Ecological Economics 93 (2013) 374–384

Contents lists available at SciVerse ScienceDirect

Ecological Economics

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

Analysis

Ecological threshold and ecological economic threshold: Implications from an ecological economic model with adaptation

Takuro Uehara *

College of Policy Science, Ritsumeikan University, 56-1 Tojiin Kita-machi, Kita-ku, 603-8577 Kyoto, Japan

ARTICLE INFO

Article history:
Received 2 August 2012
Received in revised form 12 June 2013
Accepted 18 June 2013
Available online 10 July 2013

Keywords:
Ecological economic threshold
Ecological economic system
System boundary
Non-convexity
Adaptation
Resilience

ABSTRACT

This paper investigates ecological threshold and ecological economic threshold by developing an ecological economic model—an extension of a population–resource dynamics model developed by Brander and Taylor (1998). The model reflects three critical issues regarding an ecological economic system: system boundary, non-convexity, and adaptation. The paper elucidates six main findings: ecological economic threshold may come before ecological threshold; the ecological economic threshold may exhibit a highly context-dependent and dynamic nature, which suggests the precautionary principle; markets do not respond sufficiently to maintain resiliency under an external shock as prices do not reflect thresholds; the system can be restored by intervention, even after crossing the ecological economic threshold; various transitional paths are possible in restoring the system; and adaptation affects resilience to a somewhat significant effect which suggests the importance of better information and education. Because of the complexity of the model, I adopt a system dynamics approach for the development and analysis of the model.

1. Introduction

In this study, I develop a model of an ecological economic system[1] to enhance the understanding of thresholds and resilience.

According to Limburg et al (2002), ecological economic systems are undeniably complex; therefore, it is difficult to predict the behavior of these systems and to implement optimal management (Folke et al., 2002). This paper focuses on thresholds, a key concept for the resilience of ecological economic systems. Resilience is the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks (Walker et al., 2004). Despite their critical importance, we possess a limited understanding of resilience and thresholds related to ecological economic systems (Carpenter et al., 2005).

In this study, I define two types of threshold. First is the *ecological threshold* (*ET*), a threshold for an ecological system that is independent of economic systems; *ET* is also called the minimum viable population or critical depensation (Daly and Farley, 2010). Second is the *ecological economic threshold* (*EET*), a threshold endogenously determined through the interactions between ecological and economic systems; an *EET* is the level of a resource stock below which the natural stock becomes extinct as a result of the interactions. Existing literature does not include many ecological economic models that focus on *EET*. Kahn and O'Neill (1999) discuss indirect irreversibility, a concept similar to *EET*, by developing a model for managing two competing fish species: a food fish and an inedible fish; note that the fish catch (an economic system) is exogenously given. Fenichel and Horan (2007) and Horan et al. (2008) have developed models that investigate the endogeneity of thresholds determined by the interaction of resource management activities and natural resources (wildlife and livestock). Their models adopt optimal control theory, while my model adopts adaptations. In this paper, I build a dynamic model to obtain a better understanding of *EET*, specifically, by explaining how *EET* depends on context, how *ET* and *EET* relate, how markets respond to disturbances in ecological systems, and what measures could be used to maintain or increase the resilience of an ecological economic system.[2]

The model reflects three key issues essential for studying ecological economic systems in general: 1) system boundary, 2) non-convexity of ecosystems, and 3) adaptation. The three key issues are particularly important for developing economies, as I discuss in Section 2.

The model described in this study is an extension of a population–resource dynamics model developed by Brander and Taylor (1998) (hereafter, the BT model). To reflect the three key issues, I incorporate adaptive mechanisms for price expectations, as well as a variant of

* Tel.: +81 75 466 3816.
E-mail address: ueharatakuro@gmail.com.

[1] In resilience literature (e.g., Carpenter et al., 2005; Folke et al., 2002), a social–ecological system (SES) may be more commonly used; I use an ecological economic system for a more narrow focus on economic systems rather than a broader one on social systems.

[2] In addition to the use of a model, Carpenter et al. (2005) suggest three other approaches to investigate resilience: stakeholder assessments, historical profiling, and case study comparison.

0921-8009/$ – see front matter
http://dx.doi.org/10.1016/j.ecolecon.2013.06.014

the logistic function proposed by Taylor (2009), for the growth of a natural resource that reflects a threshold in the BT model.

Because of the complexity of the model, I adopt a system dynamics approach, which uses computer simulations to analyze complex systems (e.g., Sterman, 2000). As discussed by Nagase and Uehara (2011), there are two purposes for using a model: to replicate the dynamics of a particular economy, and to analyze issues of interest using a model as a tool; this study uses the BT model for the latter. In this study, I use the BT model as a tool to understand the thresholds and resilience of an ecological economic system. The eventual target of the model is its application to today's developing economies. However, my main focus is not the model's fitness to historical data of a certain economy; this is because developing economies are currently facing unprecedented phenomena. Leach et al. (2010) describe these current phenomena as “complex and dynamic”. A UN report (UNESCAP, 2010) terms the unprecedented phenomenon as “a new economy” in which natural resource constraints are largely defining the future outlook, and for which we need a new economic paradigm.[3]

2. Background

2.1. The Three Key Issues

Economic models have been developed to study sustained economic growth and most are extensions of either the neoclassical growth theory (e.g., Dasgupta and Heal, 1974; Solow, 1974a; Stiglitz, 1974) or endogenous growth theory (e.g., Bretschger, 2005; Pittel, 2002). These models share a preference for simplification. Such simplifications are sensible provided, as Robert Solow (1956) puts it, that “the final results are not very sensitive” (p. 65) to the simplifications. However, because of the complexity of an ecological economic system, a model of the system should contain an appropriate level of complexity with appropriate simplifications.

