresponding marginal cost function, Equation (3).

We assume that biodiversity-enhancing land-use measures are allocated via the instrument of compensation payments. Here for each region ($i = 1, 2$), a payment p_i (uniform within the region) is offered for carrying out such measures and increasing the habitat area by ΔA_i . We assume that landowners will carry out biodiversity-enhancing land-use measures as long as compensation payments are higher than or equal to the corresponding marginal costs $p_i \geq c_i$. Marginal costs differ between individual plots of land within the same region, and if p_i is low only a few landowners will participate in the conservation efforts. As payments rise, participation will increase and ΔA_i will grow. With Equation (3) it follows that a compensation payment of p_i in region i will increase the habitat area by

$$\Delta A_i = \frac{p_i - c_0}{e_i} \quad (i = 1, 2) \quad (6)$$

if $p_i \geq c_0$, and $\Delta A_i = 0$ otherwise. To determine the cost-effectiveness of uniform compensation payments for given costs, in the first step we calculate the cost-effective payments \hat{p}_1 and \hat{p}_2 , and the corresponding total benefit as functions of the total costs C_{tot} . For this, we solve the optimisation problem

$$\begin{aligned} \Delta B_{\text{tot}} &\rightarrow \max && \text{under the constraint} \\ C_{\text{tot}} &= C_1 + C_2 && \text{and } C_i \geq 0 \quad (i = 1, 2) \end{aligned} \quad (7)$$

which is done numerically, as described in Appendix A. As we are interested in the degree of cost-effectiveness of uniform payments, in the second step we analyse the benefit obtained from such payments and compare it with the benefits obtained by the cost-effective payments.

As shown in Appendix A, for uniform payments ($p = p_1 = p_2$) the total benefit increase can be calculated analytically for given total costs through Equations (4), (A4) and (A7). The ratio between the total benefit increase obtained with uniform payments and the total benefit increase obtained with heterogeneous payments is a measure of the degree of cost-effectiveness of the uniform compensation payments. It is determined for a range of total costs C_{tot} .

4. Model Analysis

The model is analysed in two steps. In the first step, we explore the general behaviour of the model and consider different preliminary scenarios, each being defined by the benefit and cost structure in region 1, determined by parameters z_1 and e_1 which are set at different values between 0.2 and 3 (i.e. between sharply decreasing and increasing marginal benefits) and between $0.05c_0/A_0$ and $0.95c_0/A_0$ (i.e. between weakly and sharply increasing marginal costs), respectively. The parameters for region 2 (z_2 and e_2) are different from the values of z_1 and e_1 in increments or decrements of 0.1 and $0.05c_0/A_0$, respectively. Total costs C_{tot} range from $2c_0A_0$ to $125c_0A_0$. For values below $2c_0A_0$, uniform payments are fairly cost-effective, regardless of the other model parameters. A value of $125c_0A_0$ represents the costs arising from multiplying the habitat area in region 1 by a factor of 125, and is regarded as an upper plausible bound.

The results of this preliminary analysis are:

- Within the range considered, the level of cost-effectiveness changes only very slowly with costs C_{tot} . Therefore a single median cost level is selected in the second step of the analysis below.
- The qualitative behaviour of the model depends mainly on:
 1. The number of convex benefit functions (0, 1, or 2).
 2. Whether the benefit functions in both regions are identical.

Based on these results, in the second step we form five main scenarios which encompass most of the model's behaviour. A main scenario is defined by the combination of benefit structures in the two regions, i.e. by z_1 and z_2 . The scenarios are:

$$S_1 : z_1 = 0.3, \quad z_2 = 0.7$$

$$S_2 : z_1 = 0.5, \quad z_2 = 0.5$$

$$S_3 : z_1 = 0.3, \quad z_2 = 1.7$$

$$S_4 : z_1 = 1.3, \quad z_2 = 1.7$$

$$S_5 : z_1 = 1.5, \quad z_2 = 1.5$$

In each scenario, the parameters e_1 and e_2 , which determine the cost functions in the two regions, are varied systematically between $0.05c_0/A_0$ and $0.95c_0/A_0$ in increments of $0.05c_0/A_0$.

5. Results

Figure 2 shows the degree of cost-effectiveness of uniform payments for the five scenarios S_1 to S_5 .

