Agent-based Social Simulation of Government Incentives for Diversifying Rubber in Yunnan, China

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Abstract. Monoculture rubber plantations are conquering Southeast Asian landscapes at an unprecedented rate. The district of Xishuangbanna is not only the epitome of Chinese biodiversity but also China's cradle of rubber framing. Driven by accelerated rubber demand and rising rubber prices, large forest areas have been converted into rubber plantations. This leads to a clash between the political goal to conserve biodiversity and heritage landscapes – both driving the rapidly emerging tourism industry – and economic aspirations at household and district levels. Currently, policy options are discussed to change incentives that better balance conservation and economics. The policy process invited this research to inform the political debate. One of the methods used during this participatory process was agent-based social simulation, revealing a few surprising insights in potentially perverse outcomes of payments for ecosystem services to convert monoculture rubber into green rubber. As an outcome of this modeling-based initiative the current debate revised previously drafted payment schemes and reconsiders regulatory approaches.

Keywords: Agent-based modelling; Payment for ecosystem services; Rubber; Monoculture; Conservation; Development.

1 Introduction

Monoculture rubber plantations are expanding rapidly throughout Xishuangbanna, Southwest China, and have largely replaced evergreen broadleaf trees and swidden-fallow secondary vegetation, moving toward marginal land in higher altitudes and steeper slopes. More than 424,000 ha have been converted already, and potentially encroach on primary forest and protected areas [1]. There are both costs and benefits to these land use and land cover changes; providing high income for local farmers and more integration into global economies, but significant threats to terrestrial biodiversity, impaired hydrological services, and reduced total carbon biomass [2]. Concern about environmental consequences has been increasing from the local to provincial, to the central government in Beijing.

Yunnan, an inland province at a low latitude and high elevation, has the richest biological and cultural diversity in China, connecting two global biodiversity hotspots, the Mountains of Southwest China and Indo-Burma. It is the source of headwaters and major tributaries leading into several major rivers, which reach and have impacts on the lives of more than 600 million people. The headwaters of the Yangtze, Salween, Irrawaddy, Mekong, Red, and Pearl Rivers are located within this province. The ecological health of the "roof" of Southwest China and Southeast Asia is rapidly deteriorating. At the same time a planned increase in the socioeconomic development of this region will bring new and vast construction of transportation infrastructure and hydropower dams [3], as well as huge investment in land development including rubber plantations. Can rubber plantations and tropical rainforest co-exist? How can negative impacts of infrastructure development on wildlife habitats be mitigated? A confrontation is brewing between economic growth and habitat preservation [4].

Decision makers are sending mixed signals about their intentions. Central government initiated two nationwide conservation policies in the late 1990s – the Natural Forest Conservation Program (NFCP) and the Grain-To-Green Program (GTGP). The Yunnan Provincial Government strived to invest for expanding conservation areas and mandates in 2007 [4]. However rubber is a very profitable livelihood for local people. "Getting rich" and increasing wealth are also top mandates for local government officials, particularly at the Xishuangbanna Prefecture level. Balancing two views, of conservation and economic development, is a challenge for decision-makers. Restricting development is not a solution. Recent debates among decision-makers and research academia identified trade-offs between commercial exploitation of the region's natural resources and the need to promote sustainability of the ecosystems in the area. Insufficient attention seems to have been given to the direct and long range connection between the exploitation and sustainability points of view.

A participatory research process aims to facilitate discussions between these levels of government and provide insights in some complex social-ecological interactions. Methodologically, this learning exercise employs agent-based social simulation, to deal with the high levels of complexity this context entails. This paper is focused on the Mersim (Mekong region simulation) model, which is one of the methods developed for the participatory research in Xishuangbanna. The following Section outlines in more detail the competing goals against the backdrop of rubber in Xishuangbanna considering a multi-level governance situation. Then, the model design is explained, followed by simulation results for the two most relevant policy scenarios. The analysis of simulation results is followed by concluding remarks.

