Journal of Environmental Economics and Management 66 (2013) 141–158

Contents lists available at SciVerse ScienceDirect

Journal of Environmental Economics and Management

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

Contagious cooperation, temptation, and ecosystem collapse ☆, ☆☆

Andries Richter [a,b,*], Daan van Soest [c,d], Johan Grasman [b]

[a] Centre for Ecological and Evolutionary Synthesis (CEES), The Department of Biosciences, University of Oslo, P.O. Box 1066 Blindern, N-0316 Oslo, Norway
[b] Department of Mathematical and Statistical Methods, Wageningen University, The Netherlands
[c] Department of Spatial Economics and IVM, VU University Amsterdam, The Netherlands
[d] Department of Economics, Tilburg University, The Netherlands

A R T I C L E I N F O

Article history:
Received 16 December 2010
Available online 2 May 2013

Keywords:
Social norms
Common pool resource
Co-evolution
Resilience
Alternative stable states

A B S T R A C T

Real world observations suggest that social norms of cooperation can be effective in overcoming social dilemmas such as the joint management of a common pool resource—but also that they can be subject to slow erosion and sudden collapse. We show that these patterns of erosion and collapse emerge endogenously in a model of a closed community harvesting a renewable natural resource in which individual agents face the temptation to overexploit the resource, while a cooperative harvesting norm spreads through the community via interpersonal relations. We analyze under what circumstances small changes in key parameters (including the size of the community, and the rate of technological progress) trigger catastrophic transitions from relatively high levels of cooperation to widespread norm violation—causing the social–ecological system to collapse.

1. Introduction

The history of mankind is one of gradual change in environmental quality and natural resource abundance, punctuated with sudden collapses of populations, species, ecosystems, and sometimes even of entire civilizations [1,2]. The most common example is the collapse of the human population on Easter Island following the depletion of forest resources [2,3]. To explain patterns of gradual change and sudden collapse the literature has focused on the existence of non-linear relationships in the dynamics of renewable natural resources. Examples of natural systems characterized by non-linearities are those that feature a minimum population size below which extinction is inevitable [4,5], but also those with complex interactions between the various components of the ecological system as is the case in, for example, shallow lakes and semi-arid ecosystems [6–8]. Strong non-linearities in the regeneration functions typically give rise to the prediction that continued overharvesting of the resource results in a gradual demise of the resource until a threshold—or tipping point—is reached, beyond which collapse is inevitable and subsequent system restoration is very costly, or even impossible [9].

In this paper we contribute to the literature on tipping points in social–ecological systems by analyzing how social interactions between the users of a natural system affect its resilience. Building on [10–13] we use evolutionary game theory to develop a model in which a finite number of community members have access to a commonly owned renewable resource. As is

☆☆ The authors acknowledge the Netherlands Organisation for Scientific Research for their financial support as part of the program on Evolution and Behavior. A.R. also acknowledges the European Commission through the Marie Curie Programme (PIEF-GA-2010-274356).
* Corresponding author at: Centre for Ecological and Evolutionary Synthesis (CEES), University of Oslo, P.O. Box 1066 Blindern, N-0316 Oslo, Norway.
E-mail address: a.p.richter@ibv.uio.no (A. Richter).

0095-0696/$ - see front matter
http://dx.doi.org/10.1016/j.jeem.2013.04.004

the case in the real world, we assume that the common property regime is such that community members are allowed to harvest the resource, but that they are not allowed to hire non-community members to engage in resource harvesting too if their own time constraint is binding [14]. Next, natural regeneration is captured by a standard logistic growth function, and community members can decide to act cooperatively by limiting their extraction, or not. Agents are tempted to act non-cooperatively (also referred to as defecting) because of the extra income this generates, but we also allow for the possibility that whenever a cooperator and a defector meet, the cooperator may convince the defector of the social desirability of acting cooperatively. The diffusion of social norms regarding harvesting is thus assumed to take place via interpersonal relations, with cooperation being "contagious" [15–18]; see Ref. [19] for empirical evidence in the context of renewable resource use. This modeling approach is consistent with the experimental evidence that verbal expressions of discontent can induce and sustain cooperation in social dilemma situations [20], but the mechanism can also be interpreted as reflecting peer-to-peer sanctions or rewards [21–23].