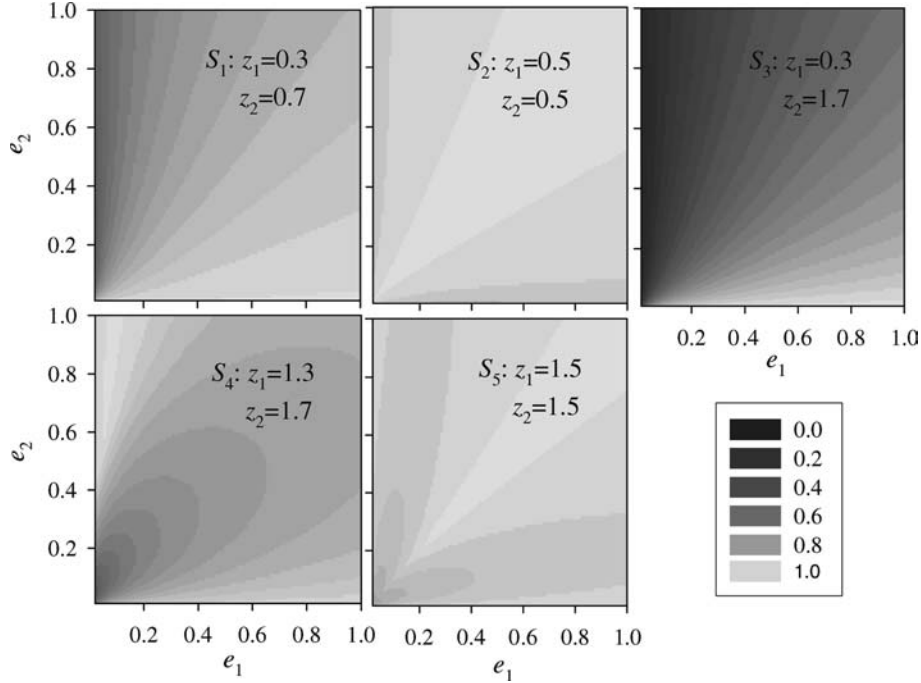


Figure 2. Cost-effectiveness of uniform payments (white = 100%; black = 0%) relative to spatially heterogeneous payments as a function of e_1 and e_2 . Marginal costs e_1 and e_2 are scaled in units of c_0/A_0 . The benefit functions differ according to the five main scenarios S_1 – S_5 .

The results for S_1 to S_3 are as expected. For S_1 and S_3 , the cost-effectiveness is high when $e_1 \gg e_2$ and low when $e_1 \ll e_2$. In the former case, the cost structure leads to more of the biodiversity-enhancing land-use measures being carried out in region 2. This region provides higher benefits and thus allocation is cost-effective. In the latter case, the biodiversity-enhancing land-use measures are concentrated in region 1 with low benefits, resulting in non-cost-effective allocation. The comparison between S_1 and S_3 shows that the cost-effectiveness decreases when the difference between $z_1 = 0.3$ and z_2 increases, and that this result is independent of whether z_2 is larger or smaller than 1. Scenario S_3 also demonstrates that the cost-effectiveness of uniform payments may be very low.

For S_2 , homogenous payments are cost-effective if the cost functions of the two regions are identical ($e_1 = e_2$) because this leads to an even allocation of biodiversity-enhancing land-use measures and thus to maximum total benefit. If $e_1 \neq e_2$, the cost-effectiveness of uniform payments is only slightly lower. This result can be understood by exploring how a heterogeneous instrument could improve cost-effectiveness. For instance, if $e_1 > e_2$ and the

payments in both regions are equal, biodiversity-enhancing land-use measures are concentrated in region 2, whereas the concavity of the benefit functions calls for uniform allocation. Increasing payments in region 1 relative to those in region 2 ($p_1 > p_2$) leads to more uniform allocation, but due to the larger e_1 , the area where such measures could be carried out for the same total costs is smaller. Alternatively, by increasing payments in region 2 ($p_1 < p_2$), more area in total can be devoted to biodiversity conservation, but compared to a situation with uniform payments the concentration of area in region 2 (and so the deviation from the cost-effective uniform allocation) is even higher.

The cost-effective allocation changes considerably when both benefit functions are convex as in scenarios S_4 and S_5 . First we consider S_4 , where the benefit functions are different. Similar to scenarios S_1 and S_3 , the cost-effectiveness of uniform payments is comparatively high when the marginal costs in the region with the higher marginal benefit are smaller than in the other region ($e_1 \gg e_2$). In contrast to scenarios S_1 and S_3 , however, a similar degree of cost-effectiveness is also observed in the opposite case, i.e. when the marginal costs in region 2 are much higher than in region 1 ($e_1 \ll e_2$).