2 Rubber, Biodiversity and Livelihood in Xishuangbanna

Rubber (*Hevea brasiliensis*) emerged as a key cash crop replacing traditional agriculture and secondary forests in the Mekong region [2], a direct result of market demands from China, the world's largest consumer [5]. Forecasts indicate that global demand for natural rubber may outpace supply by 1.4 million metric tons by 2020. Asia accounts for 97% of the world's natural rubber supply, traditionally from Thailand, Indonesia, and Malaysia. Entrepreneurs from China, Vietnam and Thailand are investing heavily in rubber plantations in less developed countries of the Mekong

Region—Laos, Cambodia and Myanmar. Currently, China contributes around 6% of the total global production [6], but consumes 30% of the production in 1990s [6].

Situated in the upper Mekong, Xishuangbanna Dai Autonomous Prefecture is a biologically diverse region in the tropical zone of southwest China. The Prefecture covers only 0.2 % of the land area of China, it harbors some 16% of the vascular flora, 21.7 % of mammals, and 36.2% of birds found in the country [7]. The northern, most tropical rainforest in the world is found here below 800 meters above sea-level, which is the habitat that has been most readily converted to rubber [8]. Xishuangbanna is an important tourism destination. Xishuangbanna National Nature Reserve was one of the earliest reserves established in China in 1958 for its high endemic species and for the conservation of Asian elephants, which are threatened by rubber monoculture expansion [9, 10].

After the 1949 Revolution, the new government of China saw rubber (Hevea brasiliensis) as an important strategic resource. After the first forestry reform in 1983, smallholder rubber plantations were initiated by lowland farmers assisted by technical guidance from the state farm and government subsidies [11].

From 1976 to 2007, rainforest in Xishuangbanna decreased from 13193 km^2 to 8336 km^2, while rubber expanded from 249 km^2 to 2256 km^2 [12]. The area under rubber reached a historical high of 4242 km^2 in 2010, almost double that in 2007 [1]; increasing income of some while eroding livelihoods of many others, in particular those dependent on non-timber forest products. The political goal is to maintain productive rubber production and secured livelihoods, while safeguarding ecosystem services and biodiversity conservation. Consequently, a vivid political debate emerged aiming to design policy instruments and economic incentives for environmentally friendly rubber across Xishuangbanna. This will set the stage for extension to other tropical developing countries particularly the Mekong downstream, where tree crop monocultures are causing similar damage to livelihoods and the environment. Both upland farmers and local government officials seek alternatives to the development dilemma in the region [1].

The political consensus and pathway for implementing such policy changes already exists. Under pressure from both national and provincial governments to address the environmental problems caused by rubber, the Xishuangbanna Prefectural government and the rubber industry established the "Leadership Group for Environmentally Friendly Rubber" (LGEFR) in 2009. This research was invited to provide insights in how far conservation goals can be achieved without compromising economic realities.

3 Methodology

3.1 Modelling Methodology

Decision makers identified interventions and relevant indicators that require the spatially explicit modelling of behavioural changes of households and environmental dynamics. Agent-based social simulation allows for the representation of such complex social-ecological interactions [13, 14].

Agent-based modelling is often employed to simulate land use change by incorporating environmental conditions, bio-physical processes, human behaviour, decision-making, and policy [14, 15]. Agents make decisions through learning from their surrounding environment and other agent's behaviour, which can be linked to land-use/cover change (LUCC), informed by proportional or disproportional up-scaling from the agents' decision-making (micro-scale) impacts on LUCC (macro-scale) [16, 17].

Over recent years LUCC has developed into a stronghold for ABM [18-24]. The spatial distribution of particular decision making is typically achieved through the development of landholder types [25-27]. ABM is also increasingly utilised to reveal the evolution of settlement patterns temporally [28]. Sanders et al. simulated the LUCC of urbanization, which started from scattered agricultural villages bottom up to functionally diverse, competing urban settlement [29].

In China, ABM has been applied to detect LUCC, particularly to analyse urbanization processes [30-32]. However, there is only one application of ABM in China on deforestation and forest degradation [33]. An et al. simulate the growth of rural populations and how this affects forests and panda habitats. So far, the rubber monoculture expansion and its economic effects on local people in China has not been studied in detail; in fact to date no study has been published on agricultural land expansion, driven by economic markets or policies, in China. Outside of China, more attention has been given to the topic – for instance, rubber expansion has been modeled in the LB-LUDAS model to explore the impacts of Payment for Ecosystem Services (PES) on the trade-offs between goods and services of jungle rubber in Jambi Province, Indonesia [34].

