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Self-organization in the commons: An empirically-tested model

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A appropriate bottom-up rule system can support the sustainability of common-pool resources such as forests and fisheries. The process that leads to the developments of such institutional settings requires the considerations of multiple social, physical, and institutional factors over long time horizons. In this paper, we present the SONICOM model as a general exploratory model of CPR systems. The model can be configured to represent different CPR systems in order to explore what kind of institutional settings result in stable systems, i.e. situations where the resource and the appropriators are in a state of well-being. We use a large-N-dataset of CPR management institutions to validate the model. The results show numerous correlations between various parameters of the system such as rule compliance, social influence and resource growth rate which help explaining the process of institutional emergence as well as unveiling the conditions under which systems are stable.

1. Introduction

A significant proportion of natural and man-made resources comprising land, water, forests, technology and data, are used by individuals as "common-pool resources" (CPRs) (Ostrom et al., 1994). CPRs are often described by two characteristics: non-excludability, i.e., difficulty in preventing appropriators from exploiting the resource, and subtractability of the resource unit. Economists refer to subtractability as rivalness, as it refers to the degree to which one person's use of a resource unit diminishes the availability of a resource unit by others (Anderies and Janssen, 2016). Ostrom (1990, 2005) developed the notion of subtractability of the resource unit. This means that for example the unit water sprayed on one farmers' field is not available anymore for another farmer, same as the fish caught by one fisherman is not available for his colleague. This unavailability however holds at a specific irrigation turn or fishing season, despite the fact that in the longer perspective the resource is renewable (appropriation problem). We further need to differentiate between the resource unit, which use is rivalry and the jointness of resource system such as irrigation canals or fishing grounds that are used and maintained jointly (provision problem).

Institutions are needed for both appropriation and provision problem in order to provide management solutions for CPRs. When the resource units produced by a common-pool resource have a high value and institutional rules do not restrict the way resource units are appropriated (an open-access situation), individuals face strong incentives to appropriate more and more resource units eventually leading to congestion, overuse, and even the destruction of the resource itself. Because of the difficulty of excluding beneficiaries, the free rider problem is a potential threat leading to a CPR dilemma (Anderies and Janssen, 2016, p. 45). No matter if the resource is per definition renewable or non-renewable, in either case there is the risk of overuse.

Depending on the resource regime in place – a continuum ranging from state-property regime, to common-property regime, to individual property regime or no-property regime (i.e., open access) – governs the appropriation of the resource units. The two characteristics (rivalry and subtractability) make up a certain challenge that if not governed well, can lead to unsustainable situations, such as the depletion of the resource, the so called "Tragedy of Open Access" (Feeny et al., 1990).[1]

Through extensive field studies and carefully designed

[1] Originally called by Hardin (1968) "Tragedy of the Commons" as he failed to distinguish between the resource characteristics and the property rights regime. Thus, it may be mainly the 'no property' or open access regime without a proper rule system that may lead to overuse and gives rise to pessimism.

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laboratory experiments, Ostrom and colleagues proved that if CPRs are managed under a common-property regime, they can be sustainable depending on the presence of an appropriate rule system. In other words, “boundedly rational, local users are potentially capable of changing their own rules, enforcing the rules they agree upon, and learning from experience to design better rules.” (Ostrom, 1999; Ostrom et al., 1994).

The difficulty of this management solution, however, lies in the formation of institutions, here understood as rules, which can be either carefully and intentionally designed or evolving by chance. Furthermore, most institutional configurations are experiments, and no one can predict if a proposed rule change leads to improvements or not (Ostrom, 1999). Yet, there are also cases of carefully designed institutions which allow for small incremental changes in order to have predictable outcomes (Theesfeld and MacKinnon, 2014). However, as Ostrom argues, we cannot come up with a set of design principles that fit all CPR situations (Ostrom et al., 2007). But, by identifying important components of a CPR situation, we can facilitate the analysis and enable a better design that may lead to stable local common-pool resource management (Ostrom, 1990) where the resource and its appropriators are in an acceptable state of well-being. One determinant are stable institutions. Stable institutions are rule systems that are socially durable and that are able to adapt to changing demands and changing environment, but keep the balance between excessive experimentation and excessive stability (March and Olsen, 1996). Incremental change does not mean that institutions choosing it will never be fundamentally changed. It simply means that such institutions will most commonly be changed slowly, almost imperceptibly, by incremental steps. A series of incremental changes over a long period of time can cumulate in very significant changes in institutions and their outcomes — Slow incremental change can however also allow the long-term survival of an institution, so it remains recognizable even as it is transformed (Theesfeld and MacKinnon, 2014). We operationalize this in our model by the fact that the institution can change, but only at specific points in time mimicking, for instance, the regular meetings of the commoners where group-relevant decisions are made. Furthermore, although, there are situations where a “stable” situation is undesirable, in this research, we assume that in a stable situation, the agents are in a state of well-being.