To understand this unexpected result for $e_1 \ll e_2$, let us again explore how a heterogeneous instrument could improve cost-effectiveness. If payments are high in region 1 ($p_1 > p_2$), biodiversity-enhancing land-use measures can be carried out in a larger area than which are carried out with the uniform instrument due to the low costs of land in region 1. However, such measures yield only comparatively low benefits because of $z_1 < z_2$. Alternatively, high payments in region 2 ($p_1 < p_2$) lead to a concentration of biodiversity-enhancing land-use measures in the region with high benefits. However, due to the high costs in region 2, the total area where measures are being carried out is comparatively small.

One may ask why such a result only appears when both benefit functions are convex. The answer is that, here the marginal benefits increase in both benefit functions, which means that even if biodiversity-enhancing land-use measures are concentrated in the region with lower z , a sufficient increase in area may achieve very high benefits. Therefore in contrast to the case of *decreasing* marginal benefits, with *increasing* marginal benefits, it does not matter so much into which region the resources flow, as long as they all flow into one region.

The lowest level of cost-effectiveness in S_4 is observed when both cost functions are equal, especially when marginal costs only increase slowly ($e_1 \approx e_2 \ll c_0/A_0$). Here the uniform instrument leads to the even allocation of biodiversity-enhancing land-use measures, while due to the strongly increasing marginal benefit in region 2 ($z_2 = 1.7$), this region should be preferred. This effect is slightly less severe when marginal costs increase sharply ($e_1 = e_2 \approx c_0/A_0$). In this case, the homogeneous allocation of

biodiversity-enhancing land-use measures becomes more advantageous as more measures can be carried out for given total costs.

Lastly we consider scenario S_5 , where both benefit functions are convex and identical ($z_1 = z_2 = 1.5$). As the marginal benefits increase in both regions equally, an inhomogeneous allocation of land-use measures is cost-effective with regard to the benefit function. Such inhomogeneous allocation is achieved by uniform payments when the cost functions strongly differ. Consequently, the uniform instrument ought to be less cost-effective if the cost functions are similar ($e_1 \approx e_2$). Indeed, the cost-effectiveness is somewhat below 100% if $e_1 \approx e_2 \ll c_0/A_0$. But why does it come close to 100% when $e_1 \approx e_2$ increases and approaches c_0/A_0 ? Here, as already mentioned in the discussion of S_4 , increasing marginal costs call for the homogeneous allocation of biodiversity-enhancing land-use measures and thus increase the cost-effectiveness of the uniform instrument.

To provide an overview, the results for the five scenarios are summarised in Table I.

It is worth briefly comparing our results with those of Babcock et al. (1997), who analyse cost-effectiveness as a function of the relative variability of costs and benefits and the correlation between them. For comparison, it should be noted that the results overlap only to a certain extent. One important aspect of the present paper is that not only concave but also convex benefit functions are considered owing to the paper's focus on biodiversity. As long as the analysis is comparable, i.e. for scenarios with only concave benefit functions (S_1 and S_2), the results are similar. For example, the results of Babcock et al. (1997, p. 333) suggest that cost-effectiveness is lower when there is a positive correlation between benefits and costs than if the correlation is negative. This result can also be found in S_1 , where the level of cost-effectiveness is lowest when the costs and benefits are positively correlated, i.e. both costs and benefits are high in region 2 and low in region 1. Scenario S_4 , however, shows that the results of Babcock et al. do not necessarily hold in the case of two convex benefit functions. In S_4 the level of cost-effectiveness is high when the costs and benefits are positively correlated, but also when they are negatively correlated. This suggests that when interpreting the results of Babcock et al., the specific assumptions behind the shape of the benefit functions need to be borne in mind.

