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Trade-off analysis of ecosystem services in Eastern Europe

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ABSTRACT

In this paper we assess trade-offs between ecosystem services in a spatially explicit manner. From a supply side perspective, we estimate opportunity costs, which reflect in monetary terms the trade-offs between ecosystem services due to a marginal land use change. These are based on estimation of the frontier function, which gives the feasible bundles of ecosystem services that can be generated. For this, a two-stage semi-parametric method is applied and spatial data are used on agricultural revenues, cultural services, carbon sequestration and biodiversity for 18 Central and Eastern European countries. Based on the estimates, we assess which regions are most suitable for expanding any of the ecosystem services. Where opportunity costs are low, a further expansion of any of the ecosystem services is cost-effective. If areas are targeted carefully, joint improvement of several ecosystem services can be reached. If carbon sequestration levels are to be increased, it is best to focus on areas already having high sequestration levels because opportunity costs of carbon sequestration decrease with increasing sequestration levels. For biodiversity and cultural services the pattern is less clear as low opportunity cost were found both in areas rich and poor with these services.

1. Introduction

Since the Millennium Ecosystem Assessment (2005), ecosystem services research has gained momentum. Step by step, it is becoming better understood how ecosystem functions and services are interrelated and which factors affect the provision of ecosystem services (see e.g. Daily et al., 2009; Haines-Young and Potschin, 2010; Isbell et al., 2011; UK National Ecosystem Assessment, 2011). Gaining insight into where particular services are weak or strong is important for making land use decisions (Daily et al., 2009). At different levels of decision making. maps can be generated, quickly and transparently showing the bundles of ecosystem services that can jointly be supplied (e.g Daily and Matson, 2008; Naidoo et al., 2008; Haines-Young, 2009; Maes et al., 2012; Martínez-Harms and Balvanera, 2012; Schulp et al., 2012).

Similarly, awareness of the importance of maintaining ecosystem services for human welfare has increased (see e.g. US Environmental Protection Agency, 2009; Haines-Young and Potschin, 2010; TEEB, 2010; Bateman et al., 2011). The economics of the natural environment is receiving increased attention owing to numerous initiatives including the TEEB studies (TEEB, 2010), assessments in the UK (UK National Ecosystem Assessment, 2011) and USA (National Research Council, 2005; US Environmental Protection Agency, 2009) and attempts by the WAVES Partnership and the UN SEEA to integrate the value of ecosystem services into national accounts and economic growth plans.[1] As a result of these initiatives, the notion that natural resources have economic value is increasingly finding its way into policy analyses and government decision processes.[2]

However, at national, regional or global scales, much remains still unknown about the trade-offs between ecosystem services resulting from land use changes. Trade-offs are location specific. Thus it is pertinent to understand where changes in land use can improve total food production, biodiversity levels, climate change mitigation, etc. in the most cost-effective way. To answer such questions, trade-offs need to be known in monetary terms.

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[1] See www.wavespartnership.org and unstats.un.org/unsd/envaccounting.

[2] An example is the White Paper published by the government of the UK in 2012 entitled 'The Natural Choice: securing the value of nature', in which it is stressed that the economic and social benefits of the environment should be properly valued. Moreover, the EU Biodiversity Strategy specifically calls on the member states to assess the status of ecosystem services in their territory and to assess their economic value. Furthermore, the WAVES Global Partnership has brought together a broad coalition of organizations to mainstream ecosystem services valuation in national accounts and development planning and the UN SEEA proposes to add ecosystem services accounts to their system of environmental economic accounts.

The objective of this paper is to present a method to estimate the trade-offs between the different ecosystem services due to a land use change. The tradeoffs are to be spatially explicit and in monetary terms. With these results, the method aims to answer two questions of practical policy relevance: first, which regions should decision makers target to achieve national and international biodiversity objectives in a cost-effective way? and second, is it better to jointly generate ecosystem services in a region or to specialize in one of them?

The novelty of this paper is derived from the way in which the reported approach combines a supply side perspective for ecosystem services with a non-parametric method to estimate transformation functions and opportunity costs and a unique data set. Most directly related to our work are recent studies at the micro level (e.g. Macpherson et al., 2010; Bostian and Herlihy, 2012; Sauer and Wossink, 2013). We are not aware of studies that use a non-parametric methods to estimate transformation functions for the analysis of ecosystem services and apply this to analyse supply at sub-national to global levels.

By following a supply side approach, we assess the expected change in ecosystem services supply due to a land use change. In contrast to most existing supply side analyses, that quantify trade-offs of land use changes in biophysical terms (see e.g. Millennium Ecosystem Assessment, 2005; Maes et al., 2012), we quantify these trade-offs in monetary terms. Studies that evaluate the monetary value of ecosystem services, commonly follow a demand side approach (see TEEB, 2010 for a review of the literature) and in that way evaluate how people appraise the changes. Ideally, a combined supply–demand side approach should be adopted in which it is shown how supply changes due to a land use change and how people value these changes. This makes it possible to evaluate whether the changes are welfare improving. However, demand side valuation analyses are less reliable for studies at higher spatial scales.[3] For that reason, we refrain from demand side valuation techniques and approach cost-effectiveness of land use changes from a supply side. We assess trade-offs between ecosystem services that are jointly produced in a given area in monetary terms, i.e. we estimate opportunity costs of land use changes, with which it can be evaluated whether land use changes are cost-effective (see Diaz-Balteiro and Romero, 2008). Such analyses at higher spatial scales are rare.

