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Research article

Economics, socio-ecological resilience and ecosystem services

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ABSTRACT

The economic process transforms raw materials and energy into economic products and waste. On a finite planet, continued economic growth threatens to surpass critical socio-ecological thresholds and undermine ecosystem services upon which humans and all other species depend. For most systems, whether such thresholds exist, where they lie and whether they are reversible cannot be known with certainty until they are crossed. We argue that our central economic challenge is to maintain the resilience of the current socio-ecological regime. We must reduce net impacts of economic activity to avoid critical ecological thresholds while ensuring economic necessities. Conventional economists pursue continuous growth as the central goal of economic activity, and assume that the price mechanism and technological breakthroughs ensure system resilience. Unfortunately, the price mechanism fails to address ecological thresholds because it ignores unowned ecosystem services, and fails to address economic thresholds because it ignores the needs of the poorest individuals, who live on the edge of them. Panarchy theory suggests that systems go through a cycle of growth, conservation, release and renewal. Managing a subsystem too long for growth or conservation—which many consider to be the goal of sustainability—actually threatens to collapse the higher-level system upon which that subsystem depends. Black Swan theory suggests we should seek to reduce the risk of catastrophic thresholds and promote the likelihood of technological breakthroughs. Economic degrowth, or planned release, is required to avoid catastrophic collapse. At the same time, publicly funded, open source information can help stimulate the technological breakthroughs economists count on to ensure resilience.

1. Introduction

The human economy is a physical system whose purpose, we argue, is to balance what is biophysically possible with what is socially, ethically, and morally desirable. It is of course impossible to create something from nothing, and with current technologies, the only source of raw materials available for economic production is our finite planetary system. Energy is required to transform the raw materials provided by our finite planet into economic products. Finite stocks of fossil fuels account for nearly 82% of the energy consumed by the global economy, and finite uranium an additional 4.8% (IEA, 2014). Energy is dissipated in the process of doing work, while the material content of energy stocks is transformed into waste then returned to the ecosystem. Furthermore, all economic products ultimately wear out, break down or fall apart, and also return to the ecosystem as waste. Humans decide how fast to transform raw materials and energy into economic products and waste. Even information, created by brainpower requires additional energy and materials to be stored, shared and processed in a meaningful way (Georgescu-Roegen, 1971).

Most of the raw materials we physically transform into economic products alternatively serve as the structural building blocks of global ecosystems. A particular configuration of these raw materials is capable of generating life-sustaining ecosystem services, such as climate regulation, waste absorption capacity, and water purification. Ecosystems generate services at a rate over time that is determined by the size and health of the ecosystem, and they are not transformed into the services they generate. For example, a forest can purify water, regulate climate, and reproduce, all at a given rate, and it remains a forest afterward. In contrast, all economic activity requires raw materials and generates waste, and thus degrades the ecosystems upon which human and all other life depends. Direct conversion of ecosystems into human-dominated

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systems such as agriculture or cities is also a major source of ecological degradation, as are invasive species introduced by humans, on purpose or by accident. Both economic production and ecosystem services are absolutely essential to human survival, but while the former converts natural capital and ecosystems into economic products, the latter depends upon the preservation of ecosystems and their functions (Farley and Costanza, 2010; Kumar, 2010; Millennium Ecosystem Assessment, 2005).

All economic production also requires information, which is the main input into technological innovation. For any given technology, a larger economy degrades ecosystem services more than a smaller economy, but improved technologies can sometimes maintain a given level of economic activity while doing less harm to the environment (Commoner, 1971). To date, however, technological advance has systematically increased the damage we do to our global ecosystems and the essential services they provide (Huesemann and Huesemann, 2011).

Our challenge is to manage for socio-ecological resilience in the face of natural and human induced change. Resilience is the capacity of a system to withstand and adapt to change to remain within the critical thresholds of its current regime (Holling, 1973). Thresholds are sudden large, nonlinear, changes in a property of a system as a consequence of smooth and continuous change in a variable which affects it (Muradian, 2001); thresholds are tipping points, and crossing one leads to “a sudden shift to a contrasting dynamical regime” (Scheffer et al., 2009, p. 53). The new regime may be stable, or exhibit cyclic or chaotic variation around an attractor (Ibid.). Socio-ecological systems confront different types of thresholds that interact in complex ways. Both ecological and socio-economic thresholds are important (Liu et al., 2007).

