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Analysis

The economic insurance value of ecosystem resilience

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ABSTRACT

Ecosystem resilience, i.e. an ecosystem's ability to maintain its basic functions and controls under disturbances, is often interpreted as insurance: by decreasing the probability of future drops in the provision of ecosystem services, resilience insures risk-averse ecosystem users against potential welfare losses. Using a general and stringent definition of "insurance" and a simple ecological–economic model, we derive the (marginal) economic insurance value of ecosystem resilience and study how it depends on ecosystem properties, economic context, and the ecosystem user's risk preferences. We show that (i) the insurance value of resilience is negative (positive) for low (high) levels of resilience, (ii) it increases with the level of resilience, and (iii) it is one additive component of the (overall always positive) economic value of resilience.

1. Introduction

Ecosystems that are used and managed for the ecosystem services they provide may exhibit multiple stability domains ("basins of attraction") that differ in fundamental system structure and behavior. As a result of exogenous natural disturbances or human management, a system may flip from one stability domain into another one with different basic functions and controls (Holling, 1973; Levin et al., 1998; Scheffer et al., 2001). As a consequence, also the level, composition and quality of ecosystem services may abruptly and irreversibly change. Examples encompass a diverse set of ecosystem types that are highly relevant for economic use, such as boreal forests, semi-arid rangelands, wetlands, shallow lakes, coral reefs, and high-seas fisheries (Gunderson and Pritchard, 2002).

The term "resilience" has been used to denote an ecosystem's ability to maintain its basic functions and controls under disturbances (Carpenter et al., 2001; Holling, 1973). The economic relevance of ecosystem resilience is obvious, as a system flip may entail huge welfare losses.[1] For example, a combination of drought, fire and ill-adapted livestock grazing management in sub-Saharan Africa, central Asia and Australia have lead to severe degradation and desertification of semi-arid rangelands, which provide subsistence livelihood for more than 1 billion people worldwide. Once degraded, these grassland ecosystems cannot be used as pasture anymore (Perrings and Stern, 2000; Perrings and Walker, 1995). In Africa alone, almost 75% of semi-arid regions are threatened by degradation and desertification ([UNO] United Nations Organisation, 2002). Worldwide, the income loss associated with desertification of agricultural land is estimated to some 42 billion US dollars per year ([UNCCD] Secretariat of the United Nations Convention to Combat Desertification, 2005).

An ecosystem's resilience in a given stability domain can be measured by the probability that exogenous perturbations make the system flip into another stability domain. Therefore, enhancing the resilience of a particular (desired) domain reduces the likelihood of a flip into another

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[1] Accordingly, some have included a reference to the provision of desired ecosystem services right into the definition of ecosystem resilience, e.g. as the capacity of an ecosystem "to maintain desired ecosystem services in the face of a fluctuating environment and human use" (Brand and Jax, 2007: 3, referring to Folke et al., 2002).

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(less desired) domain. It is for this reason that ecosystem resilience has been referred to as "insurance", e.g. in the following manner:

> "Resilience can be regarded as an insurance against flips of the system into different basins of stability."
>
> [Mäler (2008: 17)]

> "[R]esilience [...] provides us with a kind of insurance against reaching a non-desired state."
>
> [Mäler and Li (2010: 708) and Mäler et al. (2009: 48)]

> "The link between biodiversity, ecosystem resilience and insurance should now be transparent. [...] It follows that the value of biodiversity conservation lies in the value of that protection: the insurance it offers against catastrophic change."
>
> [Perrings (1995: 72)]

> "The resilience of the ecological system provides 'insurance' within which managers can affordably fail and learn while applying policies and practices."
>
> [Holling et al. (2002: 415)]

So far in the resilience literature, the term "insurance" is employed in a rather metaphoric manner — as a metaphor for "keeping an ecosystem in a desirable domain". It is used to convey the message that resilience is a desirable property of some ecosystem since it helps to prevent potential catastrophic and irreversible reductions in ecosystem service flows. While ecosystem resilience obviously and undoubtedly includes an insurance aspect, no explicit attempt has been made so far to use a clearly defined concept of "insurance" from the established literature on insurance and financial economics. As a result, it remains unclear what exactly constitutes the insurance value – understood in a rigorous economic sense – of ecosystem resilience, how it depends on ecosystem properties, economic context, and the ecosystem user's risk preferences, and how it relates to the all-encompassing economic value of ecosystem resilience.