6. Multiplicative Benefits

So far, we have assumed that the benefits in the two regions are additive. However, this may not necessarily be the case, and the contribution of one region to the total benefit may depend on the benefit in the other region. The simplest, most general way of modelling this effect is to assume that the total

Table I. Summary of scenario results

Scenario						
$S_1 (z_1 = 0.3, z_2 = 0.7)$ $S_2 (z_1 = 0.5, z_2 = 0.5)$ $S_3 (z_1 = 0.3, z_2 = 1.7)$ $S_4 (z_1 = 1.3, z_2 = 1.7)$ $S_5 (z_1 = 1.5, z_2 = 1.5)$						
Number of convex benefit functions	0	0	1	2	2	2
Identical benefit functions	No	Yes	No	No	No	Yes
$e_1 \gg e_2$	+	+/-	+/-	-	-	-
$e_1 \ll e_2$	--	+/-	---	-	-	-
$e_1 \approx e_2 \ll c_0/A_0$	-	+	--	---	+/-	+/-
$e_1 \approx e_2 \approx c_0/A_0$	-	+	--	--	+	+

+ : cost-effective (95–100%), - : high (80–95%) -- : medium (40–80%), --- : low (0–40%) level of cost-effectiveness; percentages indicate the degree of cost-effectiveness of uniform payments relative to cost-effective heterogeneous payments.

benefit is not the sum but the product of the individual benefits (cf. Equation (4)):

$$B_{\text{tot}} = B_1 * B_2 \quad (8)$$

A biological justification for this benefit function can be found in the metapopulation concept (e.g. Hanski 1999). A metapopulation consists of a number of subpopulations that are physically separated but interact with each other through the exchange of individuals. Individual subpopulations may become extinct, but empty habitats can be recolonised by neighbouring subpopulations. Furthermore, the immigration of individuals into an existing subpopulation may reduce its risk of extinction. The subpopulations hence stabilise each other, and an increase in the habitat of one subpopulation will have positive effects on the other subpopulations. If a metapopulation consists of two subpopulations, it can be shown that its expected lifetime is approximately related to the product of the expected lifetimes of the two subpopulations (Frank and Wissel 2002). If we relate the ecological benefit B_i in a region i ($i = 1, 2$) to the subpopulation lifetime in region i (see ‘Discussion’) and assume that the subpopulations in the two regions interact and exhibit metapopulation dynamics, it is plausible to assume that the total benefit is related to the product of the individual benefits in the two regions as stated by Equation (8).

With Equation (2) and some algebra, the benefit increase obtained from area increases $\Delta A'_1$ and $\Delta A'_2$ becomes

$$\Delta B_{\text{tot}} = \Delta B_1 * \Delta B_2 + \Delta B_1 + \Delta B_2 \quad (9)$$

In the same manner as in the preceding sections, we determine the cost-effectiveness of uniform payments for the benefit function Equation (9). Figure 3 shows the results for the scenarios S_1 – S_5 investigated above. In all the scenarios, the area with a high level of cost-effectiveness is located along a straight line through the origin. Comparison of the five scenarios reveals that the slope of the line depends on z_1 and z_2 . Roughly speaking, the cost-effectiveness of uniform payments is high if $e_2/e_1 = (e_2/e_1)_{\text{eff}} \approx z_1/z_2$ (or in other words if the line of maximum cost-effectiveness in the e_1 – e_2 diagram has an angle with the e_1 -axis of $\varphi = \varphi_{\text{eff}} \approx \arctg(z_1/z_2)$). This implies that if z_1 is larger than (or equal to) z_2 , uniform payments are cost-effective if e_2 is larger than (or equal to) e_1 .

To understand this result, consider the optimal allocation of area ΔA and disregard the associated costs for the moment, which means maximising ΔB_{tot} under the constraint of constant total area increase $\Delta A = \Delta A_1 + \Delta A_2$. Here ΔB_{tot} is maximised if

