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Research paper

Emergence of competition and cooperation in an evolutionary resource war model

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ABSTRACT

In this paper we introduce a simple punishment scheme in the 'great fish war' model with many players. An imitative process regulates how a coalition of cooperators is dynamically updated over time. An intuitive effect of adding sanctions is that they could enlarge the possible sustainable coalitions. However, the evolution toward full cooperation can be sustained by a punishment scheme provided that a critical mass of agents enforces cooperation at the beginning of the game. Moreover, we show the presence of thresholds in sanctions or in the cost for punishing such that if these thresholds are trespassed then dramatic reductions in the resource level and in the agents' welfare may occur as a consequence of free riding effects. We show by some examples that these phenomena are due to the presence of tipping points in the model.

1. Introduction

It is a well-known issue that single agents tend to adopt sub-optimal strategies in the use of renewable natural resources such as fisheries. In most cases these decisions induce overharvesting thus endangering the sustainability of the exploitation, see [14] and [3]. In fact, even if all agents would be better off by a reduced usage of the resource, any exploiter has an incentive to free-ride and increase his/her own harvesting. This prisoner's dilemma situation is referred to as the 'tragedy of the commons' after [22]. As a matter of fact, real-world data shows that many common property fisheries are on the verge of collapse (see for instance [34]). In this context, cooperative attitudes among players can help to internalize the negative externalities of overharvesting and lead to sustainable management of the resource. Many recent papers have stressed the importance of game theoretic models for fishery economics, see [26,37] and the survey in [2]. Indeed, nowadays many countries join the so-called Regional Fisheries Management Organizations (RFMO) for a common management of high seas fish stocks and highly migratory fish stocks to ensure sustainability of fisheries for future generations.

A stylized model for understanding how the resource dynamics is influenced by the decisions of strategic interacting exploiters is presented in [31]. In this influential paper, a discrete time model is proposed (the 'great fish war') where a resource is harvested by two competitors who adopt Feedback Nash strategies. The corresponding resource dynamics is compared with the one obtained under joint utility optimization. The smaller long-run resource equilibrium under the competitive setting underlines the occurrence of the tragedy of the commons even when agents optimize their utility over an infinite time horizon.

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In the present paper we consider the issue of cooperation in the classic 'great fish war' framework with N players (see [31] and [27] for the general framework) by introducing a simple punishment scheme to non-cooperators. In particular, agents can either form a coalition and cooperate or act alone; in the latter case they could face sanctions enforced by co-operators. This decision is made by comparing discounted lifetime utilities of each strategy and agents are assumed to have static or 'Nash' conjectures on the coalition structures: an agent decides whether to join or to withdraw from the coalition given that all other players remain in the actual coalition structure. Thus, the fraction of agents acting cooperatively is dynamically modelled through evolutionary dynamics, similarly to the models proposed in [4,35,40] and [11].[1] Following [39] and [4], sanctions to defectors are assumed to be independent of the resource stock and proportional to the current fraction of cooperators, as the probability that a defector is detected by a cooperator increases when the number of cooperators increases. Related to the present paper, also [43] combines an adaptive evolutionary mechanism with intertemporal optimization to study the coexistence of cooperative and non-cooperative behaviors in a model of regulated harvesting.

The idea of punishing non-compliance behavior in environmental and resource exploitation models has been often employed (see among others [4,33,38,39],) in order to enforce cooperation and mitigate the effects of overexploitation (i.e. the tragedy of the commons). In particular, cooperators can punish defectors either directly (by charging sanctions such as material destruction of equipment or social rejection, etc.) or, more commonly, indirectly (by alerting authorities to sanction overexploiters; by developing institutions which can punish free-riding, etc.). Also real-world examples of costly and non-costly punishments can be indicated. Dissuasive sanctions are applied in the EU for serious fisheries infringments through a point system since January 2012.[2] In addition, considering defectors as members of a coalition not complying to an agreed-upon strategy, examples of non-costly punishing are provided in the EU legislation, which can impose fines on an EU government for failing to comply with its obligations (breaches on landing immature fish, particularly hake, milk quota fines, etc.).

Several other papers in the literature have addressed the issue of cooperation within the 'great fish war' framework. The problem of coalition formation among N players has been fully studied in [27], where one coalition of agents plays against all other agents acting as single selfish players. Since agents are free to enter or exit the coalition, it is relevant to study if a given coalition is "sustainable", meaning that agents inside the coalition are not tempted to free-ride and withdraw from the coalition and outsiders have no interest in joining the coalition. As clearly pointed out in [10], this kind of stability concept is often based on the assumption that agents have Nash conjectures. Assuming Nash conjectures, [27] shows that only coalitions with two players can be sustained in the multi-agent fish war, i.e. no coordination or small partial coordination equilibria occur. Moreover, even a two size coalition requires stringent conditions on the biological and preference parameters to be sustainable as the number of agents increases. Partial coordination equilibria and larger steady state resource levels can be achieved when the coalition of cooperators acts as a 'dominant player', i.e. à la Von Stackelberg. Another interesting contribution to the issue of cooperation is provided in [10], where the assumption of Nash conjecture is replaced by that of rational conjectures (farsightedness), see also [18]. Here, agents acknowledge that when a single player withdraws from the coalition, a different coalition structure could emerge as a consequence of the other players' actions to improve gains. Under the farsightedness assumption, large coalitions are possible up to the full coordination equilibrium, which is in line with the fact that the number of countries joining RFMOs nowadays is significant. The paper [9] generalizes further these results by considering agents with different time preferences. In [33] a fish war model is analyzed where different devices are employed to maintain cooperation, such as cooperative incentive equilibrium with a center who punishes players deviating from the cooperative equilibrium and an imputation distribution procedure which is time-consistent. Within an evolutionary exploitation model of a natural resource, [36] show that a stable equilibrium with cooperators and non-cooperators exists provided that a reward mechanism to cooperators is present.

As indicated before, in this paper we analyze the different approach of introducing punishments to defectors to reach cooperation in the fish war model. Several effects induced by sanctions are discussed. First of all, the set of possible sustainable coalitions of the model is widened, with respect to the model without sanctions where the greatest sustainable coalition is of size two. Moreover, punishment and social norms can lead a same set of exploiters (a 'society') to evolve toward a structure with full coordination or with no/partial coordination depending on the initial conditions of the system; thus, given the agents' time preferences and the biological growth law of the resource, the evolution toward full coordination can be sustained by a punishment scheme provided that a critical mass of agents enforces cooperation at the beginning of the game. In addition, we show the existence of punishment threshold levels such that if sanctions are decreased below such points, then dramatic reductions in the resource level and in the agents' welfare occur as consequence of considerable increment in the fraction of agents who free-ride. Thus the occurrence of hysteresis effects (see [1]) is pointed out, in the sense that once agents start to free-ride because of reduced sanctions, restoring the punishment to the earlier level does not lead the set of exploiters back to full coordination, but a big increment in punishment is necessary to induce them to act cooperatively again. Therefore catastrophic regime shifts are likely to take place within a stylized model such as the fish war.

[1] Other interesting applications of evolutionary modeling have been proposed in resource modeling in [6], [7] and [30] [see [28] for a survey], and, more generally, in oligopoly theory to understand the emergence of behavioral heterogeneity (see [17,25]) or the effect of differential information (see [8,13,19]).

[2] see https://ec.europa.eu/fisheries/cfp/control/infringements_sanctions_en last accessed on 19/04/2017.

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