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Should the biodiversity bank be a savings bank or a lending bank?

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Abstract

Conservation offsets are increasingly used as an instrument for biodiversity conservation on private lands. Since the restoration of degraded land often involves uncertainties and time lags, conservation biologists have recommended that credits in conservation offset schemes be awarded only with the completion of the restoration process ("savings bank"). These arguments, however, ignore that such a scheme design may incur higher economic costs than a design in which credits are already awarded at the initiation of the restoration process ("lending bank"). Here a generic agent-based ecological-economic simulation model is developed to explore the cost-effectiveness of savings and lending banks. The economic model compartment considers spatially heterogeneous and dynamic conservation costs and time preferences in the landowners. The ecological compartment considers uncertainty in the duration and the success of restoration process, and in the metapopulation dynamics of a species described by the rates of local population extinction and the colonisation of empty habitat patches. By this the widely used offset metric of "habitat hectares" is replaced by "metapopulation viability" which is commonly used in conservation biology. It turns out that whether credits should be awarded at the initiation or with completion of restoration depends on the ecological and economic circumstances. Larger colonisation and extinction rates, e.g., tend to favour the awarding of credits with the initiation of habitat restoration.

Key words:

conservation offsets, cost-effectiveness, ecological-economic model, habitat restoration, metapopulation, population viability, uncertainty.

Introduction

In conservation offsets (Bull et al. 2013, 2018), economic development of ecological valuable land can be offset by the restoration of economically used land. In theory, this ensures that the total amount of habitat remains constant (“no net loss”, NNL). And if one considers that usually the economically most valuable land is developed while restoration can be expected to be carried out on economically less valuable land, the offset scheme is likely to deliver NNL more cost-effectively, i.e. at lower economic costs, compared to a situation in which offsetting is not allowed. In practical applications, however, conservation offsets have been observed to largely fail on the achievement of NNL (Maron et al. 2012, Quetiér et al. 2013).

The scepticism raised by the practical experiences is reinforced by theoretical arguments (Moilanen et al. (2009), Bekessy et al. (2010), Maron et al. (2012)). A central argument in these articles is that if credits are already awarded at the initiation of a habitat restoration process and can immediately be sold to developers, then habitat is lost temporarily until the restoration process is completed. But even the assumption that at some time the habitat loss will be offset is optimistic given that restoration projects have frequently failed in the past (Maron et al. 2012). Therefore Bekessy et al (2010) proposed that credits should be awarded only with the completion of a restoration project, so that in the authors’ notion the biodiversity “lending bank” (in which credits are awarded with the initiation of restoration) becomes a “savings bank”. Further general issues and concerns around conservation offsets are discussed, e.g., by Walker et al. (2009), Maron et al. (2012), Bull et al. (2013), Quétier et al. (2014) and zu Ermgassen et al. (2020).

An approach to guarantee NNL of habitat in lending banks even in the presence of time lags and ecological uncertainty is to prescribe offset ratios or multipliers, so that the loss of one hectare of habitat can only be offset by the initiation of restoration on more than one hectare of degraded land (Moilanen et al. 2009, Bull et al. 2017). Drechsler (2022) showed with an ecological-economic simulation model that under certain conditions, such as high variability of conservation costs, lending banks with appropriate multipliers can be more cost-effective than savings banks, i.e. ensure no habitat on the temporal average at lower total economic costs. The present paper addresses shortcomings of that analysis to provide further insights into the pros and cons of savings and lending banks.

Specifically, what is missing in Drechsler (2022) is that habitat area is generally an imperfect predictor of biodiversity. Under an area metric – even if it also considers bio-physical features of the habitat (Bull et al. 2014, zu Ermgassen et al. 2019) – NNL of habitat area does not guarantee

NNL of the targeted biodiversity feature, such as the abundance of a particular bird species (Buschke and Brownlie 2020, Marshal et al. 2020, Simpson et al. 2022). The reason for the observed deviation between habitat amount ("hectares") as the nominal biodiversity target and realised biodiversity level in these studies (which could be addressed by multipliers) is the spatial heterogeneity of habitat quality which (unless explicitly accounted for) compromises the "equivalence requirement" that a restoration project must exactly reproduce what is lost due to economic development (Bruggeman et al. 2005, Wissel and Wätzold 2010, Bull et al. 2013).

The present analysis addresses another reason for the slack between habitat area and species population size in conservation offsets: the habitat dynamics induced by the development and restoration activities. As the simple but instructive model of DeWoody et al. (2005) demonstrates, even if there is a balance between the destruction and the restoration of habitat so that the amount of habitat is constant, the habitat turnover reduces the proportion of area occupied by the considered metapopulation because, among other things, habitat destruction is likely to destroy a resident local population while restored habitat has to be colonised by the species before it can contribute to the survival of the metapopulation.

