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Natural vs anthropogenic risk reduction: Facing invasion risks involving multi-stable outcomes

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ABSTRACT

Natural resources important to economic systems are managed in the presence of event uncertainty, marking the transition from a more desirable ex ante state to a less desirable ex post state. The risks of this transition are endogenous and depend on state of the natural resource system and human behavior. In designing least cost policies of risk reduction, policy makers should consider the optimal mix of natural and human risk reduction. Decisions about the best risk reduction mix matter most for systems vulnerable to ex post multi-stability, in which the natural resource system has the potential to begin in one of multiple, locally optimal basins of attraction. This is because ex ante decisions can affect the initial conditions for the ex post system, thereby determining the ex post basin of attraction and the optimal ex post state. In this paper, we find that an ex ante system that is convex and uniquely stable without risk may become non-convex and multi-stable in the presence of endogenous risks and ex post multi-stability. This result arises because ex post non-convexities, and the uncertainties associated with the invasion and its magnitude, can create ex ante non-convexities that generate multiple optimality candidates.

1. Introduction

Invasive species pose significant risks to biodiversity around the globe, by out-competing or preying upon native species and spreading diseases to wild and domestic animals and plants (MEA, 2005).[1] It has been well-established that these risks are endogenous (e.g., Shogren, 2000; Finnoff et al., 2013): humans can invest in self-protection or mitigation (lowering the chance of a loss) to influence the likelihood of invasion (e.g., Horan et al., 2011), in self-insurance or adaptation (lowering the realized loss) to affect the economic and ecological impacts after an invasion occurs (Knowler and Barbier, 2005; Horan et al., 2011; Olson and Roy, 2002; Perrings, 2005; Fenichel et al., 2010), or in alternatives that provide both self-protection and self-insurance (lowering both the chance of a loss and the realized loss e.g. Leung et al., 2002; Ehrlich and Becker, 1972). Investments in natural risk reduction can involve enhancing the native system's ability to protect itself (through

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[1] Invasive species pose other risks not directly related to biodiversity. For instance, their spread of diseases can ultimately reach humans (Daszak et al., 2000). They also damage or degrade assets such as power plants, boats, piers, and reservoirs (Perrings et al., 2002).

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ecosystem services) or they can involve human interventions that directly protect the native system (biosecurity or trade measures to prevent invasion; removal or sterilization of invaders as a form of adaptation). Decisions about ex ante natural and anthropogenic risk reduction matter for systems vulnerable to ex post multi-stability, in which the invaded system can begin in one of multiple, locally optimal basins of attraction (e.g., the ecosystem remains productive or collapses).[2] This is because ex ante decisions affect the initial conditions for the invaded system, which then determine the ex post basin of attraction and the optimal ex post management (Dasgupta and Maler, 2003; Brock and Starrett, 2003).

In theory, robust ecosystems can often protect themselves against invasion risks (e.g., Crocker and Shogren, 2001). This ability has been called many things in the literature, such as resilience, persistence, and resistance (see Crocker, 1995). Here, we do not differentiate among the processes, and we define natural-insurance-cum-protection (NICP) as the ability of the natural ecosystem to protect itself, by both lowering the chance the ecosystem transitions to being invaded and lowering the expected losses that occur if the ecosystem becomes invaded.[3] Environmental managers may invest in NICP by manipulating human activities that disturb the ecosystem (harvests, grazing) and allow the ecosystem to naturally combat the invader at any time during the invasion process. This investment in NICP is an investment in the ability of the ecosystem to protect itself. One example is rangeland. Relatively undisturbed perennial-dominated rangelands can naturally resist invasions by annuals such as cheat grass, yet if the range is overused by humans (e.g., for grazing), the invading annuals can establish, spread and dominate.[4] Similarly, more pristine fish populations in freshwater lakes prevent or adapt to rusty crayfish invasions (Drury and Lodge, 2009). In these cases, investments involve foregoing more intensive human use of the resource.

