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Complementarity, impatience, and the resilience of natural-resource-dependent economies

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ABSTRACT

We study how society's preferences affect the resilience of economies that depend on more than one type of natural resource. In particular, we analyze whether the degree of complementarity of natural resources in consumer preferences may give rise to multiple steady states and path dependence even when resources are managed optimally. We find that, for a given social discount rate, society tends to be less willing to buffer exogenous shocks if resource good are complements in consumption than if they are substitutes. The stronger the complementarity between the various types of natural resources, the less resilient the economy is, and even more so the higher is the social discount rate.

1. Introduction

Resilience is typically viewed as a property of natural systems and is defined as the extent to which they can buffer exogenous shocks [1]. Natural systems, whether they are ecosystems, species populations or climate systems, tend to be resilient to small perturbations. But if shocks are large enough that a system crosses a threshold or tipping point, the system may flip to another state. Examples of natural systems characterized by limited resilience include populations with a minimum population size below which extinction is inevitable [2–4], ecological systems with complex interactions between the various components of the system such as shallow lakes and semi-arid rangelands [5,6], and the Earth's climate system, where events like melting of the Greenland ice sheet or of the permafrost in the Northern Hemisphere might cause the Earth's climate to change dramatically [7–9].

The extent to which a natural system is resilient against exogenous shocks is not just a function of the underlying ecological processes; it also crucially depends on the way in which the system is managed. For example, the stock of cod in the North–East Arctic collapsed in the late 1980s due to high harvesting pressure, combined with a sudden shortage of its main prey species, capelin [10]. Overexploited natural resource systems, including open-access resources, are generally less resilient to shocks than optimally managed systems. This does not mean, however, that optimally managed systems never collapse. Optimal policy making in an uncertain world requires comparing the benefits and costs of pre-shock precaution and post-shock system restoration—if restoration is physically possible at all. Hence, resilience is not just an intrinsic feature of natural resources; institutions, technology, and preferences are likely to play an important role, too [11].

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In this paper, we explore the impact of human preferences on the resilience of optimally managed economies that depend on more than one type of renewable natural resource. If a negative shock hits one (or more) of these resources, under what circumstances does society find it optimal to restore the resource stocks back to sizes close to their pre-shock states, and under what circumstances is it optimal to gradually deplete one (or more) stocks? We focus on two preference parameters. The first is the rate at which society discounts future utility. For a given amount of time needed for natural resources to return to their 'good' state in the wake of a negative shock, system restoration is less likely to be optimal the higher the social discount rate—even if this leads to the demise of one or more resources. The second preference parameter is the extent to which the various types of natural resources are substitutes or complements in consumer preferences. We find that society's willingness to protect natural resources from collapse is larger the better substitutes in consumption the natural resources are. The reason is that if restoring a resource requires a moratorium on its exploitation, it is less costly to do so if there are good substitutes available so that instantaneous consumer welfare does not fall by much. While we pay most attention to the impact of the discount rate and the degree of complementarity in resource consumption on the resilience of the resource-dependent economy, we analyze the impact of other factors too, including the natural rate of resource regeneration and the opportunity costs of harvesting.

Over the past decade, many studies have tried to provide explanations for the collapse of historic societies as diverse as those of Easter Island, the Anasazi, and the Maya [12]. Better insights into the fate of previous civilizations may help the current one to better cope with today's major environmental crises such as climate change or biodiversity loss [13,14]. For example, Taylor [14] and Brander and Taylor [15] develop models to explain the disappearance of the civilization on Easter Island, suggesting that its demise may have been due to a nonlinear interaction between population growth and the dynamics of natural resources, especially forest resources, resulting in feast-and-famine cycles. While myopia and the lack of individual property rights are most likely causes of the collapse of the Easter Island civilization, our paper suggests that depletion of the forest resource might also have happened under optimal, forward-looking management. To feed the population, fish need to be caught, and hence trees need to be logged to produce boats. Timber consumption and catching fish are thus complements, and the instantaneous costs of reduced fishing activity to restore forest stocks may have been too large compared to the long-run benefits of recovered timber resources.

Modern society is admittedly much more complex than that of Easter Island, and our model is a stark abstraction from these complexities. However, our analysis still provides important insights for the policy challenges we face today. Similar to fish and timber resources being complements in the Easter Island case, many natural resources are ultimately complements in either production or consumption in modern society too, and this is especially true for the (provisioning) ecosystem services listed in the Millennium Ecosystem Assessment [16] such as fresh water (for drinking or irrigation), fertile soils, natural fibers (cotton, silk), genetic resources, and biogene pharmaceuticals. Life on earth would be very different if any of those resources were unavailable or exhausted. Acknowledging this fact, some researchers have advocated regionalization (as opposed to globalization) to better protect these natural resources [17,18]. The argument is that the clearer it is how dependent society is on the availability of these essential resources, the less intensive it will utilize them to better buffer these resources against negative shocks. Our model challenges this view. Dependence on local natural resources may make the economy less resilient against negative shocks.

The ecological-economic system that we consider exhibits multiple steady states even though the resource stocks, by themselves, are inherently resilient, and production technologies are convex. When all harvesting ceases, the stocks always grow back to their maximum size. The system's limited resilience is thus not caused by non-linear dynamics or positive feedback loops in the natural system, as is the case in shallow lake models or minimum viable population analyses [2–4]. Instead, it is the result of human preferences. Whether or not the resource-dependent economy is resilient against negative shocks is determined by society's willingness to restore the resource stocks to their 'good' states. Our findings can thus be seen as a major shift in the interpretation and analysis of resilience, from viewing (limited) resilience as determined by objective properties of the ecological-economic system to acknowledging that it depends on preferences as well.

The paper is organized as follows. In Section 2, we present a stylized model of an economy that depends on the use of two types of renewable natural resources, which are hit by a one-time shock of unknown size at an unknown time in the future. Because we assume that the shock only hits once, we can solve the model backwards. In Section 3, we determine optimal management after the shock has taken place and analyze whether and under what circumstances the model gives rise to multiple steady states. In particular, we study how the number of optimal steady states and their stability properties depend on the degree of complementarity of the two resources in consumption and on the social discount rate, providing both analytical results and numerical examples. In Section 4, we determine the consequences for optimal resource management in the pre-shock period, taking into account the possibility of the shock. We conclude by discussing the implications of our model for the management of global natural resources in Section 5.

2. Model of a natural-resource-dependent economy

Consider a representative agent who derives utility from the consumption of a manufactured good, $y(t)$, and two different natural resource goods, $h_1(t)$ and $h_2(t)$. The agent's instantaneous utility function is specified as

$$u(y(t), h_1(t), h_2(t)) = y(t) + \gamma \ln(v(t)), \tag{1a}$$