Calibrating Behavioural Variables in Agent-Based Models: Insights from a Case Study in East Kalimantan, Indonesia

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EXTENDED ABSTRACT

Agent-based modelling is gaining recognition as a method to understand complex system dynamics – such as those that occur in coupled social-ecological systems that link humans and nature – that arise from the collective expression of individual agent decisions. Empirical agent-based models seek to represent real-world dynamics in a more rigorous way and thereby improve their ability to be used by decision-makers. While biophysical data can often be incorporated into these models according to well-defined protocols and scientifically defensible model assumptions, the calibration of human behavioural variables in an agent-based model is somewhat less straightforward. Various methods are available to calibrate these variables, such as interviews, surveys, statistical methods, and experimental techniques, but the use and documentation of these methods have been limited to date.

In this paper we present an approach for calibrating behavioural variables in an agent-based model of deforestation in East Kalimantan, Indonesia. Developed through a stakeholder-driven process, the model simulates impacts of macro-policy changes on subsidy levels for different fuels on household livelihoods and natural resources. In order to calibrate the agent-based model, we use survey questionnaires, statistical grouping methods to cluster households according to a typology, and interviews to develop behavioural response functions for each household type. We discuss how calibration techniques such as interviews or surveys can be evaluated in light of stakeholder requirements. Additionally, we discuss how this approach can inform the development of a widely applicable guideline for calibrating behavioural variables in agent-based models.

1. INTRODUCTION

Agent-based modelling (ABM) has become an increasingly popular approach to improve understanding of complex human decision-making at multiple scales. Numerous agent-based models now exist that explore the dynamics of social-ecological systems (Janssen and Carpenter 1999, Carpenter and Brock 2004, Robinson et al. 2007), and ecosystem or natural resource management (Bousquet and Le Page 2004). Recently, a spate of agent-based models have been constructed to address questions of a development and poverty nature (e.g. Castella et al. 2005, Berger and Schreinemachers 2006), typically through participatory processes, where they are applied in local settings with stakeholders who play a central role in the dynamics the model seeks to illustrate.

For complex systems modellers, a tension often exists between developing a model that achieves a realistic representation of the world and one that maintains enough simplicity to be useful and tractable (Goldstone and Janssen 2005). Indeed, a frequent criticism of ABMs is that they have been based more on simplified views of human behaviour, and as such have limited utility beyond theoretical inquiry (Janssen and Ostrom 2006). The use of empirical data to calibrate model variables is an important way to impart realism to a theoretical description of system dynamics, but can be expensive and time-consuming, as this may require large amounts of data that may not exist, and the coordination of multi-disciplinary research efforts. This is especially true for human behavioural data. Social models and data sets have been constrained by limitations and complications – such as sensitivity about issues considered to be of a personal nature – that have not plagued their biophysical counterparts as severely, both at regional or national (Endter-Wada et al. 1998) and global scales (Leemans and Costanza 2005). For these reasons, the calibration of human behavioural processes is significantly challenging compared to that for biophysical ones. Thus, ABMs which have used empirical data have typically done so in an ad-hoc fashion and without the benefit of carefully-documented experiences of others (Berger and Schreinemachers 2006), although efforts are now being made to synthesize the current state of knowledge on the topic (Robinson et al. 2007).

Given the focus of ABMs on human decision-making dynamics, a guideline for calibration – based on previous experiences of empirical agent-based modellers but flexible enough to accommodate new experience and evolve accordingly – is an important requirement for the field of agent-based modelling to progress. Such a tool would be invaluable both for researchers seeking to develop empirically-based ABMs and decision makers in situations where models are intended to be used in actual decision-making contexts.

In the interest of developing such a guideline, we discuss a case study in East Kalimantan, Indonesia, where we model agent decision-making related to macroeconomic policy, deforestation and livelihoods. We briefly outline the motivation and context for our research before describing our objectives, approach, and selected results, and then elaborate on its apparent effectiveness and areas for improvement in the future.