While such habitat turnover will occur both in lending and in savings banks, lending banks involve an additional source of habitat variation, because even if the long-run constancy of the amount of habitat is ensured, the dynamics within the credits market can lead to temporary shortfalls of habitat (balanced by temporary excess at other times) (Drechsler 2022). This variation poses another risk to the species inhabiting the habitat. The fact that species can go extinct at a certain risk even if a considerable amount of habitat is available and even if the average population size of the species is positive is well-known among conservation biologists (see, e.g., Beissinger and McCulough 2002) but to the author's knowledge has not been considered explicitly in the quantitative analysis of conservation offsets. Here I explore how a lending bank performs if the metric for NNL is not amount ("hectares") of habitat but the viability of a species. In particular, can a lending bank can deliver species viability more cost-effectively than a savings bank so that a given level of metapopulation viability can be achieved at lower economic costs?

To explore the issue, I extend the economic model of Drechsler (2022) by adding a metapopulation model of a species inhabiting the model region. The economic model considers credits trading and land-use dynamics in dependence of the above-mentioned spatial heterogeneity and temporal dynamics of the conservation costs, uncertainty in the duration and success of habitat restoration, as well as time preferences (discounting of future revenues) in the landowners. Heterogeneity in the habitat quality of (restored) land parcels is ignored for simplicity, as well as spatial structure, so that the numbers of land parcels that are in economic use, in restoration, and that have been successfully restored are known but not their spatial locations. By this the model falls into the class of "spatially implicit" models.

Probably the best known spatially implicit metapopulation model is by Levins (1969) in which local populations colonise empty habitat patches at some rate *c* and go extinct at some rate *e*. In the present case, these metapopulation dynamics are disturbed by the destruction of habitat patches in the course of economic development and the creation of habitat patches due to restoration. With this model I will compare the cost-effectiveness of savings and lending banks, and how the result depends on the colonisation and extinction rates *c* and *e*. Cost-effectiveness is measured here so that a given level of metapopulation viability is achieved at least total economic cost.

Metapopulation viability is measured by the temporal average of the proportion of occupied land parcels as well as the probability of the metapopulation surviving until the end of the simulation. The nature of these viability measures implies that NNL on the level of habitat amount does not necessarily ensure metapopulation survival – neither in the savings nor in the lending bank. Therefore I avoid the term NNL and refer to metapopulation viability.

Due to the abstractness and simplicity of the model, the results cannot be concrete recommendations for the design of an offset scheme (such as the appropriate size of a multiplier) for a specific real conservation problem. Instead they will be rather of a strategic nature, indicating under which broad ecological and economic circumstances lending banks or savings banks can be expected to be more cost-effective than the respective other scheme.

2 Methods

2.1 Rationale

To conserve biodiversity cost-effectively, conservation efforts should, all other things equal, be allocated where costs are lowest. On private lands, conservation cost largely represents the forgone economic profit associated with environmentally friendly land use. Other private costs (such as landowners' management costs as well as the costs of information acquisition and bureaucracy) and public costs (such as monitoring landowners' compliance with the scheme) are ignored for simplicity (implications of this assumption are discussed in the Discussion).

Under this assumption, if profitable land is currently conserved while unprofitable land is used economically, the allocation of conservation measures is obviously not cost-effective. To resolve this "spatial mismatch" so that conservation efforts are carried out where they lead to the highest profit losses, the economically profitable but currently conserved land would need to be developed into economic use while the unprofitable economically used land would need to be restored into species habitat.

Facilitating this process is the major motivation of conservation offset schemes in which this re-allocation is organised through the trade of conservation credits (e.g., Simpson et al. 2021, 2022): Owners of conserved profitable land buy credits that allow them to develop their land; the required credits are supplied by owners who restore land that is currently in economic use. The dynamics of the market is driven by the described spatial mismatch (e.g., Simpson et al. 2021, 2022) which can be the result of economic change so that less profitable land has recently become more profitable (e.g., at the fringe of growing settlements) while more profitable land has recently become less profitable.

As outlined above, the re-allocation of conservation efforts can be problematic if the restoration of habitat takes time or may fail. One option to ensure no net loss of habitat is to award credits only for completely restored habitat ("savings bank") rather than with the initiation of restoration efforts ("lending bank"). To achieve no habitat net loss in a lending bank two options are considered in this study. The first is the above-mentioned multiplier (denoted as q), so that the initiation of a restoration process earns one credit while the development of habitat requires $q > 1$ credits (for technical reasons, the simulation analysis actually assumes, formally equivalently, that the initiation of a restoration process earns $1/q$ credits while the development of habitat requires one credit). By this, if e.g., restoration is successful on one out of two restored hectares, a multiplier of $q = 2$ ensures that one average each developed hectare is offset by the successful restoration of one hectare.