3.2 Model Design

The development of an agent-based model for Xishuangbanna focused on simulating household responses to payments for ecosystem services and impacts on rubber production and land use change. However, this modelling effort was part of a larger effort that aimed to improve the understanding of the connectivity of the wider Mekong Region [35]. This paper is only focused on the Yunnan part of that work.

The description of the agent-based model Mersim (Mekong region simulation) [36] follows the ODD (Overview – Design concepts – Details) protocol [37, 38].

Purpose: The simulation model aims to facilitate parts of a larger participatory learning process [39, 40]. While the overarching process allows stakeholders with competing goals to interact, the model aims to provide insights in more complex social-ecological interaction. Of particular interest is the effectiveness of PES to achieve biodiversity outcomes. At this stage the model does not include biodiversity indicators per se. Instead land use change and changes in rubber production are implemented to match dominating stakeholder indicators.

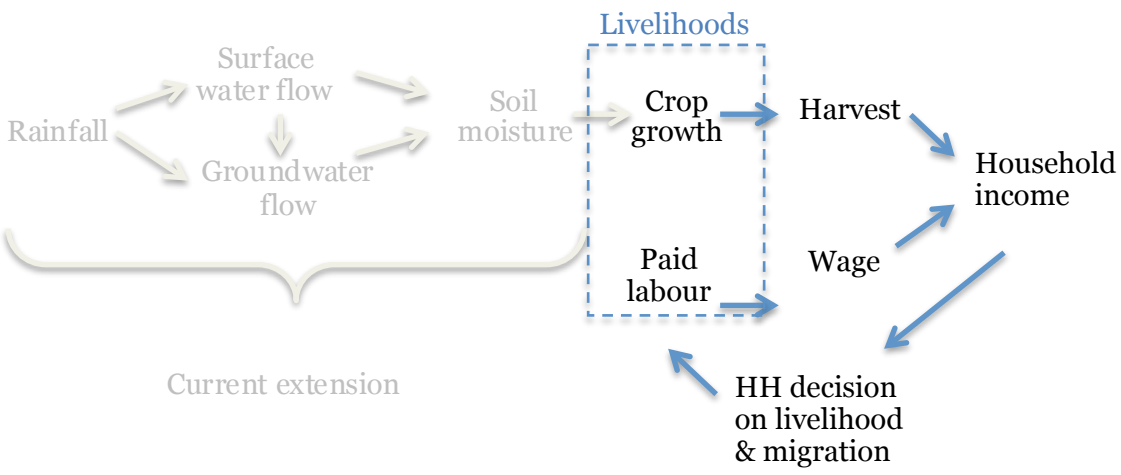

Fig. 1. Process overview of the Mekong Region model

State variables: Household income, Household livelihoods, Household location, land cover, and rubber production.

Emergence: Emergent phenomena include household income and spatial income distributions patterns. Livelihood changes emerge in response to changes in environmental, economic and political factors. Land use patterns evolve as a consequence of social-environmental interaction, including the area used for cultivating rubber. Fig. 1 depicts the principle model processes.

Adaptation & Objective: Household agents respond to income levels that result from paid labour or agricultural activities. Households' objectives are implicit to their behavioural response functions (or rules). Agents respond to changes based on intentional data elicited in large-scale surveys, as the next Section explains in detail. No additional optimisation or satisficing assumption is implemented. Consequentially, household expectations and learning are not explicitly represented but implicitly captured by the empirically derived response strategies.

Stochasticity: Most parameters are assumed to be stochastic, including crop prices, productivity, wages, and rainfall.

Initialisation: The Mersim model utilises five sets of GIS data: (1) administrative boundaries down to administrative villages, (2) soil data, (3) land cover data, (4) rainfall projections, and (5) a digital elevation model. These datasets were used to specify the artificial landscape while household survey data provided the necessary data on household attributes and behavioural responses. The survey and the parameterisation process are described below.

