Ecological Economics 70 (2011) 1121–1128

Contents lists available at ScienceDirect

Ecological Economics

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

Analysis

The relationship between resilience and sustainability of ecological-economic systems

Sandra Derissen [a,*], Martin F. Quaas [a], Stefan Baumgärtner [b]

[a] Department of Economics, University of Kiel, Germany
[b] Department of Sustainability Sciences and Department of Economics, Leuphana University of Lüneburg, Germany

ARTICLE INFO

Article history:
Received 7 October 2009
Received in revised form 16 December 2010
Accepted 17 January 2011
Available online 26 February 2011

JEL Classification:
Q20
Q56
Q57

Keywords:
Ecosystem resilience
Dynamics
Management of ecological-economic systems
Sustainability

ABSTRACT

Resilience as a descriptive concept gives insight into the dynamic properties of an ecological-economic system. Sustainability as a normative concept captures basic ideas of intergenerational justice when human well-being depends on natural capital and services. Thus, resilience and sustainability are independent concepts. In this paper, we discuss the relationship between resilience and sustainability of ecological-economic systems. We use a simple dynamic model where two natural capital stocks provide ecosystem services that are complements for human well-being, to illustrate different possible cases of the relationship between resilience and sustainability, and to identify the conditions under which each of those will hold: a) resilience of the system is necessary, but not sufficient, for sustainability; b) resilience of the system is sufficient, but not necessary, for sustainability; c) resilience of the system is neither necessary nor sufficient for sustainability; and d) resilience is both necessary and sufficient for sustainability. We conclude that more criteria than just resilience have to be taken into account when designing policies for the sustainable development of ecological-economic systems, and, vice versa, the property of resilience should not be confused with the positive normative connotations of sustainability.

1. Introduction

Speaking about resilience and sustainability is speaking about two highly abstract and multi-farious concepts, each of which has a great variety of interpretations and definitions. Here we adopt what seems to be the most general and at the same time most widely accepted definitions of resilience and sustainability.[1] We understand sustainable development as the Brundtland Commission defines it as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). In this definition, sustainability is a normative concept capturing basic ideas of intra- and intergenerational justice.[2] Concerning obligations towards future generations, the primary question of sustainability then is to what extent do natural capital stocks have to be maintained to enable future generations to meet their needs.[3]

In contrast, resilience is a descriptive concept. In a most common definition that goes back to Holling (1973), resilience is thought of as "[…] the magnitude of disturbance that can be absorbed before the system changes its structure by changing the variables and processes that control behavior" (Holling and Gunderson, 2002: 4). The underlying idea is that a system may flip from one domain of attraction into another one as a result of exogenous disturbance. If the system will not flip due to exogenous disturbance, the system in its initial state is called resilient. Although Holling-resilience can be quantitatively measured (Holling, 1973), we focus on the qualitative classification, where a system in a given state is either resilient, or it is not.[4]

In the literature, many connections have been drawn between resilience and sustainability (e.g. Folke et al., 2004; Walker and Salt, 2006; Mäler, 2008). In some contributions, resilience is seen as a necessary precondition for sustainability. For example, Lebel et al. (2006: 2) point out that "[s]trengthening the capacity of societies to manage resilience is critical to effectively pursuing sustainable

* Corresponding author at: Department of Economics, University of Kiel, Wilhelm-Seelig-Platz, D-24118 Kiel, Germany. Tel.: +49 431 880 5633.
E-mail address: derissen@economics.uni-kiel.de (S. Derissen).

[1] Evidently, as definitions are not universal and are appropriate for a certain objective only (Jax, 2002), the relationship between resilience and sustainability depends on the particular definitions of these two terms.

[2] We do not consider the issue of intragenerational justice in this paper, but focus on an operational notion of sustainability that captures intergenerational justice.

[3] The term "natural capital" was established to distinguish services and functions of ecosystems from other capital stocks (Pearce, 1988).

[4] An alternative definition of resilience is due to Pimm (1991), who defines resilience as the rate at which a system returns to equilibrium following a disturbance. Resilience, according to Pimm's definition, is not defined for unstable systems. Nevertheless, it is a useful concept for ecological-economic analyses. Martin (2004), for example, suggests a quantitative measure of resilience *sensu* Pimm, namely the costs of the restoration of the system after a disturbance where costs are defined as the "minimal time of crisis", i.e. the minimal time the system is violating pre-specified state-restrictions and, thus, is outside the viability kernel Béné et al. (2001).

0921-8009/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.ecolecon.2011.01.003

development". Similarly, Arrow et al. (1995: 93) conclude that "economic activities are sustainable only if the life-support ecosystems upon which they depend are resilient", and Perrings (2006: 418) states that "[a] development strategy is not sustainable if it is not resilient".

Some authors explicitly define or implicitly understand the notions of resilience and sustainability such that they are essentially equivalent: "A system may be said to be Holling-sustainable, if and only if it is Holling-resilient" (Common and Perrings, 1992: 28), or similarly: "A resilient socio-ecological system is synonymous with a region that is ecologically, economically, and socially sustainable" (Holling and Walker, 2003: 1). Levin et al. (1998) claim in general that "[r]esilience is the preferred way to think about sustainability in social as well as natural systems", thus also suggesting an equivalence of resilience and sustainability.

In contrast to this view, it has been noted that "[r]esilience, per se, is not necessarily a good thing. Undesirable system configurations (e.g. Stalin's regime, collapsed fish stocks) can be very resilient, and they can have high adaptive capacity in the sense of re-configuring to retain the same controls on function" (Holling and Walker, 2003: 1). In other words, resilience is not sufficient for sustainability, and it can therefore not be taken as an objective of its own.

