Environmental Modelling & Software 87 (2017) 39–48

Contents lists available at ScienceDirect

Environmental Modelling & Software

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

Theoretical foundations of human decision-making in agent-based land use models – A review

J. Groeneveld [a, b, *], B. Müller [b], C.M. Buchmann [c, d], G. Dressler [b], C. Guo [c], N. Hase [b], F. Hoffmann [b, c], F. John [b], C. Klassert [e, f], T. Lauf [e], V. Liebelt [c], H. Nolzen [b], N. Pannicke [e], J. Schulze [b], H. Weise [g], N. Schwarz [c]

[a] Institute of Forest Growth and Computer Science, TU Dresden, PO 1117, 01735, Tharandt, Germany
[b] Helmholtz Centre for Environmental Research – UFZ, Department of Ecological Modelling, Permoserstr 15, 04318, Leipzig, Germany
[c] Helmholtz Centre for Environmental Research – UFZ, Department of Computational Landscape Ecology, Permoserstr 15, 04318, Leipzig, Germany
[d] University of Hohenheim, Institute of Landscape and Plant Ecology, 70593, Stuttgart, Germany
[e] Helmholtz Centre for Environmental Research – UFZ, Department of Economics, Permoserstr 15, 04318, Leipzig, Germany
[f] Leipzig University, Institute of Infrastructure and Resources Management, Faculty of Economics, Grimmaische Str. 12, 04109, Leipzig, Germany
[g] Freie Universität Berlin, Institute of Biology, Biodiversity and Ecological Modeling, Altensteinstr 6, D-14195, Berlin, Germany

ARTICLE INFO

Article history:
Received 16 March 2016
Received in revised form
19 October 2016
Accepted 26 October 2016

Keywords:
Adaptation
Heterogeneity
Human behaviour
Learning
Multi-agent systems
ODD+D
Uncertainty

ABSTRACT

Recent reviews stated that the complex and context-dependent nature of human decision-making resulted in ad-hoc representations of human decision in agent-based land use change models (LUCC ABMs) and that these representations are often not explicitly grounded in theory. However, a systematic survey on the characteristics (e.g. uncertainty, adaptation, learning, interactions and heterogeneities of agents) of representing human decision-making in LUCC ABMs is missing. Therefore, the aim of this study is to inform this debate by reviewing 134 LUCC ABM papers. We show that most human decision sub-models are not explicitly based on a specific theory and if so they are mostly based on economic theories, such as the rational actor, and mainly ignoring other relevant disciplines. Consolidating and enlarging the theoretical basis for modelling human decision-making may be achieved by using a structural framework for modellers, re-using published decision models, learning from other disciplines and fostering collaboration with social scientists.

Contents

* Corresponding author. Technical University Dresden, Institute of Forest Growth and Computer Science, PO 1117, 01735, Tharandt, Germany.
E-mail address: juergen.groeneveld@tu-dresden.de (J. Groeneveld).

http://dx.doi.org/10.1016/j.envsoft.2016.10.008
1364-8152/

1. Introduction

Agent-based models (ABMs) have been suggested as powerful tools to investigate land use and land cover change (LUCC) (Parker et al., 2003; Matthews et al., 2007; Rounsevell et al., 2014). This is due to the fact that human decision-making in ABMs can be represented in a very flexible and context-dependent way (An, 2012). Such flexibility is needed to describe human decisions beyond neo-classical assumptions of the fully rational and self-interested *Homo economicus* (Parker et al., 2003; Balke and Gilbert, 2014) to reflect that laboratory economic experiments show the departure of human decision makers from rational or fully informed behaviour (Heckbert et al., 2010). Apart from that, land use systems behave as complex adaptive systems (CAS) (Rindfuss et al., 2008). ABMs offer the possibility to address issues relevant in CAS like learning, adaptation, heterogeneity, interactions and uncertainty in/of human behaviour (Nolan et al., 2009; Milner-Gulland, 2012). To adequately represent human decision-making is not only an academic issue, but crucial for models in order to provide reliable policy recommendations and avoid unintended consequences (Milner-Gulland, 2012; World Bank Report, 2015).