As an alternative to multipliers, one could consider that the described restoration uncertainties reduce the average amount of habitat compared to the initial amount by some number d. To offset this loss, one may simply raise the scheme's ("nominal") habitat target by that number d. Technically, this could be achieved by initiating the scheme with a credits "debt" of amount d which has to be balanced by the initiation of d restoration processes before any credit can be sold to a developer. Formally, this is equivalent to the removal of emission permits by the policy maker in an emissions trading scheme, in order to reduce overall emissions. Both options, multiplier q and target increase d will be considered in the present analysis.

The land use dynamics induced by the trading and land-use decisions are assumed to affect the population dynamics of a species that is structured as a metapopulation. The viability of the species is measured by the mean number of local populations over time (occupancy, m_{occ}) and by the probability of surviving the considered time horizon of the simulation (survival probability, p_{surv}). To compare savings with lending banks, first the dynamics induced by the savings bank are modelled for a given combination of model parameters (that characterise the ecological and economic conditions) and the population viability (m_{occ} and p_{surv}) are determined. After this, the dynamics of the lending bank are simulated and d or q chosen so that the obtained m_{occ} and p_{surv} are larger than, but as close as possible to those of the savings bank.

2.2 The model

The credits market and land-use model

A detailed description of this part of the model can be found in Drechsler (2022), so here I provide an outline. A model region with N = 200 land parcels is considered. Each land parcel i is owned by a single landowner who can use it for economic purposes or for conservation. If it is used economically it earns an economic profit $a_i(t)$ in time step t, which is forgone if the land parcel is used for conservation (if not the entire economic profit is forgone one may regard a_i as the difference between the profit from economic use and that from conservation). The a_i can increase or decrease monotonically at individual rates r_i. These rates are drawn randomly for each land parcel from a uniform distribution with bounds $[-\gamma, +\gamma]$, so that γ measures the speed of the economic change. Despite these changes, the a_i are in any time step uniform distributed with relative range $\pm\sigma$ around the mean. Each land parcel can be in one of three states: in economic use, conserved and in restoration, and conserved and habitat. All habitat parcels have the same ecological value, and in particular the same suitability for the species modelled below. Transitions between economic use and conservation and from habitat to economic use are instantaneous, while a land parcel that has switched from economic use to conservation requires m times steps to be restored and become a habitat.

The restoration process is subject to uncertainty. Two (for numerical simplicity, separate) types of restoration uncertainty are considered: the restoration always succeeds but its duration m is uncertain and sampled from a Poisson distribution with mean M; or the duration is certain with length M, but the process fails with probability φ. A land parcel that successfully ends a restoration process becomes habitat, while after failure (realised after M time steps) it returns to economic use in the following time step. Partially successful restoration and restoration costs are ignored for simplicity (see the Discussion for implications).

Initially, $n(0)$ land parcels are habitat, and for reasons explained in Drechsler (2022) it is assumed that these are the $n(0)$ land parcels with the lowest profitabilities a_i; while the other $N - n(0)$ land parcels are in economic use. So the initial allocation of conservation efforts is cost-effective, but the spatial match between conservation costs and conservation efforts can change in the course of the dynamics in the a_i.

Development of a habitat requires one credit. In the savings bank there is an equivalence between credits and habitat because a credit is earned only once a habitat has been established. Therefore, each habitat that is developed into economic use, requiring one credit, is immediately offset by the establishment of one habitat (earning one credit), so the number of habitat parcels cannot change.

In the lending bank, if restoration takes time and/or can fail this equivalence between credits and habitat parcels is broken, leading to net habitat decline. As explained in Section 2.1 “Rationale” above, two scheme designs are considered to avoid this on the long-term average. Either multipliers q ($q > 1$) are introduced, so that the development of a habitat parcel requires one credit, while the initiation of a restoration process earns only $1/q < 1$ credits. Or the (“nominal”) habitat target is raised by an amount $d > 0$, which is implemented technically by demanding that the offset scheme is initiated with a credits debt d that must be balanced by d initiated restoration processes before any credit can be sold to a developer.

As explained in Drechsler (2022) (and may be regarded as plausible from the remarks in model outline), if in the lending bank habitat restoration is prone to fail ($\varphi > 0$) net habitat loss can, in the long run, be avoided only through multipliers $q > 1$ but not by an initial credits debt $d > 0$. Alternatively, if the success of habitat restoration is certain ($\varphi = 0$) but the duration is uncertain, a multiplier $q > 1$ would, in the long run, lead to net habitat gain which would complicate the comparison of savings and lending banks. So in this case $q = 1$, but the habitat target is increased: $d > 0$. To avoid numeral difficulties in the calculation on the credits market clearance (see below), d and q are chosen as integer numbers.

The landowners, for their decisions, compare the utility of keeping the current land use (economic use or conservation) with that of switching to the respective other land use. For this they consider for each alternative the present value of the economic revenues which is the sum of the discounted revenues in all future time steps.

To start with the change from economic use to conservation, in the lending bank the (present value) revenue of initiating a restoration process on an economically used land parcel is the current credits price divided by the multiplier q, while the present value of keeping the land parcel in economic use is the sum of the discounted economic profits a (introduced above) of all future time steps.