2.1.1. System Boundary

Treating ecological systems and economic systems separately is “a poor choice of boundary” (Costanza et al., 1993). Specifically, population, economic growth, and natural resources should all be treated as endogenous variables within the boundary of a system (Dasgupta, 2008). When a variable is treated as exogenous, the model loses the feedback loops among the variables. While the original BT and its descendants treat them as endogenous variables, a consideration of these feedback loops has not been the primary focus of modern growth economists. While new growth theory tends to assume a fixed (or zero) population growth, unified growth theory tends not to incorporate natural resources in these models.

2.1.2. Non-convexity of Ecosystems[4]

The reflection of “ecosystem non-convexity” (Dasgupta and Mäler, 2003) in a model is key to more fully addressing the complex dynamics of renewable resources. The non-convexity of ecosystems often indicates the existence of multiple equilibria, thresholds, and positive feedback loops (Dasgupta and Mäler, 2003). To incorporate non-convex ecosystems into an economic model is particularly important for two reasons (Dasgupta and Mäler, 2003). First, developing economies, particularly poor economies, often have to operate very close to the threshold. Once an ecological economic system crosses the threshold for overusing natural resources, positive feedback drives the system to a state of equilibrium (often to a bad state). Second, poor economies often depend heavily on natural resources and do not have the substitutes that are available in rich countries. There is also some empirical evidence that indicates that some economies have already crossed their thresholds (e.g., Rockstrom et al., 2009).

2.1.3. Adaptation

Most economic models employ the presumption of instantaneously achieved equilibrium states, neglecting adaptation or learning processes that allow a system to remain in an out-of-equilibrium state for extended periods of time. When the state of a system changes rapidly or there is a sudden external shock, agents may have imperfect information and cannot make rational decisions assumed in instantaneous equilibrium models. Under such circumstances, incorporating adaptation processes into a model could contribute to a better depiction of the dynamics of the system. An economy dependent significantly on non-convex ecosystems may possess such an attribute. In the context of sustainability and resilience, existing studies have often indicated the importance of adaptation and out-of-equilibrium behavior (e.g., Folke et al., 2002; Leach et al., 2010; Levin et al., 1998).[5] However, modeling out-of-equilibrium conditions is not well developed. While modeling adaptation or learning is a prevailing subject in modern macroeconomics (e.g., Arifovic and Maschek, 2006; Evans and Honkapohja, 2011), there exist only a few applications to natural resource issues (e.g., Forini et al., 2003; Hommes and Rosser, 2001).[6] Adaptation is likely to be an important theme in developing economies where there is limited available information.

2.2. Resilience

The resilience of an ecological economic system is key to sustainability because of the importance of the non-convexity of the system in developing economies, as discussed in the previous section.[7,8] Resilience emphasizes non-linear dynamics, thresholds, uncertainty, and surprise (Folke, 2006).

Resilience is a concept rooted in ecology (e.g., Holling, 1973; Pimm, 1992) and has also been applied recently to ecological economic systems.[9] There are three types of resilience concepts: engineering resilience, ecological/ecosystem resilience and social resilience, and social–ecological resilience (Folke, 2006). Engineering resilience is the time needed to return to the original state of equilibrium (e.g., Pimm, 1992). It focuses on the vicinity of equilibrium but not on the possibility of crossing a threshold. Ecological/ecosystem resilience and social resilience are the abilities of a system to absorb disturbances and maintain

[3] One good example of developing economies with ecological economic systems is the Caribbean island of Hispaniola that includes Haiti and the Dominican Republic; both of them were rich in forests, but were divided into two different states. While 28% of the Dominican Republic is still forested, only 1% of Haiti is forested (Diamond, 2005). The deforestation has led to various consequences including soil erosion, loss of watershed protection, and consequently loss of potential hydroelectric power. Haiti is one of the poorest countries, and its dire situation is a reflection of their heavy dependency on forests (e.g., forest-derived charcoal), poor national reserve systems, and rapid agricultural and population growth at the expense of its environmental capital of forests and soils.

[4] I adopt the definition of convexity given by Dasgupta and Mäler (2003), which states that a set of commodity vectors is said to be *convex* if every convex combination of every pair of commodity vectors in the set is in the set. Further, a set is *non-convex* if it is not convex.

[5] Interestingly, Solow (1974b) also indicated this importance, although he did not provide a formal model.

[6] Here, adaptation is different from “adaptive management,” which is recently being often used in sustainability issues. It implies a so-called exponential smoothing or adaptive expectations (Sterman, 2000) in which a belief (e.g., the expected price of a good) gradually adjusts to the actual value of the variable (e.g., the actual price of the good in a market).

[7] While resilience is a key concept to sustainability, their relationship varies. For example, Mäler (2008) and Arrow et al. (1995) consider resilience as a necessary condition for sustainability. Holling and Walker (2003) consider them synonymous for a socio-ecological system. Derissen et al. (2011) show that the nature of their relationship (i.e., necessary and/or sufficient) depends on the situation.

[8] For a good summary of economic interpretations of sustainability, see Pezzey and Toman (2005).

[9] For example, Environment and Development Economics (1998 (3), p. 221–262) published a policy forum on the resilience of ecological economic systems.