In order to conceptually determine and to empirically capture the economic value of ecosystem resilience, Mäler and his co-authors use the shadow price of resilience as a measure of its economic value (Mäler, 2008; Mäler and Li, 2010; Mäler et al., 2007; Walker et al., 2010). They calculate the present discounted value of future improvements in expected welfare from ecosystem services, where these future improvements accrue from reduced risks of a system flip due to a unit increase in the initial level of resilience. While this approach establishes an adequate measure of the marginal economic value of resilience in an explicitly dynamic setting, it has two shortcomings in view of understanding the insurance function of resilience. First, in the explicit modeling it focuses on the dynamics of ecological–economic systems and pays less attention to the insurance aspect. In particular, none of the papers cited above analyzes how the economic value of resilience depends on the type or degree of ecosystem users' risk aversion. Second, the shadow price of resilience is the economic value of resilience which includes, but is larger than its insurance value. As resilience also has economic value beyond its insurance value, it remains to be clarified what fraction of the economic value of resilience is due to its insurance function, and how this insurance function relates to the other value-constituting functions to make the overall economic value of resilience.

In this paper, we aim to close these gaps and to provide some conceptual clarification. Any idea of "insurance" fundamentally refers to a combination of three elements: (i) the objective characteristics of risk in terms of different possible states of nature, (ii) the decision maker's subjective risk preferences over these states, and (iii) a mechanism that allows mitigation of (i) in view of (ii). We believe that the ongoing discussion of resilience as an insurance could be clarified and fruitfully advanced if reference to these three elements was made explicitly and rigorously, and we propose an analytical framework for that purpose. For clarity, we perform an atemporal analysis that focuses on the risk-and-insurance aspect, but neglects explicit dynamics of the ecological–economic system. Our analysis therefore complements the strand of literature cited above that focuses explicitly on dynamics but is less explicit on the risk-and-insurance aspect.

We adopt a clear and generally accepted definition of "insurance" from the risk and finance literature, according to which *insurance* is an action or institution that mitigates the influence of uncertainty on a person's well-being (McCall, 1987). Based on this definition, we conceptualize resilience's (marginal) economic insurance value[2] as the value of one very specific function of resilience: to reduce an ecosystem user's income risk from using ecosystem services under uncertainty. We also analyze how exactly the insurance value of ecosystem resilience depends on ecosystem properties, economic context, and on the ecosystem user's risk preferences.

Our analysis yields several interesting results. First, the insurance value of resilience is negative for low levels of resilience and positive for high levels of resilience. That is, ecosystem resilience actually functions as an insurance only at sufficiently high levels of resilience; it does *not* function as an insurance at low levels of resilience. Second, the (marginal) insurance value of resilience increases with the level of resilience — for some ecosystem types even monotonically. This is in contrast to normal economic goods, the (marginal) value of which *decreases* with their quantity. Third, the insurance value of resilience is one additive component of its economic value. That is, the economic value of resilience is larger than just its insurance value. While the latter may be negative, the economic value of resilience is always positive.

The paper is organized as follows. In Section 2, we present a stylized model of an ecological–economic system that describes how different degrees of ecosystem resilience are related to different system outcomes, and how this contributes to an ecosystem user's well-being under uncertainty. In Section 3, we clarify what exactly we mean by "insurance value". In Section 4, we present our results about the insurance value and the economic value of ecosystem resilience, with all proofs and formal derivations contained in Appendix A. In Section 5, we discuss these findings and draw conclusions.

2. Model

Consider an ecosystem that potentially exhibits two different stability domains with respective levels of ecosystem services-production. One domain is characterized by a high level of ecosystem service provision and corresponding net income $y_H > 0$, the other domain is characterized by a low level of ecosystem service provision and corresponding net income $y_L > 0$, with $y_L < y_H$ so that

$$\Delta y := y_H - y_L > 0 \tag{1}$$

is the potential income loss when the system flips from the high-production into the low-production stability domain.

Initially, the ecosystem is in the high-production stability domain. In this domain, an exogenous stochastic disturbance threatens to trigger a flip into the low-production stability domain. Such a flip may occur with probability p with $0 \le p \le 1$. Conversely, the ecosystem stays in the high-production domain with probability $1 - p$.

In line with Holling's (1973) notion of resilience as the maximum amount of disturbance a system can absorb in a given stability domain while still remaining in that stability domain, we define and measure

[2] As it should be clear by now that we are concerned with the *economic* insurance value of resilience here, as opposed to the so-called "*ecological* insurance hypothesis" of biodiversity (e.g. Gonzalez et al., 2009; Yachi and Loreau, 1999), we drop the adjective "economic" from here on.