In the savings bank the present value revenue of initiating a restoration process depends on the type of restoration uncertainty. If the duration is uncertain, the credit is earned m time periods after the decision to restore land, so the present value revenue is the credits price at that time step discounted by m time steps (Fig. 1).

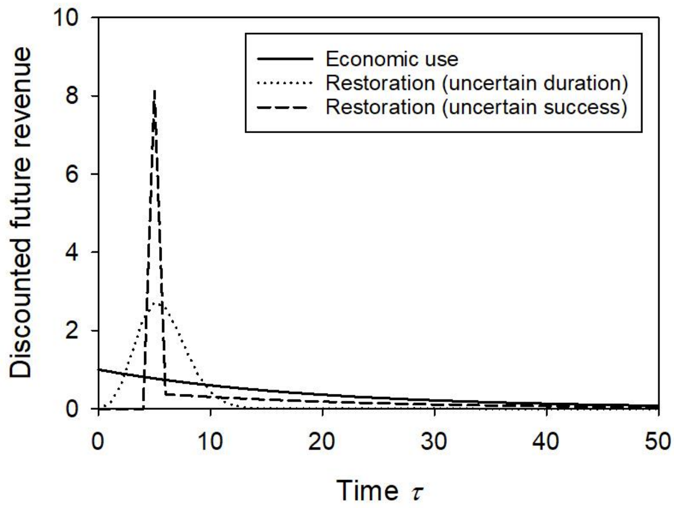

Figure 1: Discounted future revenues at each future time step τ, measured from the current time step (t) at which the land-use decision is taken, assuming a discount rate of $\delta = 0.05$ per time step. Solid line: discounted profits $a(\tau)/(1+\delta)^{\tau}$ of economic use, assuming $a(\tau) = 0.7$. Summing over these discounted economic profits yields the net present value (≈ 13.9) of managing the land parcel economically in perpetuity (also considered as the parcel's land price). Dotted line: discounted revenues of selling a credit at price $p = 20$ at the time $\tau = m$ at which the restoration process successfully completes (restoration never fails: $\varphi = 0$); m is sampled from a Poisson distribution, with mean $M = 5$. Summing over these discounted revenues yields the expected (expected, due to the uncertainty in m) net present value (≈ 14.8) of initiating a restoration process. Dashed line: discounted expected revenues composed of two possible outcomes: selling a credit at price $p = 20$ after the restoration process successfully completed at time $\tau = M = 5$ with probability $1 - \varphi = 0.5$), and the discounted profits $a(\tau)/(1+\delta)^{\tau}$ (with $\tau > M$) that accrue after failed restoration (with probability $\varphi = 0.5$) and the land parcel is used economically again in perpetuity (note that for $\tau \geq 6$ the values of the dashed line are 0.5 times the values of the solid line. Summing over these discounted revenues yields the net present value (≈ 13.1) of initiating a restoration process. Comparing the net present values for the above numerical example, if restoration duration is uncertain and success certain it is overall profitable ($14.8 > 13.9$) to initiate restoration; while if

restoration duration is certain and success uncertain it is overall profitable (13.9 > 13.1) to keep the land parcel in economic use.

Alternatively, if the duration of restoration is certain but the success is uncertain the landowner takes the expected value of the two possible outcomes (success with probability $1 - \varphi$, and failure with probability φ). If the present value of restoration exceeds the present value of keeping the land parcel in economic use a restoration process is initiated on the land parcel, while otherwise the land parcel is kept in economic use (Fig. 1). Here the landowner acts somewhat myopically, so that future land-use changes like the re-development of a successfully restored land parcel (which also reflects best offset practice) or the later initiation of a restoration process after it had been decided to keep the land in economic use are excluded. As argued in Drechsler (2022), this assumption is plausible at least within the general framework of the model.

To model the change from conservation to economic use, the landowner compares the sum of the discounted economic profits in all future time steps with the current credits price. If the former exceeds the latter the land parcel is developed into economic use, and otherwise it remains conserved. The current credits price is determined in the standard manner in economics (e.g., Simpson et al. 2021) by equating credit supply (credits earned through habitat restoration) with credit demand (credits required for developing habitat into economic use).

The ecological model

The species dynamics are modelled via the spatially implicit metapopulation model of Levins (1969), but with stochastic colonisation and extinction rates. Each habitat parcel can harbour a local population. Any local population goes extinct with probability e per time step. A local population colonises another habitat parcel with probability c. Following Levins' arguments, the colonisation processes change the number of local populations (y) on n habitat parcels according to

$$\frac{dy}{dt} = cy\left(1 - \frac{y}{n}\right) \qquad (1)$$

The change per empty habitat parcel thus is

$$\frac{1}{n-y}\frac{dy}{dt} = \frac{cy}{n-y}\left(\frac{n-y}{n}\right) = \frac{cy}{n} \qquad (2)$$

Thus, an occupied habitat parcel becomes empty at rate e, while an empty habitat parcel becomes occupied at rate cy/n. Analogous to the model of De Woody et al. (2005), destruction of a habitat (in the present case due to economic development) destroys any residing local population and adds to the local extinction rate e; while created habitat parcels (in the present case due to completed habitat restoration) are initially empty and need to be colonised (at rate cy/n) before they harbour a local population.

