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Generating spatially optimized habitat in a trade-off between social optimality and cost-effectiveness

Martin Drechsler

UFZ – Helmholtz Centre for Environmental Research

Permoserstr. 15

04318 Leipzig, Germany,

email martin.drechsler@ufz.de

Running head: Spatially optimized habitat

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Abstract

Auctions have been proposed as alternatives to payments for environmental services when there are spatial interactions and costs are better known to landowners than to the conservation agency (asymmetric information). Recently an auction scheme has been proposed that delivers optimal conservation in the sense that social welfare is maximised. However, as I show in this paper, the auction scheme is not budget-efficient, because the regulator's budget exceeds the social benefits of the scheme. In comparison, the agglomeration payment proposed by various authors is budget-efficient, though it is less optimal than the auction.

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Introduction

The quality of ecosystems services and the survival of species often depend on the spatial configuration of habitats. Metapopulation theory (Hanski 1999), e.g., predicts that species are more viable if their habitats are aggregated in space. That means that the ecological benefit of a particular habitat patch increases with the presence of other habitats nearby.

Often the provision of habitats requires particular land-use measures and incurs costs, such as opportunity costs (forgone profits if the land was formerly used for commercial agriculture or forestry and is now used, e.g., for extensive agriculture or forestry) and management costs. These costs are often spatially heterogeneous, which begs the question of how conservation resources and measures should be optimally allocated in space (Naidoo et al. 2006, Pe'er et al. 2014). If the costs are known to the conservation agency then planning approaches may be used to establish an optimal land-use pattern. Often, however, the land is under private property and costs are not known to the conservation agency. In these cases market-based instruments like payments of environmental services (Engel et al. 2008, Ferraro 2011) or auctions (Latacz-Lohmann & Schilizzi 2007, Lennox & Armsworth 2011) are often used to induce environmentally-friendly land-use measures.

Recently, Polasky et al. (2014) suggested an auction mechanism that induces an optimal spatial configuration of environmentally-friendly land-use measures where optimal means that the social welfare, i.e. the difference between the social benefits of conservation and the sum of all costs, is maximized. The trick with this auction mechanism is that landowners are induced to offer bids that equal their costs so together with the publicly known benefit function the agency has all information to determine the optimal land-use configuration. It then can offer suitable (see below) payments to those landowners whose land patches are required for the optimal land-use configuration.

Focusing a conservation policy on social welfare has advantages and disadvantages. An advantage is that it allows taking other societal objectives than biodiversity into account and that the preferences and attitudes of the public towards conservation are considered. The latter, however, may also be regarded as a disadvantage, because taking societal preferences into account usually requires some form of monetary valuation of biodiversity, which is a critical and controversial issue (Bartkowski et al. 2015). Another advantage of the concept of social welfare is that it is insensitive to the question of who pays for the conservation of biodiversity and how large the payments of the agency to the landowners are, because for social welfare only the total costs to society are relevant and not any transfer payments from one part of the society to another. This, however, is an idealization. Usually, conservation has to be financed through limited budgets. To create these budgets taxes have to be raised, which incurs transaction costs. Raising taxes further leads to so-called tax distortions which can reduce social welfare by up to 30 percent of the raised budget (Innes 2000). Polasky et al. (2014) propose a workaround for the problem of limited budgets by designing the auction as a tax mechanism. This, however, would require a shift of property rights from the landowners to the government, so this option is not considered in the present paper.

A policy criterion that takes the problem of limited budgets into account and that avoids the controversies of monetary valuation is budget-efficiency which may be defined as maximizing ecological benefits for a given budget (cf. Wätzold & Schwerdtner 2005). The ecological benefit does not need to be monetized but can be measured on a biologically sensible scale, such as species richness or population extinction risk. For these reasons budget-efficiency is an important criterion for practical conservation policy. While Polasky et al. (2014) showed their auction mechanism to maximise social welfare, they did not show that it also maximises budget-efficiency.

In the present paper I will show that it is not budget-efficient. By comparing the auction mechanism with the agglomeration payment of Drechsler et al. (2010) and Wätzold and Drechsler (2014) I show that the auction performs better with regard to social welfare but much worse with regard to budget-efficiency. To be able to determine the budget-efficiency of the auction and to make it comparable to the evaluation of social welfare the above definition of budget-efficiency has to be rephrased and calculated as the difference between the social benefit and the agency's budget where social benefit is understood as monetized ecological benefit like in Polasky et al. (2014). This implies that formally a parameter has to be introduced that measures society's willingness-to-pay for biodiversity – which however, does not mean that this has to be known in the practical application of budget-efficiency because here the former definition of budget-efficiency (Wätzold & Schwerdtner 2005) can be used. In Online Appendix A I argue that both definitions of budget-efficiency are formally equivalent so the conclusions of the present analysis also apply for the definition of Wätzold and Schwerdtner (2005). The only complexity that arises for the present analysis is that the willingness-to-pay is an additional unknown parameter, so all results will be presented as a function of this parameter.