While systems with multiple stable states are widely discussed, a systematic analysis of the relationship between the concepts of resilience and sustainability in a system with multiple stable states has not yet been conducted. To illustrate this research gap, the statements quoted above do not take into account the following possibilities: if some particular management does not conserve a system's resilience, such that under exogenous disturbance the system may flip from an undesirable state into a desirable one, or from a desirable state into another desirable state, the system management might still achieve sustainable development of the system, even though it is not resilient. As a consequence, one may conclude that resilience is neither desirable in itself nor is it in general a necessary or sufficient condition for sustainable development.

In general, four relationships between resilience and sustainability are logically possible, and any of those may hold in a given system: a) resilience of the system is necessary, but not sufficient, for sustainability; b) resilience of the system is sufficient, but not necessary, for sustainability; c) resilience of the system is neither necessary nor sufficient for sustainability; and d) resilience of the system is both necessary and sufficient for sustainability. In order to clarify and illustrate the different possibilities, and to identify the conditions under which each of those will hold, we use a simple dynamic ecological-economic model where two natural capital stocks provide ecosystem services that are complementary in the satisfaction of human needs.

This model is not meant to represent a real ecological-economic system, or to give a fully general representation of ecological-economic systems. Rather, it is meant to illustrate the complexity of relationships between resilience and sustainability even in a simple dynamic model. In contrast to other models used to study resilience of ecological-economic systems, such as the shallow lake model (e.g. Scheffer, 1997; Mäler et al., 2003) or rangeland models (e.g. Perrings and Stern, 2000; Anderies et al., 2002; Janssen et al., 2004), it features more than two domains of attraction and the possibility of more than one desirable state. In traditional models of bistable systems only two relationships of resilience and sustainability are possible: (i) the system is resilient in a desired state, such that the system's resilience has to be maintained for sustainability; and (ii) the system is resilient in its current state which is, however, not a desired one, such that resilience prevents sustainability. A situation in which the system is not resilient in a desired state but nevertheless on a path of sustainability cannot – by construction of these traditional models – possibly occur. Our dynamic model, as simple as it is, overcomes this shortcoming and may therefore add another valuable dimension to the model-based study of resilience and sustainability.

The outline of the paper is as follows. In the following section, we present the model (Section 2.1), analyze its basic dynamics (Section 2.2), introduce formal definitions of resilience and sustainability (Section 2.3), and discuss the possible relationships between resilience and sustainability (Section 2.4). In Section 3, we discuss our findings and draw conclusions concerning the sustainable management of ecological-economic systems.

2. Resilience and Sustainability in a Simple Dynamic Model of an Ecological-Economic System

2.1. Model

The model describes the use of two natural capital stocks – say, fish and wood – and features multiple equilibria with different domains of attraction. The deterministic dynamics of the two stocks of fish (x) and wood (w) are described by the following differential equations, referring to the growth of the stocks of fish $\dot{x}$ and wood $\dot{w}$:

$$\dot{x} = f(x) - C = r_x(x - v_x)\left(1 - \frac{x}{k_x}\right) - C \tag{1}$$

$$\dot{w} = g(w) - H = r_w(w - v_w)\left(1 - \frac{w}{k_w}\right) - H \tag{2}$$

where r_x and r_w denote the intrinsic growth rates, v_x and v_w the minimum viable populations, and k_x and k_w the carrying capacities of the stocks of fish and wood, respectively. Let $x_0 = x(0)$ and $w_0 = w(0)$ denote the initial state of the system. The differential Eqs. (1) and (2) do not contain ecological interactions, although, of course, in reality ecological interactions may exist. As a consequence, interactions of the stock dynamics are only due to the interrelated harvests of fish and timber. We use C and H to denote the aggregate amounts of harvested fish and timber; $f(\cdot)$ and $g(\cdot)$ describe the intrinsic growth of the two stocks. We assume logistic growth functions for simplicity and because using a well-known functional form of the growth functions helps to clarify the argument.

Suppose that myopic profit-maximizing firms harvest the resources under open-access to ecosystems and sell these ecosystem services as market products to consumers at prices p_x and p_w for fish and timber, respectively. Assuming Schaefer production functions, the amounts of fish and timber harvested from the respective stocks by individual firms are described by

$$C = q_x x e_x \quad \text{and} \tag{3}$$

$$H = q_w w e_w, \tag{4}$$

where e_x and e_w denote the aggregate effort, measured in units of labor, spent by fish-harvesting-firms and timber-harvesting-firms, respectively, and q_x and q_w denote the productivity of harvesting fish and timber, respectively. Firms can enter and exit the two industries at no costs.

Society consists of n identical utility-maximizing individuals who derive utility from the consumption of manufactured goods (y) as well as from the consumption of the two ecosystem services, fish (c) and timber (h). We assume that all three goods are essential for individual well-being. The utility function of a representative household is

$$u(y, c, h) = y^{1-\alpha}\left[c^{\frac{\sigma-1}{\sigma}} + h^{\frac{\sigma-1}{\sigma}}\right]^{\alpha\frac{\sigma}{\sigma-1}}, \tag{5}$$

where $\alpha \in (0,1)$ is the household's elasticity of marginal utility for consumption of ecosystem services, and σ is the elasticity of substitution between the consumption of fish and timber. Both