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ANALYSIS

Applying tradable permits to biodiversity conservation: Effects of space-dependent conservation benefits and cost heterogeneity on habitat allocation

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ABSTRACT

This paper is concerned with the cost-effective allocation of habitat for species under spatio-temporally heterogeneous economic development. To address the dynamic dimension of the problem we consider tradable development rights as the instrument of choice. A particular challenge in applying tradable development rights is that the conservation benefit of an individual habitat patch depends on its spatial relationship with other habitat patches and thus is an emergent rather than a fixed property. We analyse with a conceptual model the spatial and temporal dynamics of habitats in a region under a tradable development rights market that takes spatial interaction of habitats explicitly into account. In our analysis two different outcomes may emerge depending on the levels of spatial interaction and cost heterogeneity: an "ordered" structure where habitat patches are clustered in space and are stable over time, and a "disordered" structure where habitat patches are scattered in space and subject to high turnover of destruction and recreation. A high level of spatial interaction or a low level of cost heterogeneity favours an ordered structure while a low level of spatial interaction or a high level of cost heterogeneity favours a disordered structure.

1. Introduction

This paper is concerned with the problem that a conservation agency wishes to cost-effectively allocate a certain proportion of a region as conservation areas in a dynamic setting. With a dynamic setting we mean that economic development exists and land prices (representing opportunity costs of designating an area for conservation in terms of foregone economic development) change in a spatially heterogeneous manner. Cost-effectiveness is here understood as the achievement of an ecological target at least costs. At least in principle, the agency is able to select the cost-effective spatial allocation of conservation areas in a static setting (e.g. Ando et al., 1998; Polasky et al., 2001). In a dynamic perspective, however, changing land prices may lead to a situation where the initially cost-effective selection is not cost-effective anymore. In order to re-establish a cost-

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effective allocation, the agency would be confronted with the problem of designating new areas for conservational purposes and allowing economic development in former conservation areas. Such a bureaucratic approach requires a high level of information about cost changes on the side of the agency and is also very sensitive to political lobbying activities regarding the questions which areas shall be released for economic development and which areas shall be designated for conservation.

An alternative to this bureaucratic approach to addressing changing land prices are tradable development rights. Based on the concept of tradable permits, such a system would allow economic development of a formerly conservation area if a permit is submitted to the conservation agency which certifies that an area with previously no conservation value has been transformed back into a conservation area of ecological value equal to the area to be destroyed. There is no requirement that developers establish new habitats themselves, but the permit can be bought from other landowners. This allows a market for tradable development rights to emerge.

The instrument of tradable permits has gained increasing popularity in environmental policy. It has been applied in a wide range of fields in air pollution control (see Tietenberg, 2006 for an overview) and is moving increasingly into other areas with the EU CO_2-emissions trading scheme being the most prominent example of a recent application (e.g., Hansjürgens, 2005). However, until now there are only a few schemes related to biodiversity conservation that exhibit at least some elements of trading. One example is species conservation banking in the United States (Fox and Nino-Murcia, 2005). A conservation bank is a piece of private land that is conserved and managed in perpetuity under a conservation easement to protect rare species. The party that holds the easement is granted credits by a federal or state agency for the land's conservation value. These credits may be used to address a bank owner's mitigation required by law. However, it may also be sold to other landowners with mitigation requirements. Another example of conservation related trading opportunities exists in Brazil where regulations require each rural property to maintain a proportion of forest under natural vegetation (Chomitz et al., 2004). Recent provisional regulations allow landowners to satisfy the requirement for one property through a forest reserve located on another. The reserve site may be owned by another party, opening the possibility of trading land development rights.

One of the challenges of applying tradable permits to biodiversity conservation arises because the ecological value of habitat patches for the survival of species is space dependent, i.e. it depends on the presence and location of other habitat patches (e.g. Hanski, 1999; Vos et al., 2001; Ovaskainen and Hanski, 2003). In this paper we develop a conceptual model to analyse how these spatial interdependencies influence the allocation of habitat patches and areas for economic development over time, if a market for tradable development rights exists. The role of spatial dependencies in tradable development rights has been largely ignored so far and the purpose of the model analysis is to provide some first general insights.

This paper is related to the literature on applying tradable permits to environmental pollutants whose emission location strongly influences their damage size. There is a significant body of literature on how to optimally design trading areas and rules when emission location matters (see Tietenberg, 2006 for an overview). An example of such research is Atkinson and Morton (2004) who analysed the cost-effective size of an emission trading region taking into account that for small areas there is less potential for cost-saving trades and for large areas emissions may be reduced at locations where they contribute little to damage reduction. Our paper is also related to the literature on models that specifically address issues arising when tradable permits are applied to conservation. Chomitz et al. (2004) investigated with a spatially explicit simulation model for a hypothetical forest trading program in the Brazilian state of Minas Gerais how the size of the trading domain influences cost savings that arise from trading. Saeed (2004) developed a systems dynamic model for helping to design effective conservation banking institutions. This model has been further developed by Arquitt and Johnstone (2008) with the purpose of analysing the design of a restoration banking scheme for coastal mangroves in Thailand. However, none of these models focuses on spatial interdependencies.

Our model considers a setting with stochastic changes in costs, and the flexibility of the market for development rights is used to adapt to this change. We will show that within the model the space-dependency of the conservation benefit and the dynamics in the costs substantially affects the dynamics in the market for tradable development rights and, particularly, the spatio-temporal dynamics of the habitat network in the landscape. The next section presents the model, which is solved partly analytically and partly numerically in Section 3. The results are discussed in the final Section 4.

2. The model

The model presented in this section is a grid-based stochastic cellular automaton. We are interested in comprehensibility and, where possible, analytical tractability and thus choose a parsimonious model structure. First we introduce the landscape and the conservation benefit function, then the trading and decision rules of the market, and finally the economic dynamics that drive the market. All model parameters and state variables are compiled in Table 1.

Consider a landscape with $N>>1$ land patches, numbered $i=1\ldots N$, of identical sizes. Whether a patch can serve as a habitat depends on the type of use. Land may be either used for economic purposes and is of no conservational value, or it may be used for conservation which leads to opportunity costs in terms of foregone economic development c_i.[1] Let x be a vector with N elements that can take values of 1 and 0, where $x_i=1$ indicates that patch i is a habitat and $x_i=0$ otherwise. Let $\mathbf{r}=(\mathbf{r}_1,\ldots,\mathbf{r}_N)$ be an N-element vector containing the spatial coordinates $\mathbf{r}_i$ of the patches $i=1\ldots N$. Let $V(\mathbf{x},\mathbf{r})$ be the conservation benefit of the

[1] In order to create a habitat patch in the real world, not only opportunity costs in terms of foregone economic development but other costs such as transaction costs and costs for restoration and management activities may be relevant as well. However, for reasons of simplification we only consider opportunity costs in terms of foregone economic development in the model.