The paper is structured as follows. In the next section I briefly describe the rationales of the auction and the agglomeration payment. Section 3 will present a numerical analysis of the auction mechanism and the agglomeration payment in a fictitious landscape with regard to social welfare and budget-efficiency. The paper concludes with a discussion in section 4.

Rationales of the auction and the agglomeration payment

This section contains a brief outline of the functioning of the two schemes, but for further details see below and the original articles of Polasky et al. (2014), Drechsler et al. (2010) and Drechsler & Wätzold (2010). In the auction the agency has information about the monetized ecological benefit $B(X)$ that arises from a given land-use vector $X=(x_1,\ldots,x_N)$ with $x_i=1$ if patch i is conserved and $x_i=0$ otherwise. The conservation agency collects bids from the landowners where the bids represent the payments the landowners demand if they conserve their land patch. Assuming that these bids equal the landowners' conservation costs (Polasky et al. (2014) show that it is indeed a dominant strategy for the landowners to bid their true costs) the agency calculates for each patch its contribution to social welfare. The agency accepts the bid of a landowner if his or her patch has a positive contribution to social welfare and offers a payment equal to the contribution to social welfare. The sum of the landowners costs are used to calculate the social welfare (cf. eq. (3) below) and the sum of the payments can be used to calculate the budget-efficiency (cf. eq. (4) below).

In the agglomeration payment the conservation agency has the information that spatially agglomerated habitat patches lead to higher ecological benefit $V(X)$ than dispersed ones. It offers a payment to landowners who conserve their patch, but in order to provide an incentive for spatial agglomeration, this payment is offered only to those landowners whose patches are located in a certain compartment of the landscape, and if in this compartment the habitat density (number of habitat patches per unit area) exceeds a certain threshold specified by the agency. The landowners now select the landscape compartment that maximises their aggregated profit and conserve those patches in the compartment in which the agency's payment exceeds the conservation costs. Social welfare and budget-efficiency are determined for the emerged land-use pattern in the same manner as for the auction.

Numerical analysis of the two schemes

In this section a fictitious landscape is considered and it is shown that the social benefit of the conservation auction is smaller than the agency's expenses. The landscape has 5 times 5 patches with next-neighbour distance 1. The ecological benefit is given by the following function

$$V(X)=\sum_{i=1}^{25}\sum_{j=i}^{25}x_i x_j \exp(-d_{ij}/d) \tag{1}$$

where d_{ij} is the distance between patches *i* and *j* and *d* is the mean dispersal distance of the species of concern (Wätzold & Drechsler 2014). Function *V* rewards both the quantity of habitat patches (i.e. increases with the number of habitat patches) as well as the proximity of neighboured habitats in space (i.e. decreases with increasing distances d_{ij} between patches).

The social benefit is $B=wV$ where *w* is society's willingness to pay for a unit of *V*. The costs c_i are independent normally distributed random numbers with mean 1 and standard deviation σ=0.5 (negative values are truncated to zero). With these assumptions I simulate the auction mechanism of Polasky et al. (2014) and the agglomeration payment of Drechsler et al. (2010).

Auction

Following the recipe by Polasky et al. (2014) I start with the analysis of the first patch (*i*=1) and maximise

$$B(X)-\sum_{i=1}^{25}x_i c_i = wV(X)-\sum_{i=1}^{25}x_i c_i \tag{2}$$

The maximization is done (1) given that the first patch is conserved, and (2) given that the first patch is not conserved. Similar to above, x_1=1 if patch 1 is conserved and x_1=0 otherwise. The optimization is done through simulated annealing (Kirkpatrick et al. 1983, Hartig & Drechsler 2010; see also the Online Appendix). The results are the optimal conservation strategies X_1* and $X_{\sim 1}$*, respectively. These are evaluated according to steps 3 and 4 of Polasky et al. (2014) to obtain the values $W_1(X_1^*)$ and $W_1(X_{\sim 1}^*)$. If the difference $\Delta W_1 = W_1(X_1^*) - W_1(X_{\sim 1}^*)$ exceeds the cost c_1 of the first patch, the patch is conserved and the associated payment p_1 to the owner of patch 1 is given by ΔW_1.

This analysis is repeated for all other patches (i>1). As a result I obtain the optimal conservation strategy X* and the payments p_i. I use this information to calculate the social welfare

$$\Phi = wV(X^*) - \sum_{i=1}^{25} x_i^* c_i \tag{3}$$

and the budget efficiency

$$\Psi = wV(X^*) - \sum_{i=1}^{25} x_i^* p_i \tag{4}$$

(note that the social welfare depends on the costs c_i while the budget efficiency depends on the payments p_i). As can be seen the outcome depends on the chosen willingness to pay, w, and therefore I determine Φ and Ψ as functions of w. Since the costs c_i are random numbers I do this for 20 random cost landscapes $\{c_i\}_{i=1\ldots25}$.