Submodels: Household income is calculated in weekly steps as the sum, across household members, of all livelihoods they engage in. This includes the monetisation of subsistence production – to avoid a misleading quantification of household income.

3.3 Household Data for Parameterisation

The parameterisation process is described based on the framework provided in Smajgl et al. [16].

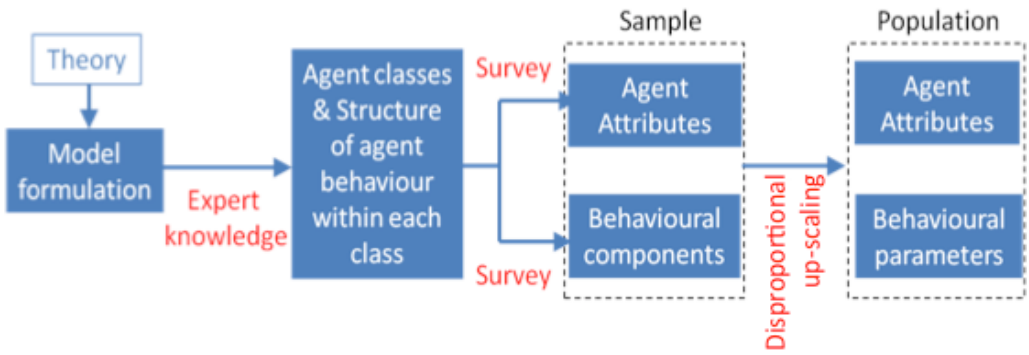

Fig. 2. Parameterisation Sequence for the Mersim model, adapted from Smajgl et al. [16]

Fig. 2 shows the principle parameterisation steps an empirical model requires. The Mersim model formulation is based on theory conceptualising social-ecological complexity. Key dimensions of these underpinnings are the bottom-up design of a systems view that includes non-linear dynamics and interactions.

Experts helped identify principle agent classes, such as household agents, government agents and spatial agents. This expert-based process also identified principle agent behaviour such as the harvest of tea and the tapping of rubber. These livelihood-related activities were put into a typical calendar and linked to certain regions and altitudes where necessary.

The next step involves the specification of household attributes and household behaviours. Based on random sampling 1,000 households across Xishuangbanna were surveyed to elicit their key characteristics (i.e. location, household size, livelihoods, production, and income), their wellbeing, their values, and their intentions. Intentions are responses to questions that frame a hypothetical change. In this case the change households were asked to imagine included:

- Government payments for planting trees on an existing rubber plantation.
- The reduction of household income by 50% for at least 3 consecutive years.

- The availability of third sector employment.

Households had four principle response options

- To maintain their livelihood where they are
- To change their livelihood where they live
- To migrate out but maintain the livelihood
- To migrate out and change the livelihood

In each of these categories follow-on questions specified as required the magnitude or type of livelihood response and/or the location for migration.

The sample data for attributes and behavioural rules is then disproportionally up-scaled. This means that the proportions within the sample are changed when stepping to the whole agent population. Land use determines the new proportions and ensures that responses from rubber farmers are only used to characterise and parameterise agents where rubber is actually planted. This GIS-based adjustment aims for a more realistic spatial distribution of simulated household behaviour.

4 Simulation Results

The participatory research process required simulations to compare three principle scenarios:

- The impact of government payments on the spatial extension of rubber
- The impact of new regulation (assuming effective monitoring) that prohibits rubber above 900m and reduced rubber below 900m by 20% to create ecological buffer zones along water bodies.
- The impact of additional off-farm employment options, in particular in the tourism industry

The first two scenarios allow for the actual assessment of the market-based and the regulatory approach and their comparative evaluation. Based on options debated among decision makers the market-based scenario assumes that payments are made if 20% of rubber trees are replaced by native trees. The economic incentive is provided by replacing the rubber related income loss. Considering the new forestry based income farmers could expect higher income. For the regulatory mechanism we assume no compensation. The third scenario defines the expansion of tourism activities and simulates how households respond to such a change.