$$\frac{A_0 + \Delta A_1}{A_0 + \Delta A_2} = \frac{z_1}{z_2}. \quad (10)$$

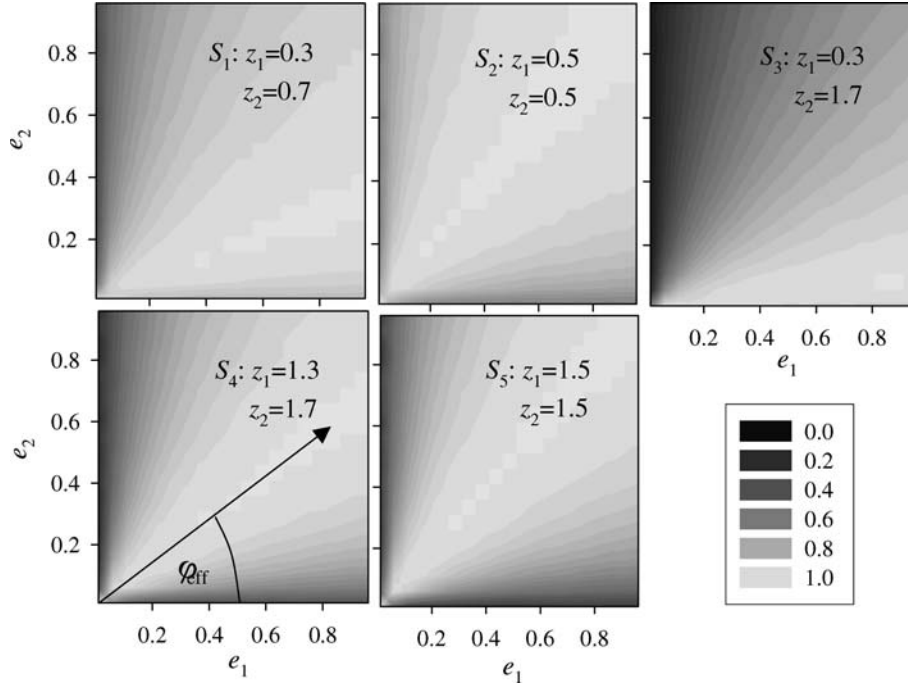


Figure 3. Cost-effectiveness of the uniform instrument with multiplicative benefits (Equation (9)) for scenarios S_1 – S_5 . The angle between the line of highest cost-effectiveness and the e_1 -axis is denoted as φ (see text); all other details as in Figure 3.

This implies that if z_1 is larger than (equal to/smaller than) z_2 , more (equal/less) habitat should be allocated to region 1 compared to region 2. Now taking into account the cost functions, homogenous payments lead to justification of this optimal allocation of area if e_2 is larger than (equal to/smaller than) e_1 .

If the area increase ΔA_i is large compared to the initial area A_0 , then the observation in Figure 3 can also be proved analytically, because then with Equation (6) the left hand side of Equation (10) can simply be approximated by $e_2(\hat{p}_1 - c_0)/e_1(\hat{p}_2 - c_0)$ where \hat{p}_1 and \hat{p}_2 are the cost-effective payments. Inserting this into Equation (10) immediately delivers for the cost-effective payments, \hat{p}_1 and \hat{p}_2 : $\hat{p}_1 \approx \hat{p}_2$ if $e_2/e_1 = z_1/z_2$, which means that homogenous payments are cost-effective if $e_2/e_1 = z_1/z_2$.

7. Discussion

The purpose of this paper is to analyse the cost-effectiveness of uniform compensation payments for biodiversity-enhancing land-use measures when the costs and benefits spatially differ. In the model, marginal costs may

increase more or less sharply and the benefit functions may be concave, convex or linear and additive or multiplicative. The results clearly indicate that the cost-effectiveness of uniform payments may be low. Within the framework of the model, the level of cost-effectiveness was close to 0% under certain conditions in the case of both additive and multiplicative benefits (see Table 1; Figures 2 and 3, scenario S_3). This suggests that the issue of cost-effectiveness merits the regulator's attention when deciding whether to implement spatially uniform or heterogeneous payments, and whether to implement payments for measures or results.

In the case of additive benefits, we found that the qualitative behaviour of the model strongly depends on whether both benefit functions are convex (scenarios S_4 – S_5) or not (scenarios S_1 – S_3). The results of the latter scenarios are as expected, and comparable to the results of Babcock et al. (1997) and Ferraro (2003). More surprising results are obtained when both benefit functions are convex (S_4 – S_5). If the cost functions in the two scenarios are strongly dissimilar, the cost-effectiveness of uniform payments is high, regardless of whether cost and benefit functions are positively correlated or not. If the cost functions are identical/similar, the cost-effectiveness strongly depends on whether the benefit functions are identical/similar as well. If they are identical/similar (S_5), the cost-effectiveness is high; if they are dissimilar, the cost-effectiveness is comparatively low (S_4). In the case of multiplicative benefits, uniform compensation payments are cost-effective when the ratio e_2/e_1 is equal to the ratio z_1/z_2 of the exponents of the benefit functions. This was found to hold regardless of whether the benefit functions are concave or convex.

