Ecological Economics 135 (2017) 76–90

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Modelling Land Use, Deforestation, and Policy: A Hybrid Optimisation-Heterogeneous Agent Model with Application to the Bolivian Amazon

Lykke E. Andersen [a], Ben Groom [b], Evan Killick [c], Juan Carlos Ledezma [d], Charles Palmer [b,*], Diana Weinhold [e]

[a] Institute for Advanced Development Studies (INESAD), Av. Hector Ormachea, #6115, entre C. 15 y 16, Obrajes, La Paz, Bolivia
[b] Department of Geography and Environment, London School of Economics and Political Science, Houghton Street, London WC2A 2AE, UK
[c] University of Sussex, Sussex House, Falmer, Brighton, BN1 9RH, UK
[d] Conservation International Bolivia, Calle 13 de Calacoto Nro. 8008 entre Sanchez Bustamante y Julio C. Patino, 13593 La Paz, Bolivia
[e] Department of International Development, London School of Economics and Political Science, Houghton Street, London WC2A 2AE, UK

ARTICLE INFO

Article history:
Received 17 June 2015
Received in revised form 22 July 2016
Accepted 11 December 2016

JEL classification:
Q23
Q28
Q56
R14

Keywords:
Simulation
Bolivia
Deforestation
Land use
Policy
REDD

ABSTRACT

We introduce a hybrid simulation model ('SimPachamama') designed to explore the complex socio-environmental trade-offs of alternative policy bundles and policy sequencing options for stemming deforestation and reducing poverty in tropical countries. Designed and calibrated to the initial conditions of a small forest village in rural Bolivia, the model consists of: (a) an optimising agricultural household module of heterogeneous agents that make individually optimal land-use decisions based on factor endowments and market conditions; (b) an encompassing general equilibrium 'shell' module that endogenously determines wages and links the agricultural labour market and rural-urban migration rates; and (c) a novel user-controlled policy-maker module that allows the user to make 'real time' choices over a variety of public and environmental policies that in turn impact land use, welfare, and migration. Over a 20-year simulation period the results highlight trade-offs between reductions in deforestation and improvements in household welfare that can only be overcome either when international REDD payments are offered or when decentralized deforestation taxes are implemented. The sequencing of policies plays a critical role in the determination of these results.

1. Introduction

For decades, deforestation and forest degradation in tropical nations have reduced supplies of forest ecosystem services (MEA, 2005; FAO, 2010). These losses have had consequences at all scales, from local to global. Forest users with incomes and livelihoods dependent on, e.g. watershed services, have experienced adverse effects on their welfare. Emissions of carbon dioxide from deforestation and forest degradation influence the trajectory of anthropogenic climate change with welfare implications for future generations across the globe (Stern, 2008). Yet, policies which aim to conserve forests, such as protected areas, can also adversely affect the welfare of the forest-dependent poor, for instance, by restricting their access to natural resources (Barrett et al., 2011). Evidence is also emerging of how measures to improve welfare, such as *anti*-poverty programs, can induce environmental change, for example deforestation through increasing the local consumption and production of agricultural commodities (see Alix-Garcia et al., 2013).

In response, policy makers have increasingly sought to design interventions which not only aim to conserve forests but also improve the incomes and livelihoods of forest users (e.g., see Merger et al., 2011; Ollivier, 2012; Groom and Palmer, 2012). Targeted towards agents of deforestation, interventions such as payments for environmental services (PES) and the provision of off-farm labour opportunities could, under certain conditions, enhance their welfare as well as conserve forests (Groom and Palmer, 2010, 2014). Though multiple impacts are rarely evaluated together, a growing body of empirical research suggests variable outcomes from such policies (e.g. Shively and Pagiola, 2004; Groom et al., 2010). Beyond these effects, where external interventions necessitate public and/or private funding, there are also likely to be wider policy and welfare implications that may only be observed in a general equilibrium setting.

* Corresponding author.
E-mail addresses: landersen@inesad.edu.bo (L.E. Andersen), b.groom@lse.ac.uk (B. Groom), E.Killick@sussex.ac.uk (E. Killick), jledezma@conservation.org (J.C. Ledezma), c.palmer1@lse.ac.uk (C. Palmer), d.weinhold@lse.ac.uk (D. Weinhold).

http://dx.doi.org/10.1016/j.ecolecon.2016.12.033
0921-8009/

In this paper, we examine potential trade-offs in policy outcomes with a focus on two design features that help to better understand dynamic policy interactions: 'policy bundles' and policy sequencing. The former refers to combinations of policies that all, to some extent, impact on land-use decision making while the latter refers to the order in which policies are implemented. We incorporate these two features into a landscape- (or village-) scale model based on the structural, cultural and institutional features of a typical Bolivian frontier forest village, and we allow the model user, in the role of a local policymaker ('the Mayor'), the opportunity not only to implement policy bundles but also to react to the consequences of her policy choices over time. Thus, policy parameters can be changed and new policies can be implemented.