Many indicators were tracked in the simulations, but two are of particular importance. A critical indicator for central and Province level government agencies is the area under rubber, largely as a proxy for conserved tourism potential, heritage and biodiversity. Additionally, impacts on household income need to be estimated, in particular for village level interests.

4.1 Area under Rubber

Fig. 3 depicts the average impacts of the three policy scenarios on the area under rubber. Results are shown as per cent changes compared to the baseline and are calculated as averages over 200 simulation runs. The respective changes are activated in 2013, explaining the sudden response in area under rubber.

The market-based option is taken up by about half of the rubber farmers. However, the government payments have a surprising result. The area under rubber or green rubber increases by 19.6% as the additional payments create sufficient incentive for landowners that did not cultivate rubber to start planting rubber as a mixed crop. The expanding area combined with the decrease in rubber density per ha results in only minimal changes in provincial rubber production, with the average only dropping by 0.44%.

The legislative solution reduces area under rubber by 61%. This is a direct effect of reducing lowland rubber by 20% and upland rubber by 100%. An overall reduction of 61% under these legislative constraints reveals that nearly a quarter (23.75%) of existing rubber plantations is currently located in altitudes above 900m, an area that is considered marginal. Experts and remote sensing information validated this simulation result.

The provision of additional tourism employment has no impact on area under rubber because rubber farmers do not perceive tourism as an alternative livelihood. Thus, rubber farmers are likely to continue growing rubber, leaving the area under rubber unchanged.

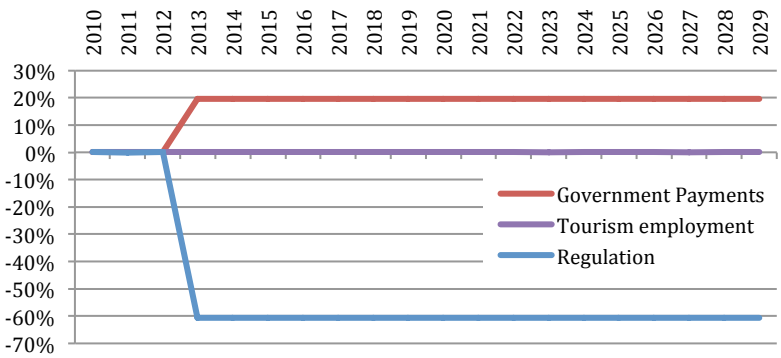

Fig. 3. Simulation results for area in Xishuangbanna under rubber for 2010-2029 (average of 200 runs)

4.2 Household Income

Fig. 4 depicts the results for average household income for Xishuangbanna for the period 2010-2029 for all three policy scenarios. These results are based on the same 200 simulation runs as the previous indicator and the changes are activated in 2013.