Our paper generates tipping points without explicitly introducing (strong) non-linearities in the dynamics of either the ecological system or the social–economic system. The resource's logistic growth function implies that the percentage rate of resource regeneration increases linearly with resource scarcity, and the social–economic system is self-stabilizing as well. If, for whatever reason, the number of cooperators increases, the social pressure on defectors rises, but the benefits of defecting are larger too. Despite this apparent stability of its two components, the social–ecological system can still generate positive feedbacks between them, giving rise to alternative stable equilibria. For some range of parameter values the "good equilibrium" can be very resilient to exogenous shocks or external developments (such as population growth or technological progress in harvesting), while the same exogenous changes cause the social–ecological system to collapse if the parameters are close enough to a critical threshold. The positive feedbacks, giving rise to tipping points, emerge because the property rights regime implies that each community member's harvesting time endowment is finite. If an exogenous shock causes a decline in the resource stock, the socially optimal individual harvesting effort level decreases. Cooperation thus requires agents to decrease their effort levels, and hence the temptation to defect increases with resource scarcity. As a result, more cooperators decide to defect, putting even more pressure on the resource stock. This leads to a spiral of depletion and defection, and eventually, the system flips to the "bad" equilibrium. The societal consequences of such a flip can be substantial because the system exhibits hysteresis. Upon system collapse, moving back to the "good equilibrium" can be difficult and costly—if it is feasible at all.

We thus show that collapse can be caused by interpersonal interactions and economic constraints, rather than by the presence of inherently non-linear functional forms. In that sense, our model is related to models that generate tipping points in a general equilibrium framework because of interactions between economic sectors, with increased harvesting in the resource sector imposing a negative externality on another sector, resulting in even more intensive resource harvesting [24,25]. Our focus on the social dynamics at the community level is especially relevant because of the role of social norms in community governance of common pool resources such as fish, forests, or grazing lands [26–28]. Our paper identifies a mechanism why community resource management can be successful in some situations and not in others, and is even relevant for resources whose regeneration functions are not characterized by strong non-linearities. As such, the mechanism may have been one of the factors that contributed to social–ecological collapses in the past [29,30]. But the insights obtained by this paper may also be relevant for today's policy makers. If centralized enforcement is cheap and effective, community resource management is inefficient. But if the monitoring and policing costs of formal regulation are high (for example when it regards resources that are geographically remote), community management may be more efficient as long as the community's support for the social harvesting norms is sufficiently large, and this paper provides insights for the government to start intervening to prevent collapse. In that sense the paper also complements the literature in which a formal regulator aims to enforce property rights [31,32].

Our paper is, however, not the first in noting that coupled social–ecological systems can be inherently complex [33–35]. Iwasa et al. [36] analyze a system in which agents are more inclined to undertake pollution-mitigating activities when the environmental quality is poor, and also when social pressure is high. In their model, alternative stable states occur when social pressure increases strongly with the fraction of cooperators in the community. This framework has been extended to incorporate non-linear resource dynamics as well, leading to even richer dynamics [37]. Taylor [25] develops a minimum viable population model in which resource extraction has a negative effect on the profitability of a competing sector, rendering extraction even more attractive. Our paper is complementary to this research in that we do not use any functional forms that, by themselves, give rise to tipping points; in our model collapse can occur because of personal interactions, and the fact that individuals' time endowments are not infinite.

The setup of the paper is as follows. In Section 2 we present the model, focusing on the mechanisms driving changes in the size of the resource stock and on those affecting the number of cooperating individuals in the community. The analysis is fairly complex, and hence we present the intuition behind the underlying mechanism in Section 3, providing the proofs as well as a numerical robustness analysis in Section 4. Section 5 concludes.

2. The model

We assume that there are $N>1$ agents in a community who have access to a commonly-owned natural resource. The right to extract is exclusively associated with community membership; community members are not allowed to employ outsiders to assist in harvesting [14]. The size of the resource stock at time t is denoted by $X(t)$. Each agent is endowed with a fixed effort level $\hat{e}$ which she can allocate to harvesting the common pool resource, or to an alternative economic activity. The amount of effort agent i ($i=1\ldots N$) allocates to resource harvesting at time t is denoted by $e_i(t)$. Assuming that the return