Our model is best defined as 'scenario-based' with 'coupled components' (Kelly et al., 2013). Specifically, in common with popular complex agricultural simulation models, such as AgriPoliS (e.g. Happe et al., 2009) and MP-MAS (Schreinemachers and Berger, 2011), the simulation comprises distinct 'modules' of submodels that each perform a specific role. First, a farm household module enables agents (households) to make decisions about agricultural land use and labour allocation, and includes separate crop and cattle components. The crop model builds on partial equilibrium models of the household (e.g. Angelsen, 1999; Ferraro and Simpson, 2002; Groom and Palmer, 2010, 2014) and models of land use allocation (Groom et al., 2010); Pascual and Barbier, 2007; and Shively and Pagiola, 2004) to simulate the optimising labour and land use decisions of heterogeneous farm households given their specific constraints and community wide attributes. Household decision making in the cattle submodel follows more heuristic rules that are consistent with insights gleaned from qualitative fieldwork in the region and reflect the special cultural significance of cattle ranching and local preferences for using cattle as a savings vehicle.

Second a state-space controlling 'shell' module defines the dynamics of the evolving physical and economic landscape in which the community of heterogeneous farm-households reside, endogenously adjusting wages to local labour market conditions, growing the cattle herd at a natural reproduction rate, and determining net migration to/from the city. Finally, in a novel contribution that is, to the authors' knowledge, unique to the simulation modelling literature, a third policy maker (or 'Mayor') module observes real-time information on community well-being, deforestation, macroeconomic conditions and the Mayor's budget (all provided by the shell module), and can then adjust a range of policies to try to reduce deforestation and improve welfare, subject to not running out of money. Policy interventions that can be adjusted throughout the simulated 20-year period of the model include ones with a development focus such as public investments made from the Mayor's budget. These, in turn, impact welfare, productivity, and migration. Local land-use interventions with an environmental focus include conservation payments, international payments for reducing emissions from deforestation (e.g. REDD), and deforestation taxes that both impact land use and the Mayor's budget, as well as welfare.

The model, called 'SimPachamama' (and freely available for download at: http://www.inesad.edu.bo/simpachamama/), is initialised and calibrated using rural household survey data from communities in the Beni river region of the Bolivian Amazonian frontier and is designed to be useful for students, scholars and stakeholders concerned about land-use change and social welfare in tropical forest settings. The model's open source code is based on solid academic foundations and can be easily altered or augmented by students and scholars. The attractive, user-friendly interface can be easily understood and mastered by non-expert stakeholders, including policy makers and villagers/farmers.

Bolivia provides an appropriate setting for our model. It loses an estimated 300,000 ha of forest annually,[1] mostly due to the expansion of the agricultural frontier (Andersen et al., 2012). Furthermore, as in many tropical countries, annual per capita income remains below USD 5000. Outlined in Section 2, the government's approach has been to attempt to tackle both problems simultaneously, developing a programme for both reducing deforestation and rural poverty that relies on a broad set of interventions (INESAD, 2013).

Described in detail in Section 3, following the ODD + D protocol (Müller et al., 2013), the model is designed to reflect both the realities of the forest frontier and existing knowledge of socio-environmental trade-offs in such a setting. In theory, the model allows us to explore policy outcomes across an infinite combination of policy choices; in practice, the mayor reacts by adjusting policy choices as these outcomes evolve in response to previous choices. Over repeated simulations, the relative degree of success of different strategies becomes apparent to the mayor, the general results of which are shown in Section 4. This allows for experimentation and active policy learning in a simulated yet 'real-world' setting that can be easily adjusted to other settings. For researchers, by recording and comparing these policy sequences and outcomes a number of potential lessons have emerged that are theoretically coherent and potentially empirically testable. We further discuss these lessons and conclude in Section 5.

2. The Bolivian Setting, Methods, and Calibration

2.1. Setting

Bolivia is relatively early in its forest transition, with >50% forest cover remaining and medium rates of deforestation (FAO, 2010). The country's 1996 land tenure reform law formally recognises indigenous communal properties (*Tierra Comunitaria de Orígen*, TCOs), and a new forestry law promoting sustainable forest management recognises some rights of private and communal landowners to forest resources. Nevertheless, work remains to finalise reforms and consolidate new property rights.

Bolivia was one of the first countries to develop a national REDD strategy. Between 2006 and 2010 its government advocated a strong role for forests in international climate change negotiations. There were >10 different, small-scale REDD projects and proposals in Bolivia, including some organised by local NGOs and indigenous groups. For example, the 'Subnational Indigenous REDD Programme in the Bolivian Amazon' was supposed to involve 6 million ha in three TCOs, six municipal governments and national agencies responsible for forest monitoring.

However, in April of 2010 the political viability of REDD mechanisms was seriously challenged at the politically influential 'World People's Conference on Climate Change and the Rights of Mother Earth:'

> "We condemn market mechanisms such as REDD (Reducing Emissions from Deforestation and Forest Degradation) and its versions + and + +, which are violating the sovereignty of peoples and their right to prior free and informed consent as well as the sovereignty of national States, the customs of Peoples, and the Rights of Nature."

Although political causality is unclear, after the Conference the REDD preparation process in Bolivia stalled and the political environment grew quite hostile, with the Bolivian Government writing to the UNFCCC: "in all actions related to forest, the integrity and multifunctionality of the ecological systems shall be preserved and no offsetting or market mechanisms shall be applied or developed."[2] (Andersen et al., 2012).

The Government has instead started developing an alternative policy for reducing deforestation and rural poverty, called the *Joint Mitigation and Adaptation Mechanism for the Integral and Sustainable Management of Forests* (The Mechanism). While still in development, the Mechanism relies on a broad set of interventions, including both

[1] Killeen et al. (2007) and FAO (2010).

[2] FCCC/AWGLCA/2011/CRP.23, dated 4 October 2011.