2. CAPTURING HETEROGENEITY WITH A TYPOLOGY

Our case study was part of a larger research collaboration to assess the likely economic, ecological and social (i.e. the "triple bottom line") consequences of alternative development pathways in Indonesia, and more broadly, to develop approaches and results that the national, regional, and local governments can use to realize better investment outcomes for environmental sustainability and poverty alleviation. With a strong capacity building focus, this work contributes to the broader field of agent-based modelling for applied poverty and development research. As several examples have shown (Erasmus et al. 2002, Berger and Schreinemachers 2006), agent-based modelling provides a powerful avenue for understanding poverty in a multi-dimensional context in ways that other approaches cannot.

Our case study seeks to better understand household behaviour in response to specific policy actions being considered by the Indonesian government. The study area is the southern half of East Kalimantan, an area of approximately 220,400 square kilometres. Some 2 million people live in this region and there is high diversity among households which represent a wide range of urban, peri-urban, and rural livelihoods based on the primary, secondary and tertiary economic sectors.

An empirical ABM can realistically only deal with a limited number of heterogeneous agents due to the difficulty of calibrating behavioural characteristics of cognitive agents, particularly when agents possess complex characteristics and sophisticated decision-making capabilities (Goldstone and Janssen 2005). In this case study, we included this case study, we included 27 questions relating to household characteristics, in order to capture a holistic view of the households' livelihoods and the non-market values they believed they derive from natural and social resources. Twelve of these questions were linked to 17 natural and social resources, resulting in 250 statistical variables. Considering the large number of variables and the size of the total population, it was necessary to simplify the heterogeneity of the real-world population by developing a household typology. The objective of the typology was to capture the key characteristics distinguishing households in the region, their livelihood strategies, and their values, in order to identify their likely behavioural responses to certain policy or economic changes at the broader (national or regional) level. We assumed that households with similar characteristics will exhibit similar behaviour in response to these changes (Byron and Arnold 1999).

Previous studies in the region have employed or developed household typologies to investigate deforestation dynamics, but these have been limited to specific livelihoods or resource types, such as rattan cultivation (Pambudhi et al. 2004), non-timber forest products (Belcher et al. 2005). or a broad range of forest benefits (Byron and Arnold 1999). However, as the scope of our research extends beyond forest-based livelihoods, these existing typologies were too narrow for our purposes.

3. METHODS

Figure 1 illustrates the key steps in the model calibration process. In the first step, a survey instrument was developed, with the input of local researchers based in the study area, in order to capture what were perceived to be the major attributes that would distinguish households. Data were collected on household location, composition, assets, wage income, and benefits derived from natural and social resources (Table 1). The survey was carried out by a local research team at approximately 3000 households spread equally across six sites: four *kabupaten* or districts, and two *kota*, or municipalities, that collectively form the southern half of East Kalimantan. In the second step, a cluster analysis was performed to determine household typologies. The analysis included a two-step approach, where the final typologies depended on an overall set as well as site-specific sets of clusters. Given that most of the variables were categorical, extraction of the important variables underlying the clusters relied on regression tree approaches. This enabled the development of a decision tree (with a limited set of variables) through which a typology could be assigned to each household in the area.

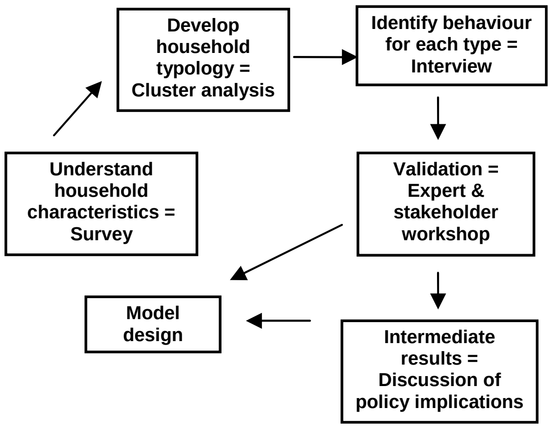

Figure 1. Steps in model calibration process.