Simulation of the ecological-economic model dynamics

For the simulation of the model dynamics a time horizon of $T = 50$ time steps is chosen. In each time step the landowners determine their demand or supply and their land use as a function of the credits price, and the equilibrium credits price is determined by equating credits demand and supply. Taking this equilibrium price, the landowners' actual demand and supply and their land-use are determined. For each land parcel on which a restoration process is initiated the duration m (if that is uncertain) is sampled or (if restoration success is uncertain) it is sampled whether the process succeeds after M time steps (with probability $1 - \varphi$) or not.

2.3 Model analysis

While simulating the ecological-economic model dynamics, in each time step the number of local populations (y) and the total conservation cost (forgone economic revenues on the conserved land parcels) are recorded. At the end of a simulation run the temporal averages of these two variables, Y and C are calculated as well as whether after $T = 50$ time steps the species has survived ($y(T) > 0$). Model stochasticity is accounted for by replicating the simulation 200 times and calculating the mean of the occupancies Y, denoted as m_{occ}, the survival probability p_{surv} as the proportion of model runs with $y(T) > 0$, and mean and standard deviation of the cost C, denoted as m_C and σ_C, respectively.

To compare the savings and the lending banks for a given model parameter combination, first the dynamics of the savings bank are simulated with 200 replicates and the described output variables determined. Then the dynamics of the lending bank are simulated with 200 replicates. Most likely, without an increase of the habitat target ($d = 0$) or without multiplier ($q = 1$), m_{occ} and p_{surv} will be below their values obtained for the savings bank. To prevent this loss of population viability, d (if the duration restoration is uncertain) or q (if the restoration success is uncertain) are raised until that loss is zero. Both population viability measures, m_{occ} and p_{surv} are considered separately.

To determine the efficiency gain of the lending bank, relative to the savings bank, a statistical effect size (Cohen 1988) is calculated for the conservation cost C, via

$$E = \frac{m_C^{(\text{lending bank})} - m_C^{(\text{savings bank})}}{\left[\left(\sigma_C^{(\text{lending bank})}\right)^2 + \left(\sigma_C^{(\text{savings bank})}\right)^2\right]^{0.5}} \qquad (3)$$

By this formulation, E measures the effect of the replacement of the savings bank by the lending bank.

To determine the distribution of E and the impact of the model parameters on E, the above-described analyses are carried out for 500 random model parameter combinations where each parameter is drawn from a uniform distribution with bounds given in Table 1. These bounds are motivated as follows (Drechsler 2022). A value of $\sigma = 0.2$ (0.8) corresponds to a profit ratio between the most and the least profitable land parcels of of 1.5 (9), which covers a broad range of possible situations. Values for $\lg(\gamma/(2\sigma))$ between –3 and –1 (i.e., γ ranging from $0.001 \cdot 2\sigma$ to $0.1 \cdot 2\sigma$) encompass a rather wide range from slowly to fast changing economic profits (Fig. A1 in the Supplementary Material).

Table 1: Bounds of the model parameters. If uncertainty is in the duration of the restoration process, the probability of restoration failure is fixed at $\varphi = 0$.

Model parameter	Symbol	Lower and upper bounds
Economic profit heterogeneity	σ	0.2, 0.8
Logarithm of economic profit dynamics	$\lg(\gamma/(2\sigma))$	–3, –1
Discount rate	δ	0.02, 0.08
Mean restoration time	M	2, 10
Probability of restoration failure	φ	0, 0.8
Initial number of habitat parcels	$\lambda_0 \equiv n(t = 0)/N$	0.1, 0.4
Local extinction probability	e	0.05, 0.2
Metapopulation turnover ratio	c/e	1.25, 2

The meaning of the values of M depend on the time scale of the model. If land use is considered to change every year (or decade) then values of $M = 2, 10$ represent restoration times of 2, 10 years (or decades). A restoration failure probability of $\varphi = 0.8$, so that only 20 percent of the restoration projects end successfully) can be regarded as quite pessimistic (Moilanen et al. (2009) consider $\varphi = 0.5$). The initial proportion of conserved land parcel ranges between 10 and 40 percent.