Agglomeration payment

In the agglomeration payment scheme, landowners are induced to conserve their patches by a payment p from the conservation agency. If the payment exceeds the cost c_i then patch i is conserved, otherwise it is not conserved. The agglomeration payment is offered to every land owner whose patch is located within a certain zone if the proportion of conserved patches in that zone exceeds a certain threshold ρ_{min}. A payment offer altogether is defined by *p* and ρ_{min}. The landowners respond to this offer and specify location and size of the zone in which the density exceeds ρ_{min} and which is profit-maximising for them. For simplicity the zone is assumed to be of rectangular shape and only a single zone can be specified. To determine location and size of the zone I numerically test all possible zones, ranging from one-patch zones to one large zone covering the entire landscape. For each zone I calculate the aggregated landowners' profit which is the sum of p-c_i over all conserved patches in the zone where *p* and c_i are the agency payment and the conservation cost, respectively. A patch is conserved if the individual profit for landowner *i* is positive, i.e. if $p>c_i$.

Like in the auction scheme the analysis of the agglomeration payment scheme is based on the 5x5 patch landscape introduced above. For the scheme parameters I choose ρ_{min}=0.6, which has been shown to lead to high ecological benefit *V* for given budget (Drechsler et al. 2010). The payment *p* has to be chosen in dependence of the willingness-to-pay *w*. If this is small there should obviously be not much conservation because the social benefit cannot outweigh the agency's expenses and *p* should be small. As *w* increases so should *p*. The simplest functional relationship is to assume p=w (in a practical application one could simulate the scheme's performance based on statistical information on the conservation costs and test different relationships; Appendix D shows that the conclusions of the simulation are valid for a rather broad range of linear relationships between *p* and *w*). The outcome of the chosen payment scheme (p,ρ_{min}) is the land-use pattern *X*. Like in the auction scheme this outcome is evaluated with the social welfare function Φ and the budget efficiency Ψ. For the 20 random cost landscapes, the functions Φ and Ψ are determined as functions of *w*.

Based on the 20 replicates, for both schemes the means and standard deviations of Φ and Ψ are calculated. Figure 1 shows that the auction generates slightly higher expected social welfare than the agglomeration payment. With regard to budget-efficiency, in contrast, the agglomeration payment clearly outperforms the auction.

Discussion and conclusion

Auctions have been proposed as instruments to conserve biodiversity when there are spatial interactions and costs are better known to landowners than to the conservation agency (asymmetric information). Especially the possibility of reducing information rents (meaning that because of asymmetric information the agency has to pay higher payments than the actual costs accruing to the landowners) compared to spatially homogenous payments has been emphasised.

Polasky et al. (2014) propose an auction scheme that delivers socially optimal conservation. One question to be investigated in the present paper is whether the auction scheme is also budget-efficient in the sense that the social benefit (monetized ecological benefit) exceeds the regulator’s budget. I find that this is not the case.

This result is based on a numerical analysis in a fictitious landscape with particular size and distribution of conservation costs. The analyses shown in Appendix D indicate that this result is insensitive to the size of the landscape, the distribution of the conservation costs and the number of stochastic replications.

The conclusion that the auction is not budget-efficiency is well in line with Milgrom (2004). In contrast, in the agglomeration payment by Drechsler et al. (2010) social benefits exceed the budget, partly because the agglomeration payment substantially reduces information rents (Drechsler et al. (2010), i.e. the difference between payment and actual conservation cost.

The advantage of the auction scheme of Polasky et al. (2014), however, is its optimality: Social welfare is higher than that produced by the agglomeration payment. Both criteria, social welfare and budget-efficiency, are relevant for conservation policy. Maximising social welfare is certainly the ultimate goal of policy making, since (at least in theory) it takes all objectives relevant to the society into account. However, it is difficult to quantify, since it relies on the controversial monetary valuation of biodiversity and ecosystems by humans. Budget-efficiency (in its standard definition, which I showed to be equivalent to the definition used in the present analysis) is less controversial because it does not require monetisation. It is relevant because generally conservation agencies operate under limited budgets.

Another advantage of the auction scheme of Polasky et al. (2014) is that it is more flexible with regard to the ecological benefit function. While the agglomeration payment was designed to induce the spatial agglomeration of habitat patches, the auction scheme can deliver all sorts of land-use patterns optimally, including the spatial segregation of habitat patches.

Altogether, the auction scheme of Polasky et al. (2014) and the agglomeration payment of Drechsler et al. (2010) have their pros and cons. It should be carefully considered by conservation agencies whether social welfare or budget-efficiency should be maximized by a conservation scheme and that the optimal choice of scheme depends on the targeted policy objective. The present analysis shows that agglomeration payments are likely to outperform auctions with regard to budget-efficiency while auctions are better for social welfare.

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Figure 1: Means and standard deviations of social welfare and budget-efficiency based on 20 replicates as functions of the willingness-to-pay *w*. Solid lines: auction, dotted lines: agglomeration payment.