In the third step, semi-structured interviews were conducted, again by the local research team, in order to identify the major behavioural responses to eight policy scenarios. A total of 540 households were interviewed and classified according to the types defined by the decision trees from the survey instrument. Ninety households were interviewed at each of the six sites in which the survey was conducted. We required that a minimum of 10 households be interviewed for each household type. The interview began with a series of questions corresponding to the decision tree variables to identify the household type. Next, eight "what-if" questions were asked to pose hypothetical scenarios related to energy policy change or employment opportunities, and to then ask how this would affect a household's use of natural resources, the hours of paid work it undertakes per week, migration with and without the rest of the household, investment in assets (i.e. a motorbike, house or boat), and application for work should a new coal mining, logging, or oil palm company begin operating in the area. Where migration or new work was involved, the household was also asked where they would be most likely to go. Households were also asked if they would do anything differently that was not already specified. A final set of open-ended questions was asked to give respondents the opportunity to elaborate on their earlier responses and to allow for cross-checking of consistency.

In the fourth step, the results of both the cluster analysis and the interview were presented in a workshop with regional experts and stakeholders in order to define and clarify agent rules. The fifth step was to use the "intermediate" results obtained in the workshop to discuss the policy implications of these results. Both the results of the validation and the policy implications were incorporated into the model design. Finally, in order to assign a type for each household in the study area, clear discriminators were isolated that link to one agent type only and are included in the national census data, which could then be used to assign the spatial location of agents within the region.

4. SELECTED RESULTS

A three-day workshop with experts and stakeholders, including university research staff and officials from national and regional government, was conducted to elicit their views on the household typology and responses to decide how to best represent these in the ABM. This entailed an overview of the project and research objectives, methodology, presentation and discussion of the survey results, followed by presentation and discussion of the interview results.

The cluster analysis identified 19 household types, based on a detailed consideration of important factors driving households' decisions at each of the six sites. The variables with the greatest ability to distinguish types were unique to each site. For example, two household types in Samarinda, one of the urban sites, were identified on the basis of the household's dependence on natural resources (as expressed by the importance placed on these resources for income and other purposes), the ethnic group to which the household belongs, number of boat engines the household owns, and the extent to which the household values recreation, roads, education, and social networks for income (Table 2). This distinction suggests that one type is much more connected to and dependent on natural resources, while also placing much higher values on "social" resources like education and roads.

The interview results were grouped by household type to evaluate responses to the eight policy scenarios for each type. For clarity of presentation at the workshop, we considered only the extent of change in use of key resources (timber, rubber, rattan, and fish), whether the household would increase its paid working hours per week, whether the household would migrate with their family and without their family, whether they would invest in additional resources, and whether they would apply for a job if a new opportunity arose in a coal mine, logging company, or oil palm plantation.

Following these discussions, participants were presented with a summary of the most frequently-employed household responses for each type under each scenario, and asked to provide feedback (Table 3). Finally, the relevance of these results for policy development was discussed with the participating decision-makers from national, regional, and local government.

5. DISCUSSION

The overarching objective of the process outlined above was to capture heterogeneity among households in a diverse region, so that key drivers of their behaviour could be explored in a meaningful and rigorous, yet cost-effective way. A major benefit of the approach was the time- and cost-savings, in that the cluster analysis allowed us to reduce number of interviews to 540, eliminating the need to interview a larger number of households as was done for the survey. However, there were several limitations. One is that "meaningful" variables did not readily emerge from the cluster analysis, requiring contextualisation and ultimately validation by local experts. This adds additional time to the analytical process, and while this engagement and involvement are important aspects of the participatory nature of our research and its application, they also increase the possibility of introducing personal or institutional biases about what are the critical variables related to household decision-making behaviour. Of course, such bias is not limited to empirical agent-based modelling, but affects more theoretical models as well. Additionally, because this was a previously untested approach, a rigorous pilot study to test the entire process would have been beneficial to identify ambiguity of particular questions, language and interpretation issues, and data entry problems. Most of these were able to be resolved in consultation with local researchers or in the workshop, however. We identified issues that were not able to be easily resolved for further investigation and consideration of alternative approaches for future case studies.

