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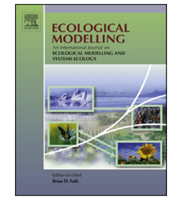

Game-theoretic insights into the role of environmentalism and social-ecological relevance: A cognitive model of resource consumption

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ABSTRACT

The environmental and social attitudes of consumers can greatly affect the consumption of common-pool resources by the whole society – as demonstrated by many experimental and theoretical studies. Rooting in the current knowledge of consumer psychology, and employing the game-theoretic modelling framework, we formalise the decision making process of individuals about their resource consumption levels depending on their level of environmental concern, and relative importance placed on social and ecological information. Our model demonstrates, in a stylized fashion, how profound preference to social information can help avert free-riding behaviour and result in globally stable resource consumption dynamics. This avoids the "Tragedy of the Commons", leading to affluence in the resource stock as well as in the individual consumption. Furthermore, we find that heterogeneity of the levels of individuals' environmentalism promotes free-riding, whereas heterogeneity in relative information preferences helps avoiding tragedies. Our analysis demonstrates that accounting for heterogeneity of consumers and their social relationships can yield additional insights regarding to what kind of societies may have better chances to ensure sustainable consumption of a natural resource.

1. Introduction

Understanding and taking into account consumer behaviour in socio-ecological systems is of prime importance for designing an effective solution to phenomena, which are usually referred to as "The Tragedy of the Commons" (Hardin, 1968). Social psychologists have carried out a wealth of research to identify factors driving the decision processes of individuals. For instance, Festinger (1954) hypothesizes, that human beings are continuously driven to evaluate their decisions, and, in the absence of any objective non-social means, they do so by comparison with decisions of other individuals. Thus, if a consumer is uncertain about the state of a resource, she may make her decision based on the information gathered from other consumers. Simon postulates (Simon, 1976), that individuals seldom optimize their outcomes over different available alternatives, mainly due to their limited cognitive resources, and instead act according to automated habitual behaviour. This implies, that although a consumer might be aware of the consequences of over-utilization of a natural resource, she may still do so according to habit, as long as the outcome is satisfying to her for the time-being (assuming that there is enough of the resource to permit her over-utilization).

These theoretical propositions have been supplemented by various laboratory and field experiments of common-pool resource settings. Samuelson et al. (1984) conduct an experiment to observe how consumers respond to information on the overall consumption of the resource. They find that individual consumptions tend to increase over time, however there is little or no increase in consumption when the resource is being overused. Rutte et al. (1987) demonstrate, through an experiment, that consumer behaviour is determined by whether the society or the environment is held responsible for the scarcity or abundance of resource. They conclude that when the environment is held responsible, consumers give ecological information more preference than social information, for evaluation of their consumption levels. Accordingly, when the society is held responsible, social information is given more

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preference than ecological information. Brucks and Mosler (2011) conduct an experiment to find what type of information is important to consumers while making decisions on consumption. They observe, among other findings, that when the resource availability is low, the importance of the information regarding the situation of the resource increases, while the importance of the information regarding consumption of other individuals decreases.

Building on the aforementioned psychological research, scientists have proposed various computational models that simulate consumer behaviour during resource crises. Much of these models have been developed under the umbrella of "multi-agent simulations", or "agent-based modelling" (these terms are often used interchangeably), in which several heterogeneous individuals (agents) are programmed according to some psychological rules. Such a framework can be used to identify key behavioural elements that shape large-scale societal transitions. Deadman (1999) presents one of the first agent-based models of the tragedy of the commons. Since then, various computational agent-based models of resource dilemmas have been developed – see, for instance (Jager et al., 2000; Feuillette et al., 2003; Jager and Mosler, 2007). These models differ in the principles used to simulate the behaviour of individual agents, as each group of authors, depending upon the posed research question, attempts to incorporate different psychological findings into the behaviour rules of agents. Bousquet and Le Page (2004) give an extensive review of the development of this field and early applications to ecosystem management.