At the upper and lower bounds of the local extinction rate e, local populations go extinct per time step with a probability of 20 and 5 percent, respectively. In a deterministic setting and without the destruction and creation of habitat patches, the equilibrium proportion of occupied land parcels is given by $1 - e/c$ (Levins 1969). So the lower and upper bounds of $c/e = 1.25$ and $c/e = 2$ would yield equilibrium proportions of 0.2 and 0.5, respectively. In a stochastic setting like the present one, such values are associated with substantial extinction risks of the metapopulation (Frank and Wissel 2002), so the model parameters well encompass the range that is relevant in a conservation context.

Based on the effects sizes for the 500 random model parameter combinations, the mean and standard deviation of E are calculated. To assess the main effects of the model parameters, a multiple linear regression is performed, based on the 500 random samples, with E as the explained variable. To account for the different dimensions and ranges of the model parameters, before inserting them as explaining variables in the regression they are normalised to a range between zero and one. To obtain these rescaled values, for each model parameter p the maximum (p_{max}) and minimum (p_{min}) of all values is determined; the minimum then is subtracted from each original parameter value p_i in the sample and the difference divided by the parameter range (maximum minus minimum): $p_i \rightarrow p_i' = (p_i - p_{min})/(p_{max} - p_{min})$.

To identify interaction effects between model parameters, all pairwise products of model parameters (1 + … + 6 = 21 interaction terms for the case of uncertainty in restoration durations, $\varphi = 0$, and 1 + … + 7 = 28 interaction terms for the case of uncertainty in the restoration success, $\varphi > 0$). Regressions are carried out with these 21 respectively 28 explaining variables.

3 Results

According to Table 2, the mean of the effect size E is generally positive, so that the savings bank tends to be more cost-effective than the lending bank in the considered model parameter space. However, the effect is not significant, as the large standard deviation of E indicates. The reason is that, depending on the choice of the model parameters, both positive and negative E can be observed. The regression coefficients allow for the following insights into the effects of the model parameters on E. The coefficients for the profit variation σ are negative, indicating that increasing σ

reduces E, i.e. increases the cost-effectiveness of the lending bank relative to that of the savings bank. The opposite is observed for the discount rate δ and the mean restoration duration M whose increase would reduce the cost-effectiveness of the lending bank relative to that of the savings bank.

If the success of restoration is uncertain (right half of Table 2), an increase in the speed of the profit dynamics (γ) reduces E, i.e. increases the cost-effectiveness of the lending bank relative to that of the savings bank. If the restoration duration is uncertain (left half of Table 2) the effect tends to be opposite. An increasing initial proportion of habitat parcels (λ_0) reduces E, i.e. increases the cost-effectiveness of the lending bank relative to that of the savings bank, as does an increase in the probability of restoration failure φ. The reason for the latter is that although the performance of both schemes suffers from an increased φ, the lending bank suffers less because here the risk is spread over more land parcels than in the savings bank (Drechsler 2024).

Table 2: Means and standard deviations of the effect size E for the scheme cost (eq. 3) over all 500 combinations of the economic and restoration parameters; and Pearson's correlation coefficients between the effect sizes and the eight model parameters.

	Uncertainty in restoration duration		Uncertainty in restoration success	
	m_{occ}	p_{surv}	m_{occ}	p_{surv}
Mean E	11.3	3.27	–0.38	–0.49
Standard deviation of E	13.9	8.07	1.24	1.40
Regression coefficients				
Profit heterogeneity σ	–24.7	–11.3	–0.75	–0.73
lg(Profit dynamics $\gamma/(2\sigma)$)	16.9	–0.2	–1.93	–2.14
Discount rate δ	11.4	6.8	1.97	1.92
Mean restoration duration M	14.7	6.0	1.21	1.19
Prob. of restoration failure φ	–	–	–0.71	–0.63
Initial proportion of habitats λ_0	–7.4	–1.9	–0.06	0.34
Local extinction probability e	1.4	–5.0	–0.12	–0.52
Metapopulation turnover ratio c/e	–1.0	0.2	0.07	0.15

The metapopulation turnover rate c/e has a comparatively little influence on E, and the same is found for the local extinction rate e if metapopulation viability is measured by habitat occupancy m_{occ}. If metapopulation viability is measured by survival probability p_{surv} an increasing e reduces E, i.e. increases the cost-effectiveness of the lending bank relative to that of the savings bank.

Considering interactions between model parameter (Table B1 in the Supplementary Material), if the duration of restoration is uncertain, interactions with large regression coefficients for both measures of metapopulation viability include $\gamma\delta$ and γM (positive sign) and $\sigma\delta$ and σM (negative sign). The interaction between heterogeneity (σ) and dynamics (γ) of the economic profits is negative.

If the *main effects* of two parameters have equal signs, a positive interaction coefficient indicates that both parameters amplify each other's influence, while a negative interaction coefficient indicates a mutual attenuation. The opposite is concluded if the main effects of the two parameters have opposite signs. By this, in all five mentioned interactions the two model parameters amplify each other, so that an increase (decrease) in the one increases (decreases) the influence of the other.