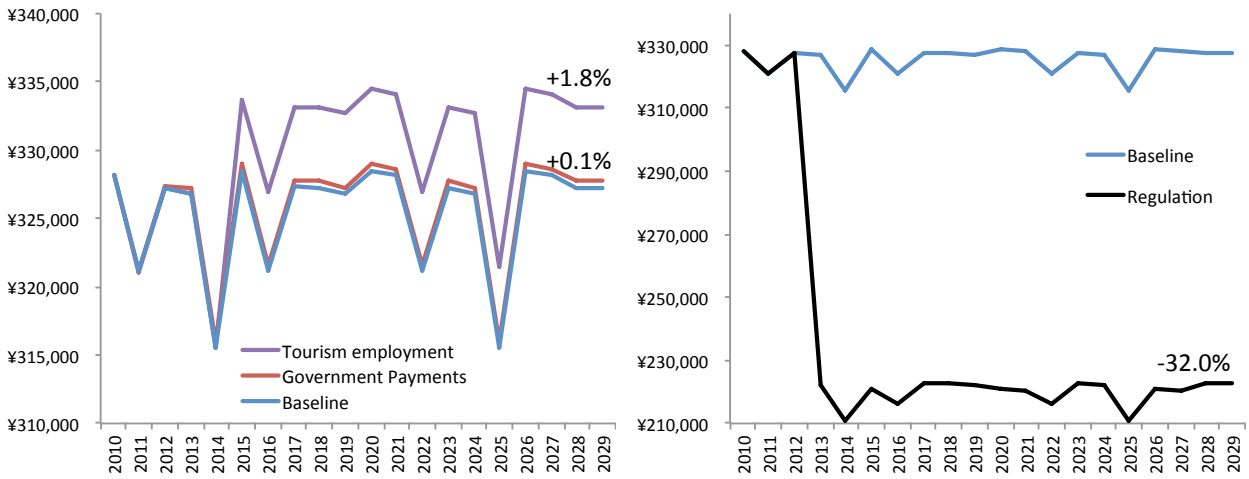

Fig. 4. Simulation results for average household income for 2010-2029 (average of 200 runs). The left diagram shows average income for baseline runs, for the scenario with Government payments and the scenario with expanded tourism employment. The right diagram compares average income of the baseline runs with the regulation scenario.

The PES scheme increases household income marginally, by 0.1%, while the regulatory approach triggers a decline in average household income by around 32%. The expansion of employment in tourism increases average household income by nearly 2%.

When we consider income distribution, all three strategies increase existing disparities. However, tourism expansions lead to increases for both, top-end (+2.6%) and low-end earner (+1.8%). Regulation that assumes no compensation disadvantages lower income earners slightly more (-32%) than high income earners (-31.4%). Government payments have a similarly negative impact on income distribution as minimum income remains unchanged while maximum income increases by about 0.9%.

5 Analysis

The results indicate that the proposed PES scheme is likely to create perverse incentives and is likely to trigger a further expansion of rubber in Xishuangbanna. In contrast, regulatory instruments help – effectively achieving the goal of limiting rubber plantations. However, the environmental success comes at a cost as income levels drop substantially. This should not be a surprise as the difference between income from rubber and most other livelihoods is substantial. The expansions of alternative high-income livelihoods such as employment in tourism seems ineffective for reducing the cultivation of rubber, while this instrument helps increase average income.

This work should not indicate that PES is per se an ineffective mechanism. Instead, it emphasises the need to design such monetary incentives very carefully to avoid perverse incentives. If combined with a new regulation that prohibits the establishment of new rubber cultivations and aligned with effective monitoring of land use change on the ground, conservation goals could be achieved without compromising income levels.

The success of regulatory alternative to PES is based on the assumption that institutional arrangements ensure effective monitoring and enforcement. Considering that currently rubber is also cultivated in protected areas [1] it seems like an unrealistic assumption. The evidently absent monitoring and enforcement mechanisms make the comparisons between the payments and regulation difficult as both require effective institutional arrangements [41] to ensure compliance.

6 Conclusion

From a policy perspective four significant findings emerge. First, the currently proposed PES design is likely to extend rubber further instead of reducing it. Second, regulation could be successful but nearly 100,000 households are likely to experience a substantial drop in income, demanding a slow implementation with some temporal compensation to avoid social unrest. Third, either option will require an effective improvement of on-the-ground monitoring and enforcement to ensure effective compliance. Fourth, the development of alternative sectors (i.e. tourism) is unlikely to achieve conservation goals as it is unlikely to provide a livelihood alternative for rubber farmer.

In synthesis, conservation goals require an effective combination of regulation, household payments and monitoring to achieve the land use change desired by Central and Provincial governments without either worsening the environmental degradation or creating social strain.

Methodologically, the combination of field work and agent-based social simulation within a participatory process have proven very effective in revealing potentially counter-productive effects of PES, which emerged very unexpectedly. The dominating expectation was that the proposed PES design will be effective and the modelling process allowed facilitated an effective learning experience for decision makers and decision influencers. It is critical to emphasise that this work was implemented in a learning-focused process to challenge beliefs stakeholders hold. This distinguishes this work from modelling for prediction. The above results were presented to stakeholders to encourage further thought around uncertainties and assumptions in the endeavour, as discussions gave the sense that stakeholders perceived PES schemes as a panacea for achieving conservation goals. To the surprise of all stakeholders participating in the engagement process, the modelling reveals the potential for perverse incentives and shifts the focus to important design details of PES.

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