Are the scenarios with convex benefit functions relevant to conservation policy? To answer this question, let us briefly recall the ecological meaning of z and give some examples of benefit functions where $z < 1$ and where $z > 1$. According to Drechsler and Wätzold (2001), the ecological benefit function (Equation (1)) may be interpreted in two different ways:

1. Maximising the number of species.
2. Maximising the expected lifetime of a particular species.

Which interpretation is the more appropriate depends on the priority in a particular context, i.e. whether species richness has to be increased in general or whether there is an endangered species that needs to be protected as a matter of priority. Below, we take a brief look at both interpretations:

(1) According to empirical observations, the number of species S in a habitat patch of size A can be approximated by $S = \alpha A^z$ where $z = 0.1, \dots, 0.7$, depending on the species and the type and structure of habitat (Begon et al. 1990). For instance, in Begon et al. (1990, Table 22.1) the richness of beetle species in the West Indies is described by $z = 0.34$ and the richness of flow-

ering plants in England by $z = 0.1$. The structural diversity of the habitat patch affects z such that structurally diverse patches have a higher z than less diverse ones (Begon et al. 1990, p. 777).¹ The species–area relationship has also been confirmed by theoretical analysis. Köhler et al. (2002), for example, estimated the bird-species richness in a modelled dynamic and spatially structured tropical rainforest. The algebraic species–area relationship above fitted the results in this heterogeneous ecosystem reasonably well with $z = 0.41$.

(2) Using theoretical models, Lande (1993) and Wissel et al. (1994) independently found the expected lifetime of a population T to be related to habitat area via $T \sim A^z$, a relationship that is now used in many other contexts (e.g. Hanski 1999). In contrast to the above interpretation of z as a parameter determining species richness, here z may assume values not only smaller but also larger than 1. In particular, z is inversely related to the temporal variation in the population growth rate which depends on the species and on habitat quality. Although originally derived from very simple and conceptual models, it has been verified in various case studies for populations with complex structures. For instance, in a spatially and socially structured model population of marmots (*Marmota marmota*), Grimm et al. (2003) found a strong convex dependence of expected population life time with habitat size. A similar outcome was found by Grimm and Storch (2000) for a population of capercaillie (*Tetrao urogallus*). Stephan et al. (2000) modelled natterjack toad populations (*Bufo calamita*) in different locations near the city of Halle in Germany and found that z depends on the habitat quality and growth rate of the population. At a location with poor habitat quality and low population growth, a concave relationship between expected lifetime and habitat size is observed, while at a location where habitat quality and population growth are higher, a convex relationship is observed. Such benefit functions correspond to scenario S_3 in the present analysis.

The model in this paper is based on a number of plausible assumptions which capture many relevant situations in reality. However, the analysis of other situations may require assumptions to be modified. While a detailed analysis of alternative assumptions is beyond the scope of this paper but could be the subject of further research, we will briefly discuss what assumptions may be modified and how these modifications are expected to affect the results.

In the model, it is assumed that marginal costs for biodiversity-enhancing land-use measures are initially equal in both regions (i.e. the intercept c_0 is the same). How will the cost-effectiveness of uniform payments be affected if initial marginal costs differ? Such differences imply that compared to a situation where initial marginal costs are equal and all other parameters are identical, more biodiversity-enhancing land-use measures are carried out in the region with lower initial marginal costs. How such an allocation influ-

ences the cost-effectiveness of uniform payments depends on the shape of the benefit functions. For example, cost-effectiveness is increased if ecological benefits are maximised when funds are concentrated in the region with lower initial marginal costs.

Another assumption related to the cost function is that the marginal costs of biodiversity-enhancing land-use measures rise. The reason for this assumption is that costs for biodiversity-enhancing land-use measures may vary within the same region. However, there may be situations in which the assumption of constant marginal costs is more adequate and even situations in which economies of scale lead to decreasing marginal costs. In the case of constant marginal costs ($e_1 = e_2 = 0$), the allocation of biodiversity-enhancing land-use measures is determined by the marginal costs c_0 if these marginal costs differ between the two regions. If payments are uniform, all the funds will go to the region with lower marginal costs. This is cost-effective if ecological benefits are maximised in such a case. It is not cost-effective if the benefits are maximised when measures are carried out in both regions or concentrated in the other region. If the marginal costs c_0 are equal in the two regions and payments exceed marginal costs ($p \geq c$), all land-users are willing to carry out biodiversity-enhancing measures and the agency selecting the programme participants can choose the cost-effective solution. Decreasing marginal costs resulting from economies of scale will lead to a concentration of funds in one region if compensation payments are uniform. As in the case of constant marginal costs, the cost-effectiveness of such an allocation depends on the benefit functions.