If uncertainty is in the success of restoration, interactions with large regression coefficients for both measures of metapopulation viability include $\gamma\delta$ and φM (positive sign) and σM, $\sigma\varphi$, $\gamma\varphi$ and γe (negative sign). Considering the signs of the main effects of these model parameters, in all interactions except for σM the model parameters attenuate each other.

4 Discussion

A generic agent-based ecological-economic simulation model was developed to address the question of whether credits in conservation offset schemes should be awarded only with completion of a habitat restoration process ("savings bank") or if they can already be awarded with the initiation of the process ("lending bank").

If habitat restoration can fail the loss of habitat in lending banks can, on the temporal average, be avoided through multipliers (where more credits are required to develop a habitat of a particular size to economic use than are awarded for the restoration of an economically used land parcel of the same size). If restoration is always successful but only takes an uncertain amount of time, net loss can be avoided through an increased habitat target (which can be achieved by initiating the scheme with a credits debt that must be balanced before and credits can be purchased for habitat development).

Despite these additional constraints, lending banks cannot avoid the *temporary* loss of habitat, so savings banks have been preferred by various authors (Moilanen et al. (2009), Bekessy et al. (2010), Maron et al. (2012)). However, the previous arguments ignore that savings banks may incur higher costs to the landowners because it may overly slow down the adaptation of land use to changing economic circumstances and prevent that conservation efforts be carried out where they incur the lowest economic costs. So there is obviously a trade-off between securing NNL of habitat on the one hand and minimising economic costs in the other, rendering the question of which scheme design is more cost-effective – in the sense that NNL is achieved at least costs – is not trivial.

The analysis of Drechsler (2022) indicates that lending banks may altogether be more cost-effective, i.e. deliver NNL of habitat at lower costs, than savings banks if the conservation costs (here considered as forgone economic profits) vary strongly among land parcels and/or strongly change over time. However, measuring NNL with respect to the average amount of species habitat does not necessarily ensure NNL of species abundance or viability, and NNL of biodiversity as a whole (Bull et al. 2014, zu Ermgassen et al. 2019, Buschke and Brownlee 2020, Marshal et al. 2020, Simpson et al. 2022). In fact, even though in Drechsler (2022) both schemes conserve the same average amount of habitat, they differ with respect to the temporal variation and the turnover (rates of habitat development and restoration), both of which can substantially affect the dynamics and viability of species (e.g. DeWoody et al. 2005).

To address this shortcoming, the present study adds a simple metapopulation model to the model of Drechsler (2022) to compare the two offset schemes with respect to the economic cost associated with achieving *a given level of metapopulation viability*. The metapopulation is characterised by a colonisation rate and a local extinction rate, and metapopulation viability is measured by two alternative quantities: mean occupancy, i.e. the mean proportion of occupied land parcels, averaged over the duration of the simulation, and the probability of surviving till the end of the time horizon.

The cost-effectiveness of the lending bank relative to that of the savings bank is measured by an effect size and the influences of the model parameters on this effect size are determined through statistical regression (compared to a simple correlation analysis in Drechsler (2022)). Table 2 largely confirms the results of Drechsler (2022) about the main effects of the spatial heterogeneity and temporal dynamics of the conservation costs, as well as the landowners' time preferences (discount rates) and the uncertainty in the duration and success rates of habitat restoration. *In particular, strongly spatially and temporally variable conservation costs tend to favour the lending* *bank, while a high discount rate in the landowners and long restoration times tend to favour the savings bank.*

Two additional insights are gained from the present study that refer to the influence of the characteristics of the species, i.e. its colonisation and extinction rates, and shed more light on the pros and cons of the two offset schemes. *If metapopulation viability is measured by mean occupancy, the two rates have a negligible effect on the difference between the schemes' levels of cost-effectiveness.* An explanation for this is that the occupancy is a deterministic measure that is largely proportional to the average amount of habitat. So a decrease in the local extinction rate, e.g., would increase the occupancy level, but it would do so in a similar manner for both schemes.

Quite a different result is obtained if metapopulation viability is measured by survival probability. Here increasing the local extinction rate increases the cost-effectiveness of the lending bank relative to that of the savings bank. The reason is that the lending bank, as mentioned above and shown by Drechsler (2022), leads to higher temporal variation in the amount of habitat (despite constant temporal average). The relative importance of this habitat variation, however, declines if there are other sources of stochasticity that contribute to the variation in the metapopulation size and the metapopulation viability. Such an additional source is the colonisation-extinction stochasticity (Hanski 1991) which increases with increasing local extinction rates. Thus the larger this rate the less critical is the habitat variation and the more favourable (given its cost advantage) becomes the lending bank. *Or more generally, the cost-effectiveness of the lending bank relative to that of the savings bank increases if the target species has highly variable dynamics by its nature because such species are less sensitive to habitat dynamics.*