Several approaches have been suggested to explore institutional emergence, design and stability and its influence on the outcomes of natural resource management, such as sustainable use of the resource. First, case studies: the disadvantage is the idiosyncrasy of each case (irreplicability) and the time horizon measuring years and decades (Beckmann and Padmanabhan, 2009). Second, field and laboratory experiments: they allow much greater possibilities of manipulation of parameters. However, they can only explore a limited number of very short-term scenarios while the number of other factors is strictly limited, leading to oversimplified designs.

Third, computer simulations allow for the exploration of numerous institutional scenarios to study CPR situations (Poteete et al., 2010; Janssen and Ostrom, 2006). Besides modelling specific cases of CPR situations (e.g., Feuillette et al., 2003; van Oel et al., 2010; Schlüter and Pahl-Wostl, 2007; Castella et al., 2005, Becu et al., 2003), various researchers have studied general aspects of CPR situations and institutional developments. For example, Deadman (1999) illustrates the potential of agent-based modelling to study individual strategies and group performance in CPR dilemmas. He focuses on market behaviour and overall performance of the system but does not model institutions. In contrast, Smajgl et al. (2008) only focus on the emergence of institutions using ADICO grammar of institutions, but without bio-physical dynamics. Pitt et al. (2012) study self-organizing institutions based on Ostrom's principles, applying them to online resource constrained systems (e.g. cloud computing). Le Page and Bommel (2005) and Bousquet et al. (1998) provide a methodology and toolkit for building agent-based models of CPR systems but do not go into the details of how institutions are built and change over time.

The approaches used in the literature are methodically complementary, yet all have shortcomings. Simulations can overcome the scenario and time horizon limitations of case study experiments and laboratory experiments. Simultaneously, the latter two approaches (i.e., case study experiments and laboratory experiments) can make simulations empirically valid. Thus, the combination of these three approaches would provide a virtual lab where various cases of CPR situations and social experiments can be studied over longer time horizons and under numerous parameter setting.

In order to build a simulation-based experimental lab, the Institutional Analysis and Development (IAD) framework (Ostrom, 2005) can provide the key components of CPR situations. These components for studying institutions for CPR management have been the basis for experiments in numerous CPR situations around the world and have proven helpful in better management of such systems (Ostrom and Cox, 2010). The ultimate goal of the approach in this paper is to build a simulation model of CPR systems based on the components of the IAD framework. This generic model would provide a virtual laboratory to experiment with numerous scenarios and parameter settings in order to study different institutional configurations. These rule configurations can be the result of conscious design choices or randomly evolve. The goal of the study of the simulation scenarios is to explore conditions under which stable institutions emerge in a given CPR situation. Such simulation models can be used besides field and laboratory experiments to broaden the scope of institutional studies (Verhoog et al., 2016), and to capture more of the complexity involved in the management of CPR systems.

This paper presents the SONICOM (Self-OrgaNIzing the COMmons) model as a generic and theoretically sound agent-based model of a CPR system. We use a large existing empirical dataset on CPR cases ($n = 122$) to validate the model. The structure of this paper is as follows: in Section 2, we explain the theoretical background of CPR management regimes. In Section 3, we present the set-up of the SONICOM model. In Section 4, we explain the validation process of SONICOM. Finally, we present some exploratory results that demonstrate the type of scenario experiment that can be drawn from such model in Section 5. We conclude with Section 6.

2. Conceptualization of rules

The IAD framework, developed by Elinor Ostrom and scholars associated with the Workshop in Political Theory and Policy Analysis at Indiana University, contains a nested set of variables that scientists use in order to understand human interactions and outcomes across diverse settings. The framework has been extensively used to study diverse property regimes in the field of natural resource management (Ostrom, 1998), in particular common-pool resource management.

One of the main strengths of the IAD framework is its explicit attention to rules and rule-ordered relationships (Koontz, 2005; Ostrom, 2005). The IAD decomposition of a socio-ecological system is presented in Fig. 1. Its central concept is the ‘action arena’, in which individuals (or organizations) interact, exchange goods and services, engage in appropriation and provision activities, solve problems, or fight. The action arena is described by the participants (who have a set of resources, preferences, and selection criteria for action) and the action situation: the actual activity that is to be