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Conservation of undisturbed natural forests and economic impacts on agriculture

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ABSTRACT

Conservation of undisturbed natural forests, which are important for biodiversity, carbon storage, and other ecosystem services, affects agricultural production and cropland expansion. We analyze the economic impacts of undisturbed natural forest conservation programs on agriculture and the magnitude of avoided deforestation and avoided carbon emissions in the tropics. We apply a global agricultural land use model to estimate changes in agricultural production costs for the period 2015–2055. Our forest conservation scenarios reflect two different policy goals: either maximize forest carbon storage or minimize impacts on agricultural production. In all the scenarios, the economic impacts on agriculture are relatively low. Production costs would increase due to forest conservation by a maximum of 4%, predominantly driven by increased investments in agricultural productivity increase. We also show regional differences in Latin America, Sub-Saharan Africa, and Southeast Asia, due to different growth rates in food demand, land availability and crop productivity. The area of avoided deforestation does not exceed 1.5 million ha yr^{-1} in the period 2015–2055, while avoided carbon emissions reach a maximum of 1.9 Gt CO2 per year. According to our results on the potential changes in agricultural production costs, undisturbed natural forest conservation appears to be a low-cost option for greenhouse gas emission reduction.

Introduction

There is rising awareness in science and policy of the potential scarcity of land for an increasing number of future uses. Land is mainly used for food, feed, fiber, bioenergy, and wood production as well as infrastructure. In addition, land is reserved for carbon storage, biodiversity conservation, and other ecosystem services (Eliash, 2008; RFA, 2008; Roberts et al., 2008; Fischer et al., 2002; FAO, 2002; v. Velthuizen et al., 2007; Popp et al., 2011a; Lotze-Campen et al., 2010). Natural forest ecosystems, especially tropical natural forests (Laurance, 2007) and tropical primary forests (Barlow et al., 2007), provide carbon storage (Jackson et al., 2008; Bonan, 2008; Gumpenberger et al., 2010) and maintain biodiversity (Brooks et al., 2006). These valuable services are threatened by lasting deforestation (FAO, 2006) as well as human-induced degradation and fragmentation (Turner, 1996; Gullison et al., 2007).

Several studies in the literature highlight the importance of forests with respect to ecosystem services. Schmitt et al. (2009) emphasize the insufficient protection of non-fragmented natural forests in the tropics and subtropics within global priority areas for ecosystem conservation. Brooks et al. (2006) prioritize undisturbed natural forest ecosystems (Bryant et al., 1997: 12; Greenpeace International, 2005) to be conserved for their high biodiversity. Forest conservation programs will only be successful if they take the economic impacts on alternative land uses explicitly into account. Grig-Gran (2006) quantifies the costs of avoided deforestation in terms of foregone agricultural income, based on costs of alternative production systems at the country scale. At the global scale, Kindermann et al. (2008) estimate the costs of avoided deforestation at different price levels for forest carbon, based on the change in forestry land values relative to agriculture. Neither of the two studies focusses on particular forest types. Mittermeier et al. (2003) provide rough estimates of the costs of conserving partly forested wilderness for biodiversity purposes.

Apart from the forest type to be conserved, the spatial design and prioritization of conservation programs have to be defined. Grig-Gran (2006) circumvents the issue by reducing historical deforestation rates at aggregate country scale, while Kindermann et al. (2008) build on spatially explicit changes in land values to generate spatial patterns of avoided deforestation. There are basically two alternative goals to be pursued. First, forest conservation programs could be designed to maximize the provision of ecosystem services (e.g. maximize stored carbon). Alternatively, the impact of forest conservation programs on alternative land uses could be minimized (e.g. minimize foregone income in agriculture). To our knowledge, no study has yet compared these two options based on a comprehensive bio-economic modeling approach.

In this paper, we apply a spatially explicit global land use model to address the following research questions: What are the economic impacts of undisturbed natural forest conservation strategies on

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agricultural production in Sub-Saharan Africa, Latin America and Pacific Asia? What are the benefits of different forest conservation strategies in terms of avoided deforestation and avoided net carbon emissions from land use change?

A consistent, spatially explicit land use budgeting approach helps to better initialize different land pools and track land use changes due to agricultural expansion and forest conservation.

Opponents of large-scale forest reservation for the provision of ecosystem services argue that enforcement without involvement of local stakeholders would be questionable (Hayes and Ostrom, 2005; Schwartzman et al., 2000). In this paper we assume that decision making of local stakeholders is solely determined by the economic rationale of optimizing their net benefits from using the land. This approach allows us to quantify the implicit costs of forest conservation through foregone benefits from other landuse activities, the so called "opportunity costs".

The next section introduces the model, the land allocation mechanism and underlying assumptions. The conceptual embedding and calculation of implicit costs (i.e. "opportunity costs") of undisturbed natural forest conservation as well as the forest conservation scenarios are briefly described. Section "Results" provides model output under different forest conservation scenarios followed by the sections "Discussion" and "Conclusions".