We derive opportunity costs from transformation functions, which summarize the feasible bundles of ecosystem services generated in a region (see e.g. Smith et al., 2012). The estimated transformation functions are then used to show the effects of the land use choices available to authorities—where to develop agriculture, where to preserve biodiversity, where to keep a multifunctional landscape. Trade-offs are contingent on the curvature of the frontier function at each point. The transformation functions are estimated empirically using a two-stage, semi-parametric, distance function approach. Hof et al. (2004), Bellenger and Herlihy (2010) and Macpherson et al. (2010) also adopt non-parametric or semi-parametric estimation techniques (though different from the approach adopted by us) to select the areas that jointly produce multiple environmental outputs in the most efficient way. However, whereas these existing studies focus on efficiency, we extend the approach by explicitly considering the opportunity costs of land use changes as a basis for selecting the areas most appropriate for particular land uses. This extra dimension results in trade-off information in monetary terms which is essential but often missing in supply side analyses.

For our application we use spatial data on agricultural revenues, cultural services, carbon sequestration and biodiversity for 18 Central and Eastern European countries on the level of grid cells of a size of 0.5×0.5 degree. The data originate from the integrated assessment model IMAGE (Bouwman et al., 2006), biodiversity model GLOBIO (Alkemade et al., 2009) and additional ecosystem services models (Schulp et al., 2012).[4] These models give the state-of-the-art knowledge of the interrelations between land use, agricultural production and ecosystem functioning and results are used extensively in e.g. OECD Environmental Outlook (OECD, 2012), UNEP GEO4 (UNEP, 2012) and several other global assessments of environmental change (see e.g. Van Vuuren and Faber, 2009; Brink et al., 2010; PBL, 2012). These models, however, do not directly yield information on trade-offs or effects of a marginal land use change. Yet, their results can be used in the semi-parametric method as set up in this paper, to recover from the data the transformation function and derive the opportunity costs of a marginal land use change. Using model data is the only feasible option for our analysis because of the lack of reliable observations of the relevant variables at higher spatial scales.

Our work differs from other recent studies at the aggegated level, for example those that use bio-economic models. Examples are the InVEST model (see e.g. Daily and Matson, 2008; Polasky et al., 2008; Nelson et al., 2009; Keeler et al., 2012), the bio-economic models used to derive cost-effective ecological restoration of the Murray Darling basin in south-east Australia (Crossman and Bryan, 2009; Bryan, 2010; Bryan et al., 2011) and bio-economic models by e.g. Hauer et al. (2010) and Barraquand and Martinet (2011). Other examples of spatially explicit trade-off analyses for ecosystem services use GIS or heuristic routines to combine ecological and economic concepts (Bateman, 2009; Bateman et al., 2011; White et al., 2012) or do not estimate trade-offs in monetary terms (Naidoo et al., 2008; Raudsepp-Hearne et al., 2010; Maes et al., 2012). Most of these analyses, however, are less suitable for doing trade-off analysis at sub-national to global scales. Hussain et al. (2011) also base their analysis on IMAGE and GLOBIO data (Brink et al., 2010). They however employ benefit transfer methods to evaluate values of changes in ecosystem services provision. Such methods remain controversial especially when applied at high spatial scales.

The remainder of this paper is set up as follows. In Section 2 we briefly discuss the economic model. The data used are discussed in Section 3. In Section 4, we present estimation results. Finally, Section 5 ends with a discussion and conclusions.

2. Theoretical and empirical model

This paper focuses on the trade-offs between ecosystem services due to land use changes. We consider a situation in which a social planner makes land use choices—where to grow crops, where to preserve biodiversity, where to keep a multifunctional landscape. These choices have a multitude of effects on the

[3] Revealed or stated preference studies yield informative results about people's preferences especially for analyses at low spatial scales, such as local or regional public project assessments. For analyses at higher spatial scales, however, demand side valuation approaches are less reliable. See e.g. the discussion of Costanza et al. (1997) and the reply in Costanza et al. (1998). Moreover, the use of benefit transfer methods which is used more and more for analyses at higher spatial scales (see e.g. Hussain et al., 2011) often gives unacceptably large transfer errors (Brouwer et al., 2012), despite of recent methodological improvements (Ghermandi et al., 2010; Brander and Koetse, 2011).

[4] IMAGE (Integrated Model to Assess the Global Environment) simulates the environmental consequences of human activities worldwide. It represents interactions between society, the biosphere and the climate system to explore the long-term dynamics of global change as the result of interacting demographic, technological, economic, social, cultural and political factors. GLOBIO (Global Biodiversity model) is used in the assessment of policy options for reducing global biodiversity loss and is based on the GLC2000 land use map.