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Original Article

Exploitation of renewable resources with differentiated technologies: An evolutionary analysis

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Abstract

In this paper, we propose a dynamical model of technology adoption for the exploitation of a renewable natural resource. Each technology has a different efficiency and environmental impact. The process of technology adoption over time is modeled through an evolutionary game employed by profit maximizing exploiters. The loss in profits due to lower efficiency levels of environmentally-friendly technologies can be counterbalanced by the higher consumers' propensity to pay for greener goods. The dynamics of the resource take place in continuous time, whereas the technology choice can be revised either in continuous-time or in discrete-time. In the latter case, the model assumes the form of a hybrid system, whose dynamics is mainly explored numerically. We shows that: (1) overexploitation of the resource arises whenever the reduction in harvesting due to a lower efficiency of clean technology is more than compensated by a higher propensity to pay for greener goods; (2) the difference between the fixed costs of these technologies can be exogenously fixed to provide an incentive for adopting clean technology without affecting the long-run level of the resource; and (3) in some cases, discrete switching of the technology causes overshooting in the dynamics whereas in others it enhances the stability of the system.

Keywords: Resource dynamics; Stock externality; Evolutionary game theory; Hybrid systems

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1. Introduction

A main issue in the exploitation of common property resources is the so-called "stock externality": individual exploiters do not take into account the effects of their current catch on the resource and on its future abundance. The non-coincidence between individual optima and collective optima is commonly referred to as the "tragedy of the commons", after [21], and characterizes the exploitation of almost all shared natural resources, see also [13,28]. Moreover, enforcing control on the resource is a very difficult and often an ineffective task.

In this paper, we address a descriptive model for the exploitation of a common pool renewable resource, on which the regulator does not enforce any restraint. However, some exploiters can decide to employ a less efficient but more "environmentally-friendly" technology if the loss in efficiency is counterbalanced by a higher price that consumers

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might be willing to pay for the greener product.[1] The choice of the technology, which is an exogenous component of the model,[2] only depends on the agents' assessment on expected profits and not on ethical or environmental concerns, as agents are assumed to be selfish profit maximizers. Exploiters have to make two choices over time: which technology to adopt and, given that, the quantity to harvest. With respect to the problem of technology adoption, we model it through an evolutionary game in the spirit of [24,34], as is customary in natural resource exploitation models, see, among others, [32,36,1,8,9]. Thus, agents can switch from the selected technology to another that is available if they expect that the change can be profitable. Regarding the quantities to be harvested, we follow [32] and assume that agents choose their catches continuously in order to be in a Nash equilibrium at any given time.

We first address the case in which the choice of the technology can be revised continuously. This step constitutes a useful benchmark to understand the main qualitative properties of the model. Then we break down this assumption to conceive a scenario that is more similar to what could take place in a more realistic setting. In fact, changing technology immediately is not feasible in practical cases for different reasons, the most obvious of which is due to the interval of time required to conclude a single harvesting operation. Thus, it is natural to assume that only after a certain time interval may a change in the employed technology take place. In this circumstance the system can be modeled mathematically through a hybrid model, including continuous-time resource growth and impulsive changes of strategies. The latter takes place at discrete points in time according to an evolutionary endogenous switching mechanism. In recent years, hybrid dynamical systems have been widely employed for studying real-world problems in several branches of applied mathematics, such as engineering, biology and biomedical science (see e.g. [11,12,3,18–20]). In fishery models, hybrid systems have been recently proposed in [6,7].

The first goal of this paper is to gain an understanding of the influence of the length of the switching interval on the dynamics of the natural resource and profits. In some cases, continuous technology switching just speeds up the convergence to the same attractor of the hybrid system. In others, discrete switching and continuous switching exhibit different long-run behaviors. Interestingly, under some circumstances discrete switching may even introduce a stabilizing effect in the model because of more inertia in the system when switching decisions are based upon past profits. Another aim of the paper is to assess whether an unregulated use of the resource can be sustained in the long-run. Although this is true in some cases, we show some examples where every agent tends to use the less-efficient technology but the level of the resource in the long run is lower than the level obtained if every agent would have used the traditional technology. This occurs whenever the high price for the green product induces too many exploiters to over-harvest it. In these cases, the market itself is not able to mitigate the effects of the tragedy of the commons but additional regulatory policies must be introduced. For instance, a regulator could avoid poverty traps by providing an incentive for adopting a technology over the other. Analytic and numerical analysis show that the stability of equilibria is quite sensible to the difference in the fixed costs between the two available technologies but the level of harvesting is not affected by this difference. As a result, a regulator can employ the difference in fixed costs to steer the system towards the preferred long-run level of the resource.

The problem of adopting a less efficient but more environmentally-friendly technology is motivated by some real-world cases occurring in fisheries outside exclusive economic zones. In this respect, a well-known example regards the landing of yellowfin tuna and the marketing of "dolphin safe" labels.[3] Dolphins commonly swim together with tunas, but closer to the surface. Therefore fishing boats spot dolphins more easily than tuna. Consequently, although dolphins are a non-target species and have no commercial value, they have been largely captured as bycatch in tuna fisheries. Netting dolphins with tunas has severely endangered the population of dolphins. This issue motivated the introduction in the late 20th century of the "dolphin safe" labels in several countries such as the U.S., the U.K. or New Zealand.[4] The presence of bycatch-free labels created market segmentation with different prices for labeled and non-labeled tuna cans. The model proposed in this paper can be regarded as a stylized version of this problem, but with appropriate adjustments it can be easily adapted to describe other real-world cases.

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[1] Empirical evidence has shown that the introduction of an eco-label can indeed change market behavior, see [33] for the case study of the dolphin-safe labeling.

[2] For overviews about the existence and the importance of heterogeneity among economic agents with respect to technology adoption, product activities and evolutionary paradigms for the diffusion of technologies, we refer the reader to [14]. For an example of technological adoption processes in fisheries, see [15].

[3] See the 'Dolphin Protection Consumer Information Act' at http://dolphinsafe.gov/dolprot.pdf.

[4] For more details on this specific issue we refer to [33].

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