With respect to the benefit function, the initial habitat area is considered to be the same in both regions. The effect of a larger initial habitat area in one of the two regions can easily be explained with the help of Figure 1. A larger initial habitat area in one region means that the corresponding benefit function in Figure 1 is shifted to the left. In the case of increasing marginal benefits, this is qualitatively the same as an increase in z , and in the case of decreasing marginal benefits is qualitatively the same as a decrease in z . In both cases, it implies that a higher initial habitat area moves z away from 1. In the case of constant marginal benefits, nothing changes compared to a situation where the initial habitat area is the same in both regions.

Another model assumption is that the regulator maximises the ecological benefit subject to a constraint on total costs. Alternatively, the regulator may be interested in maximising the benefit subject to a certain budget $BG = p_1\Delta A_1 + p_2\Delta A_2$. The relationship between the budget BG and total cost C is $BG = C + R$ because the budget has to cover not only the costs but also producer surpluses (R) for those landowners whose costs of carrying out biodiversity-enhancing land-use measures are lower than the compensation payments ($p_i > c_i$). The focus on costs as a constraint is motivated by the fact that C constitutes the direct costs of biodiversity conservation for society,

whereas R are transfers of financial resources from the regulator to the land-users which have no direct net welfare effect on society. However, an indirect effect arises as, in order to finance such transfers, taxes have to be raised which can create deadweight economic costs, both directly due to administrative costs of tax collection and indirectly due to labour/leisure distortions from income taxes, investment distortions from capital taxes and consumption distortions from sales taxes (see e.g. Innes 2000).² Taking the budget as a constraint would take these deadweight economic costs into account. However, even though not considered explicitly in this study, the model results can be still applied to cases where BG is a constraint instead of C . Producer surpluses can be taken into account in the context of the current model by interpreting them as part of the cost function which – *ceteris paribus* – makes the marginal cost function steeper. Thus, the cost-effectiveness of uniform compensation payments for a budget instead of a cost constraint can be found in Figures 2 and 3 for the different scenario results by moving upwards and to the right.

The model was formulated using the assumption that the aim of the regulator is to maximise the number of species or the expected lifetime of a particular species, at least cost. For many cases, this assumption may be a good approximation of the regulator's benefit function. However, it may not be true in other cases. For example, the regulator may be less interested in the mere number of species but more in the type of species, perhaps attaching greater value to attractive species such as large mammals that are fewer in number than to unattractive species like insects. Furthermore, biodiversity-enhancing land-use measures may create not only benefits related to conservation but also other benefits. For example, some measures such as planting hedge rows increase the beauty of the landscape and thus have a recreation value. These benefits may spatially differ (e.g. due to varying distances of areas to urban agglomerations) and thus influence the allocation of biodiversity-enhancing land-use measures considered best by the regulator. Although in this study the benefit functions do not take into account such benefits, the model results may still be useful in cases where the regulator's aims differ from those assumed here. The reason is that the benefit functions in the model cover a large spectrum of concave and convex functions and may in many cases, therefore also be used as representatives of benefits other than those assumed in the model.

Taking into account the issues that have been discussed in this paper on an abstract level, policy design faces the challenge that the regulator needs information about the benefit and cost functions. With respect to the cost function, the regulator may have insufficient knowledge about land-users' requirements for carrying out biodiversity-enhancing land-use measures. This may be due to a lack of information about pure

production costs (cf. Moxey et al. 1999) but also about land-users' values related to biodiversity conservation. These may differ among land-users and influence the minimum amount of compensation land-users demand for carrying out biodiversity-enhancing land-use measures (Smith and Shogren 2002). With respect to the benefit functions, their degree of concavity or convexity has to be known, and in particular how this differs between regions. Usually, establishing whether the benefit function in a region is concave, convex or linear should be relatively easy, and can often be decided on the basis of general ecological knowledge (cf. Begon et al. 1990; Wissel et al. 1994). However, the precise estimate of the degree of concavity or convexity needed to quantitatively assess the cost effectiveness of uniform payments, may be difficult to obtain in practice. Before engaging in costly investigations, results such as those from the present study should be used at first to understand the problem qualitatively. It can then be decided whether expending more effort can be expected to provide substantial benefits or not.