This finding is confirmed by an observed "attenuating" interaction of the speed of the cost change (parameter γ) and the local extinction rate (e), so that if the one is large the influence of the other one on the cost-effectiveness of the lending bank relative to that of the savings bank is small. The systematic analysis of the interactions between the model parameters (not found in Drechsler (2022)) reveals, among other things, that (i) *if the restoration duration is uncertain the spatial heterogeneity and speed of change of the conservation costs (σ and γ) "amplify" each other in their influences*, so that an increase in one parameter increases the influence of the other, and (ii) both amplify the influence of the mean duration (M) of the restoration process. If uncertainty is in the success of restoration (iii) increasing probability of restoration failure (φ) has an attenuating interaction with the spatial heterogeneity and speed of change of the conservation costs (σ and γ), because similar to the interaction between γ and e above, *the higher the stochasticity in the* *economic profit dynamics the less critical is obviously an increase in the probability of restoration failure*; and (iv) *restoration duration (M) and probability of restoration failure (φ) have an amplifying interaction* so that an increase in the one increases the influence of the other.

The (relative) simplicity and abstractness of the model comes with a number of limitations. Only a single species and a single type of habitat are considered. And from the species' point of view, a land parcel is either habitat or not, and the species colonisation and extinction rates do not depend on whether the land parcel contains original or restored habitat – assumptions that may be relaxed in future studies. For a modelled offset scheme with several species and different habitat suitabilities, Simpson et al. (2021, 2022) demonstrate the importance of spatial correlations between economic profitability and habitat suitability for the different species. However, their model is static and does not consider any ecological or economic dynamics.

In the present model, spatial structure, including limited dispersal and spatial locations of the land parcels, is ignored. There is a number of spatially explicit economic and ecological-economic models of conservation offsets that demonstrate the importance of spatial interactions in the economic and/or ecological processes (e.g., Hartig and Drechsler 2009, Buschke and Sinclair 2019) but like Simpson et al. (2021, 2022) they are static (or though considering changing conservation costs, assuming instantaneous habitat restoration, as in Surun and Drechsler (2018)).

In the present model, restoration itself is either successful or not, so that there is no partial restoration (that might generate an intermediate level of habitat suitability). And restoration is assumed to incur not cost beyond the foregone profits of the economic land use. Restoration costs have been considered in the model of Drechsler et al. (2011) and were shown to reduce trading activity and land-use change (the turnover of habitat development and restoration). This would reduce both the advantage (higher economic flexibility and lower cost) and disadvantage (increased metapopulation extinction risk) of the lending bank, so the difference between the two offset schemes in terms of their cost-effectiveness would probably decline

However, one can expect that the restoration costs will not qualitatively change the observed main effects of the other model parameters. For instance, if large heterogeneity and fast change of the conservation costs favour the lending bank because the savings bank would overly inhibit an adaptation of conservation efforts to the least costly sites, there is no reason why this should change qualitatively when restoration costs are introduced.

Similar can be said about many other simplifying assumptions, including those above (number of species and habitat types, and spatial structure). Clearly, they will affect the effectiveness and cost-effectiveness of the two schemes, but it is not very likely that they will change the general conclusions about the effects of the model parameters on the ranking of the two schemes in terms of their cost-effectiveness. On a conceptual level this agrees with other findings (e.g., McCarthy et al. 2003, Drechsler et al. 2003, Salomon et al. 2020) that statements about the rank order of outcomes of decision alternatives is quite robust even if the uncertainty in the absolute outcomes of the decision alternatives is high.

In the present case this “robustness of rankings” also largely holds for the influence of the NNL metric: the influences of profit dynamics, restoration uncertainty and landowners discount rate only slightly depend on whether savings and lending banks are compared with respect to average amount of habitat (Table 2 in Drechsler (2022)) or with respect to metapopulation viability (present Table 2).

A limitation that may have a relevant systematic influence on the comparison of the two offset schemes is the neglect of compliance issues (Walker et al. 2009, Brown et al. 2013), so that landowners may contractually undertake to conserve their land but use it for economic purposes. Such lack of compliance is obviously more critical in the lending bank in which the landowners promise to restore their land to receive credits, while in the savings bank credits are awarded only for fully restored habitat. The additional risk of non-compliance and the monitoring costs associated with the securing of compliance is likely to reduce the overall cost-effectiveness of the lending bank. This does not invalidate the above results about the conditions (ranges of model parameter values) under which the lending bank can be expected to be more cost-effective than the savings bank, but it will most likely reduce the magnitude of these conditions (i.e., extent of the model parameter ranges.

To conclude, lending banks provide a higher level of flexibility than savings banks – which comes with additional ecological risks (zu Ermgassen et al. 2019). However, noting that risks can never be fully avoided and risk reduction is usually costly, in the face of scarce budgets one should also consider the costs that are associated with each percent of reduced risk. The present analysis identifies ecological and economic conditions (italicised above) under which lending banks can control the extinction risk of a metapopulation at lower costs than a savings bank.

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