Material and methods

Model of Agricultural Production and its Impact on the Environment

The Model of Agricultural Production and its Impact on the Environment (MAgPIE) (Lotze-Campen et al., 2008; Popp et al., 2010, 2011b; Schmitz et al., 2012) is a spatially explicit recursive-dynamic global land use optimization model which minimizes the total costs of agricultural production in decadal time steps until 2055. It covers the most important agricultural crop and livestock production types in 10 economic regions worldwide to meet commodity demand. Spatially explicit bio-physical constraints and regional economic conditions are taken into account. Obtainable crop yields and carbon contents of forests are provided by the global dynamic vegetation model LPJmL at 0.5 arc degree resolution, which is equal to 50 km $\times$ 50 km at the equator (Sitch et al., 2003; Bondeau et al., 2007; Fader et al., 2010). Productive land enters commodity production as an input which is limited by the historically derived physical crop area (Fader et al., 2010) as well as additional convertible unused land. Varying crop yields based on bio-physical conditions in different locations determine the production costs per ton of output which leads to distinct patterns of agricultural land use. Input costs per hectare for labor, chemicals and other capital are calculated from the GTAP database (Narayanan and Walmsley, 2008). Rotational constraints define maximum shares of crop types per grid cell which are related to average crop rotations and agricultural management. Depending on the spatially explicit distance of cropland to major urban centers, intra-regional transport costs per ton of agricultural output are added to agricultural production costs. Transport cost estimates are derived from GTAP total transport costs (Narayanan and Walmsley, 2008), total transport time needed due to distance to major urban centers (Nelson, 2008), and total production quantity. International trade is constrained by regional minimum self-sufficiency rates. This means that a certain level of consumption has to be fulfilled within the region. The rest can be produced in other world regions according to comparative cost advantages (Lotze-Campen et al., 2010).

Cropland expansion into convertible unused land is regarded as one option to align agricultural production with projected total food consumption. It is associated with additional costs for infrastructure, land clearing, and site preparation. These costs are calculated from the access costs of forest land in equilibrium provided by the Global Timber Model (GTM) database (Sohngen et al., 2009). As a second option for increasing production, the model can invest in agricultural research and development (R&D) for technological change, in order to increase crop yields. The costs of technological change are a function of the regional technology level and have been derived from data on public expenditure on agricultural R&D (Dietrich et al., 2010b). Input costs per hectare also increase with the intensification of agricultural land use (Dietrich et al., 2010a, 2010b; Popp et al., 2011a). As a consequence, shifts in land use patterns are determined by weighing marginal costs of land conversion, transport and factor inputs against marginal costs of intensification and the associated increase in transport and factor inputs.

For the purpose of this analysis, the model has been further developed. First, spatially explicit datasets for the initialization of available land pools for cropland expansion have been compiled (Krause et al., 2009). The available land pool has been split into "undisturbed natural forest", i.e. the union of large intact forest landscapes (Greenpeace International, 2005) and frontier forests (Bryant et al., 1997) in forestry and unused land categories (Erb et al., 2007), and "other available land", i.e. abandoned cropland plus other natural vegetation not delineated as forest or grazing land (see Appendix A). Datasets are harmonized at a resolution of 0.5 arc degree.

Second, the land allocation mechanism has been expanded by including additional land pools, rules, and cost types for cropland expansion and forest conservation activities. In our analysis we focus on cropland. Urban land and grazing land are kept constant in area. If land in the cropland pool gets scarce, additional land can be made available for cropland expansion from the two additional land pools, undisturbed natural forest and other available land (Table A.1). Abandoned cropland enters the other available land pool as succession leads to natural re-vegetation.

Undisturbed natural forest conservation activities do not directly compete for land. They are normatively set by international conservation policies in different scenarios. Appendix B provides a mathematical description of model changes.

Economic impact on agriculture due to forest protection

A number of calculations are made in a post-processing procedure after model outputs have been generated. Undisturbed natural forest conservation activities restrict the location and magnitude of available unused land for crop production. Therefore, undisturbed natural forest conservation activities change the costs of production. The analysis of economic impacts from undisturbed natural forest conservation is based on the concept of opportunity costs. Generally, opportunity costs of an actual activity are defined as the foregone net benefits from not conducting the next best activity (v. Wieser, 1928). In our context, opportunity costs of a certain land-use activity are the foregone net returns per hectare of the next-best alternative type of land use. If the actual land use activity pertains to the conservation of undisturbed natural forest, the opportunity costs per hectare indicate the implicit economic value of undisturbed natural forest and the related ecosystem services, e.g. stored carbon. Based on this concept, the costs of establishing a global undisturbed natural forest conservation program for the provision of ecosystem services to global society can be calculated as the foregone net returns from alternative land use activities. The agricultural sector may thus be compensated for providing avoided net carbon emissions or conserved biodiversity from foregone land use change. Opportunity cost estimates may serve as an indicator for the magnitude of compensation payments to make global society better off but agricultural producers not worse off.