To some extent, the precise steps to be taken for a model calibration approach depend on the type of ABM; factors like population size, diversity, and the number of variables of interest may influence the selection of an approach (e.g. Smajgl et al. 2007). Thus, the steps and sequence that we identify may need modification or reiteration, depending on the type of model. As Smajgl et al. (2007) suggest, distinctive model types can be identified and for each type a sequence of calibration steps can be identified that can be based on a selection on methods. Testing these methods and analysing the pros and cons is a necessary process in developing such a guideline for calibrating behavioural variables of cognitive agents. This paper tested and discussed a sequence of methods for the type of ABM that aims to simulate a large population with complex behavioural characteristics. Ultimately the process has broad applicability to agent-based modelling that strives to incorporate realistic human behaviour through empirical data.

6. CONCLUSION

The contribution of agent-based modelling to solving complex systems problems, through the simulation of human decision-making processes, has significant potential to increase. Ultimately, such a contribution stands to greatly improve evidence-based policy development in the domain of natural resource management and poverty reduction, as our above example from Indonesia illustrates.

However, if modellers are to win significant trust from practitioners, managers, and government officials, among others, in their modelling approaches for policy development, there is a need to continue improving the accessibility of approaches such as the one described above, and documenting their performance in a way so that the learning that they generate can be widely shared. It is thus crucial that a guideline for calibration deals not only with the technical modelling aspects but also with the process of involving model users in the concept development, design, and building the model, so that a sense of ownership is cultivated. An important component of the Indonesian case study is training of key model users, who will in turn train a second generation of model users, and so on, in order for the model accessibility to reach its full potential.

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Table 1. Categories of survey questions.

Household identification & location	**Household composition**	**Assets**	**Wage income**	**Benefits from natural & "social" resources**
- name of household head - address - district - village - type of house	- identity of respondent (e.g. role in household) - size - demographics - education - origin - ethnic group(s)	- number of assets owned (e.g. house, car, motorbike, fishing boat) - assets owned that are worth more than annual salary	- who earns - type of work - location of work - time spent working - daily wages	- type of use or value of natural resources - type of use or value of social resources (education, roads, recreation areas, social networks) - frequency of use - distance travelled to use - mode of transport to use - importance for income, nutrition, health, cultural values, recreation, security

Table 2. Example of two typologies identified for the Samarinda site. Variables shown are those with the highest discriminatory power.

	Samarinda1	**Samarinda2**
Livelihood based on Natural Resources	Most here (fruit trees, fish)	Very few (4 HH)
Ethnic groups	Sunda, Javanese (1/3) and Bunginese dominating; also Kutai, Dayak Kenyah, most Dayak Bahau here	Sunda, Javanese (2/3) and Bunginese dominating; also Maluku, Malay, Paser
Own a boat engine	None	Yes, some
Recreation important for income	All here	None
Roads important for income	All here	None
Social networks important for income	All here	None
Education important for income	All here	None

Table 3. Categorisation of interview results for policy scenario #1 (fuel subsidy reduction) for workshop validation. Codes listed in the "Household Types" column represent the types found in the six study sites. Feedback (right-hand column) was captured and entered interactively with workshop participants.

Question	**Response**	**Household Types**	**Workshop feedback**
Change natural resource use	None (<20%)	PPU1, PPU2, KuKar1, Paser1, KuBar2, Balik1, Balik2, Sama1	
	Increase (≥20%)	KuKar2	
Change hours of paid labour	No change	KuBar1, KuBar2, Balik1, Balik2	
	Increase (≥20%)	PPU1, PPU2, KuKar1, KuKar2, Paser1, Paser2, Sama1	
Migration	No change (<20%)	PPU2, Paser1, Paser2, KuBar1, Balik1, Balik2, Sama1	
	Migration out (≥20%)	PPU1, KuKar1, KuKar2, KuBar2	Unlikely where households are largely employed by the government