Critical ecological thresholds exist when a smooth change in a variable suddenly flips an ecosystem into an alternate state with profound social impacts (Ekins et al., 2003; Farley, 2008). There are at least five categories of economic activities that could lead society across critical ecological thresholds: over-harvesting of renewable resources, pollution, habitat loss, ecosystem management (see section 4), and facilitating the dispersion of invasive species (Muradian, 2001). We consider three types of socio-economic thresholds. One threshold exists when a smooth change in the quantity of an essential good or service has profound impacts on individual humans or the economy as a whole. An obvious example of a threshold at the individual level is food consumption, which below some critical level leads to death. At a larger scale, a reduction in calories per capita for a population can lead to social turmoil, violence, and political and economic collapse. This has contributed to the strife in Darfur and Burundi (Diamond, 2005), the Arab Spring (Johnstone and Mazo, 2011) and widespread rioting and political instability in Africa (Berazneva and Lee, 2013). Sudden reductions in fossil fuel consumption are known to trigger recessions, and it's quite likely that more dramatic reductions would trigger economic collapse (Hall and Day, 2009; Heinberg, 2003). A second type of economic threshold is triggered by runaway positive feedback loops in the financial sector, in the form of bubbles and busts. Credit in a capitalist economy lubricates economic activity. Financial crises stifle the flow of credit, causing the economic motor to seize up (Hudson, 2012; Keen, 2011; Minsky, 1977). A third type of economic threshold is a major technological breakthrough. Such breakthroughs could potentially shift the economy into a fundamentally new and favorable dynamic, or else prevent it from crossing a looming economic or ecological threshold. Most famously, scientists have long warned about human populations surpassing planetary carrying capacity, resulting in a crash of human populations (Catton, 1982; Ehrlich, 1968; Malthus, 1798). To date however technological breakthroughs ranging from plant breeding to nitrogen fixation through the Haber-Bosch process have held off this outcome, and most mainstream economists seem to take it for granted that new breakthroughs will continue to do so (Simpson et al., 2005). However, technological breakthroughs can also have unintended negative consequences, such as the impact of chlorofluorocarbons on the ozone layer or of DDT on birds. Speaking generally, ecologists and environmentalists worry that we are approaching critical ecological thresholds, while economists assume that technological breakthroughs allow us to avoid them.

Thresholds may be reversible, reversible with difficulty, or completely irreversible (Scheffer et al., 2001). A reversible threshold exists when a small change in a control variable leads to a large, non-linear change in a system, but restoring the control variable to its previous value also restores the system to its previous state. When systems exhibit hysteresis, restoring the control variable to its previous value may not restore the system to its previous state, though a much larger change in the control variable will do so. For example, aquatic macrophytes in shallow freshwater lakes capture phosphorus, prevent resuspension of phosphorus in sediments, provide refuge for planktivorous fish, and produce allelochemicals toxic to algae. Over a large range of phosphorus concentrations, a lake will remain clear. Beyond a certain threshold however, additional phosphorus can cause algae blooms that decrease water transparency and shade out macrophytes. Macrophyte die off flips the ecosystem into an alternate state characterized by algae blooms and turbid water. Restoring macrophytes and clear water may require reducing phosphorus stocks to far below the level required to flip the system initially. Over a potentially broad range of phosphorus emissions, a stable aquatic system could be characterized by macrophytes and transparent water or algae and turbid water (Scheffer et al., 1993). Some thresholds are simply irreversible. A recent study suggests that below a forest stock of 30% of its original cover, Brazil's Atlantic Forest will suffer a major collapse of biodiversity with catastrophic impacts on the ecosystem (Banks-Leite et al., 2014). Forest cover is currently at 11.4–16% (Ribeiro et al., 2009). Though species extinction is clearly irreversible, there is often a significant time lag between the decrease in forest stock and the species die-off it is likely to induce (Brooks and Balmford, 1996; Metzger, 2009). Aggressive ecological restoration, if undertaken quickly enough, may be sufficient to restore the stock above the 30% threshold and avert this collapse, though a lack of genetic diversity in diminished populations may already preclude recovery (Bottom et al., 2009).

Thresholds, both ecological and socioeconomic, can be exceptionally challenging to predict with any certainty, especially when a system is subject to exogenous shocks, the force of those shocks is affected by human activity, and humans are manipulating innumerable control variables simultaneously (Filatova et al., 2016). We are frequently ignorant about the existence and location of thresholds, about exogenous factors that might drive us across them, and about the nature of the new dynamical regime into which the system will flip: both possibilities and probabilities are entirely uncertain. Time lags further complicate matters: considerable time may elapse between a human activity and its ecological impacts (Liu et al., 2007). It is also impossible to predict truly innovative technologies ahead of time (Faber et al., 1998). We must develop management strategies that help us avoid critical thresholds in spite of our profound ignorance of how socio-ecological systems function.

The conflict between agriculture and ecosystem services offers a compelling case study of the challenges we currently face. Numerous studies suggest that agriculture is currently among the greatest threats to global ecosystems (Foley et al., 2011; Godfray, 2011; Millennium Ecosystem Assessment, 2005; Rockström et al., 2009). In economic terms, the marginal ecological costs of food production are immeasurably large, and marginal costs determine

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