Within the last few years, a substantial number of studies of agent-based land use models (LUCC ABMs) have been published which represent human decision-making explicitly. However, review studies have criticised that the strength of ABMs as a flexible tool to implement different theories comes along with a plethora of independent ad hoc assumptions of the decision process without being grounded on established theories from economics, psychology or sociology (Crooks et al., 2008; Ekasingh and Letcher, 2008). This indicates a mismatch between the availability of numerous decision theories and their limited usage in LUCC ABMs (Parker et al., 2003; Levine et al., 2015; World Bank Report, 2015). Using behavioural models that are based on theory has substantial advantages compared to ad hoc implementations (Rai and Henry, 2016). First of all, communication between scientists of different disciplines would be fostered, for instance between modellers and theoretically and/or empirically working scientists. Second, re-use of models could be improved if models were grounded on established theories. Re-using models is not only sensible from a practical perspective in order to save time for conceptualising and implementing a new model. More importantly, re-using models can lead to consolidation of findings and more rapid scientific advancements (Bell et al., 2015). Third, Klabunde and Willekens (2016) state also that models which are grounded in theory can be used beyond simple extrapolation, but also for predictions when conditions change substantially. Also when data is sparse or completely missing, theoretical models can be used to test alternative theories and their implications which can be confronted with empirical data (Klabunde and Willekins, 2016; Silverman et al., 2011). Overall theory is a way to explain complex phenomena. Verifying and falsifying a theory through models in different contexts can advance theory development.

The most prominent economic theory of human decision-making is Expected Utility Theory (EUT), a theory of choice under risk where a decision maker chooses the option that promises the highest expected utility (Bernoulli, 1954 – which is a translation from the original published in 1738, von Neumann and Morgenstern, 1944, Machina, 2008). Numerous ABMs assume rational decision makers that maximise their utility or profit (see for example Monticino et al., 2007). Rational decision-making in neoclassical economic theory assumes that actors have perfect and complete knowledge and unlimited computational processing powers. These assumptions have been challenged by the concept of bounded rationality. A prominent theory of bounded rationality is Satisficing developed by Simon (1956). It assumes that the decision makers have a so-called aspiration level. They sequentially assess their choice options and stop the search for better options as soon as they have found one that meets their aspiration level. Satisficing has also successfully been implemented in ABMs (e.g. Gotts et al., 2003). Another branch of theories are stochastic modifications of EUT. The general idea is that the inconsistencies of EUT are explained by incorporating stochastic elements, e.g. a random error term added to the utility function. Stochastic theories were promoted by Hey and Orme (1994), and Becker et al. (1963). An ABM that includes a stochastic theory can be found in Liu et al. (2006).

There is also a rich body of psychological theories concerning human decision-making. One prominent example is the theory of planned behaviour (TPB) developed by Ajzen (1985, 1991). TPB explicitly considers subjective norms defined as “perceived social pressure to perform or not perform the behaviour” (Ajzen, 1991, p. 188) and perceived behavioural control defined as „ … the perceived ease or difficulty of performing the behaviour reflecting past experiences as well as anticipated impediments and obstacles” (Ajzen, 1991, p. 188) which has been successfully exploited in an ABM describing the diffusion of technology (Schwarz and Ernst, 2009). In our view, TPB is a relevant theory for LUCC-ABMs as decision makers act under social influence (subjective norms) and multiple restriction factors exist for land use decisions (perceived behavioural control).

The diversity of implementations of human decision-making in LUCC ABMs may be an obstacle to better understand how human decisions affect land use change (Filatova et al., 2013), since it may be difficult to choose the appropriate decision model for a specific application. Attempts to structure decision models and to put them in a framework that may guide modellers in their choice of the most appropriate model have just started (Balke and Gilbert, 2014). To inform this debate about how to model human decision-making and to reflect the current practice and use of theories in LUCC