Future research may attempt to assess the empirical relevance of the problem tackled in this paper on a conceptual level. Carpentier et al. (1998) empirically examined cost savings through spatially heterogeneous performance standards for reducing nitrogen runoffs from dairies in the Lower Susquehanna Watershed in the US, and found that efficiency losses may be significant. In contrast, Fleming and Adams (1997) found in their empirical study on taxes to control groundwater nitrates stemming from irrigated agriculture that specifically tailored taxes only lead to small efficiency gains. What would be the results of empirical studies addressing the issue of spatially uniform versus heterogeneous compensation payments aimed at conserving biodiversity? It should be relatively easy to conduct such studies for compensation programmes for species conservation. Given spatially heterogeneous data on economic costs and ecological benefits (which may be gained through species-specific ecological simulation models; see for example Burgman et al. 1993; Hanski 1999), the cost-effectiveness of uniform payments may be calculated using methods of optimisation. By incorporating valuation methods, such studies may also provide a good opportunity to take into account other values such as recreational or aesthetic values arising from biodiversity-enhancing land-use measures.

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Notes

1. It should be noted that there is ongoing research on the precise effects of various factors such as habitat structure, heterogeneity and fragmentation on the species-area relationship (e.g. Storch et al. 2003). Beyond this, in a spatially structured region, exactly where in the region habitat area is increased may also be a factor of influence, reducing the reliability of the species-area relationship in this case. However, in an initial approximation and to provide a rough guideline the species-area relationship is a useful model for estimating the impact of habitat increase on species richness.
2. According to Innes (2000, p. 197), deadweight costs have been estimated by economists to be in the order of 10–30 cents per dollar.

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Appendix A

Below, details about the analysis of the model are given. Without loss of generality, we set the constant $\alpha \cdot A_0^z = 1$ and write

$$\Delta B_i = (1 + \Delta A_i / A_0)^z - 1 \quad (\text{A.1})$$

The costs C_i of carrying out biodiversity-enhancing land-use measures in an area ΔA_i in region i are given by the integral of Equation (3):

$$C_i = c_0 \cdot \Delta A_i + e_i / 2 \cdot (\Delta A_i)^2 \quad (\text{A.2})$$

Due to Equation (5) we can write

$$C_i = q_i \cdot C_{\text{tot}} \quad (\text{A.3})$$

with $q_1 + q_2 = 1$ and q_i giving the share of C_{tot} that falls into region i ($i = 1, 2$).

We solve Equation (A.2) for ΔA_i , insert ΔA_i in Equation (A.1) and obtain with Equation (A.3)

$$\Delta B_i = \left[1 + \frac{\sqrt{1 + 2q_i \lambda \delta_i} - 1}{\delta_i} \right]^{z_i} - 1 \quad (i = 1, 2) \quad (\text{A.4})$$

where $\lambda = C_{\text{tot}}/(c_0 A_0)$ and $\delta_i = e_i A_0/c_0$ (cf. the parameterisation of the model in Section 4).

A1. HETEROGENEOUS PAYMENTS

Cost-effectiveness is achieved by maximising $\Delta B_{\text{tot}} = \Delta B_1 + \Delta B_2$ (Equation (4)) as a function of q_1 (with $q_2 = 1 - q_1$) where ΔB_i are given by Equation (A.4). As the z_i in Equation (A.4) may be non-integer and/or greater than one, an analytical solution, e.g., via Lagrangian maximisation, is not possible. Therefore we take a straight forward numerical approach, vary q_1 systematically from 0 to 1 and determine the value \hat{q}_1 that maximises ΔB_{tot} . From \hat{q}_1 and $\hat{q}_2 = 1 - \hat{q}_1$ one may also determine the corresponding cost-effective payments via

$$\hat{q}_i = \sqrt{2e_i \hat{q}_i C_{\text{tot}} + c_0^2} \quad (i = 1, 2) \quad (\text{A.5})$$

A2. UNIFORM PAYMENTS

With $p_1 = p_2 = p$ and Equations (6) and (A.2) we have

$$C_i = \frac{p^2 - c_0^2}{2e_i} \quad (i = 1, 2) \quad (\text{A.6})$$

and with Equation (5) we obtain the corresponding q_i as

$$q_{1,2} = \frac{e_{2,1}}{e_1 + e_2} \quad (\text{A.7})$$

The total benefit $\Delta B_{\text{tot}} = \Delta B_1 + \Delta B_2$ for uniform payments is obtained by inserting Equations (A.7) into (A.4). The cost-effectiveness as defined at the end of section 3 is obtained by dividing this value ΔB_{tot} by the value ΔB_{tot} that has been obtained for the heterogeneous payments above.