Despite the power of computational agent-based models to reveal collective phenomena from individual interactions, they lack rigor, generality and elegance that is provided by mathematical models. Notable achievements on the latter front include, for example, Anderson (1974) who describes the coupled dynamics of a regenerating commons and the physical capital, as a system of few ordinary differential equations, and uses calculus to show that the model exhibits Hardin's conclusions (Hardin, 1968) explicitly. Anderies (2000) applies bifurcation analysis to two separate models of resource exploitation: (1) the slash-and-burn agricultural system of the Tsembaga tribesmen of New Guinea, and (2) the exploitation of palm forests on Easter Island by the Polynesians. The analysis is used to study the long-term behaviour of both systems under different management/behavioural regimes. The study suggests that successful institutional designs are highly site-specific and that a careful understanding of the "geometry" of the system is necessary for successful resource governance. Roopnarine (2013) suggests simple differential equation models which separately illuminate three different aspects of the tragedy of the commons: (1) the compulsion of individual users to act based on the action of other users, (2) the opportunities and limitations imposed by the networked nature of consumers, and (3) mutualisms as solutions to tragedies. Thus, these mathematical models are able to demonstrate and explain a certain phenomenon in a clear and tractable fashion, where a major focus is usually placed on the dynamics of consumption. Although no objective function or decision variables are explicitly included in their formulation, they typically assume some notion of rationality prevalent in the consumers. However, the theoretical findings provided by social psychologists are seldom incorporated in these models.

The commons dilemma has also been studied extensively in the framework of game theory. In her seminal work, Ostrom states that all institutional arrangements that can be used to avert the commons dilemma are expressible as games in extensive form, and presents several such examples (Ostrom 1990; Ostrom et al., 1994). While she expresses institutionalization for resource governance as a non-cooperative game, a large number of analysts have also used cooperative game theory to study environmental resource issues (see, for example, (Parrachino et al., 2006)). Ostrom's research has stimulated a vast amount of work, concerning use of the game theoretic framework for modelling strategic interactions between consumers of a natural resource (see for instance Madani, 2010; Cole and Grossman, 2010; Diekert, 2012). Similar to system dynamic models, game-theoretic models also assume a notion of rationality, which is made explicit by including objective functions and decision variables in the problem formulation. However, contrary to dynamical system models, they either do not take dynamics into account or do so in a simplified manner (as repeated games). More importantly, most game-theoretic models, either seek an optimal strategy of resource extraction, or seek to design models that yield strategies similar to those observed in real-world scenarios, rather than focusing on strategies that accurately depict the cognitive process of the consumers' decision making. We argue, that in order to increase the relevance of such models to real-world scenarios, it is necessary to incorporate the cognitive principles that govern consumer behaviour, as revealed by the psychological research.

In this paper, we present a dynamic model of natural resource consumption, taking into account the psychology of consumer behaviour in an open-access setting. We depart from the computational model by Mosler and Brucks (2003) and put forward a stylized version that is based on the same psychological principles employed in the original model. All essential psychological variables have been maintained in our model, which include the scarcity thresholds as perceived by consumers, the extent to which the consumers hold nature (or society) responsible for the state of the resource, and the social value of the consumers. While the original model assumes unlimited growth of the resource, we assume standard logistic growth, which is more realistic. The logistic growth model and its variants are commonly used to model many renewable resources that saturate at a certain carrying capacity. Thus the resources which lie in the scope of our study include (but are not limited to) fisheries (Gordon, 1954), forests (Fekedulegn et al., 1999), vegetation (Birch, 1999), foliage (Werker and Jaggard, 1997), saffron (Torabi et al., 2014), and so on. We do not, in this study, incorporate the effects of uncertainty in our model. Thus we assume, that perfect information is available to each consumer, regarding the resource quantity and the consumption of other individuals present in the system. While this is a strong and restrictive assumption, incorporating uncertainty is beyond the scope of this paper, as it would considerably increase the complexity of the model, and must be dealt with separately. Thus, we present the reformulation, which enables formal tractable mathematical treatment of the model. We carry out the steady-state analysis, consider our system in equilibrium and employ the game-theoretic framework to study what conditions lead to the commons problem. Namely, we introduce a non-cooperative continuous-kernel game to analyse the rational decisions of consumers for different combinations of key model parameters describing the resource dynamics and the society. Furthermore, we define a notion of "tragedy" in the commons game, based on the distance between the Nash equilibrium and the Pareto optimum. We then use exhaustive numeric simulations to reveal such trends in the system parameters, which are helpful for decreasing "tragicness" and are also beneficial to the resource stock.

2. Methods

Our starting point is the computational consumer behaviour model of Mosler and Brucks (Mosler and Brucks, 2003), which we stylize by formalizing it into a mathematical form. The resource is supposed to regenerate according to the classical logistic growth model (Perman, 2003). To begin with, we consider a society consisting of two consumer groups characterized by significantly different psychological characteristics. Within the groups these character-