Some ecosystems may be protected via direct anthropogenic interventions that prevent the introduction or establishment of the invaders without manipulating the natural system. Such interventions can be particularly effective when the native system in its current state represents a prime ecological niche for the invader. Interventions include self-protection (SP) efforts that lower the chance the invader can establish (e.g., through early response and eradication programs, and restrictions on activities that allow long-distance dispersal) or self-insurance (SI) efforts that promote adaptation and loss reduction if the invasion occurs (e.g., direct removals or sterilization of the invader).

Whether invasive species risks can be reduced by investments in natural or anthropogenic risk reduction, or both, depends on the state of the ecosystem. The timing of the investments in relation to the invasion event plays an important role. Traditionally the economics literature on invasive species has focused on either an ex ante or ex post approach, not both. But treating ex ante and ex post methods as separable implies ex post invasion risks are treated as exogenous ex ante, such that the potential economic and ecological consequences of an invasion are unaffected by ex ante decisions. Such a perspective is naïve (Keller, 2009). For example, aquatic invasions are often predictable events (Kolar and Lodge, 2001, 2002) influenced by human activities (Herborg et al., 2007; Perrings et al., 2002) such as trade flows that facilitate long distance dispersal of invasive species (Bossenbroek et al., 2001; Prasad et al., 2010). Moreover decisions about natural and anthropogenic risk reduction affect propagule pressure (e.g, Kolar and Lodge, 2001, 2002; Herborg et al., 2007; Perrings et al., 2002) as well as ecological interactions that determine the initial prevalence of the invader and whether the system can protect itself in the invaded state.[5] An endogenous risk approach (Ehrlich and Becker, 1972; Shogren and Crocker, 1991) takes these impacts into account so that managers need to consider both ex ante and ex post insurance decisions simultaneously when thinking about ex ante risk reduction.

Prior work on the ex ante management of systems facing invasion risks has neither addressed ex post multi-stability nor included the other key features of our model: the likelihood of an invasion and its magnitude being conditional on ex ante investments in natural insurance (i.e, the state of the non-invaded system).[6] Only Olson and Roy (2005) and Kim et al. (2006) model invasion likelihood and magnitude, but they only consider the effects of anthropogenic insurance. Ranjan et al. (2008) and Horan and Fenichel (2007) model the likelihood of invasion to depend on ex ante investments in natural insurance, but both analyses treat the invasion magnitude as exogenous.

Herein we capture this linkage between the ex post outcomes and the ex ante invasive species risk management problem given natural and anthropogenic risk reduction. The key result that emerges from our dynamic endogenous risk model is that an ex ante system that is convex and uniquely stable without invasion risk may become non-convex and multi-stable in the presence of endogenous invasion risks and ex post multi-stability. This result arises because the ability of the natural population in providing NICP, in terms of effects on ex post non-convexities, on managing invasion hazards in conjunction

[2] Our use of the term multi-stability refers to bioeconomic multi-stability, for which the optimal strategy depends on the initial conditions. Moreover, environmental perturbations or shocks within multi-stable systems can have non-monotonic effects by pushing the system into another basin of attraction, at which point the new initial conditions determine a newly optimal strategy (Crocker and Forster, 1981; Brown et al., 2011). Bioeconomic multi-stability generally stems from ecological or economic non-convexities.

[3] We are following Lee's (1998) definition—self-insurance-cum-protection (SICP), which implies investments in risk reduction affect both the likelihood of realizing a bad state of nature (self-protection) and the severity of the bad state (self-insurance).

[4] Over-used rangeland systems are particularly vulnerable to wildfire, which facilitates long-term changes in vegetation (Kobayashi et al., 2014; Perrings and Walker, 1997).

[5] The state of the non-invaded system may play an important role for invasion success (Case, 1990; Namba and Takahashi, 1993; Davis et al., 2000; Gilligan and van den Bosch, 2008; Drury and Lodge, 2009). Thriving native competitor or predator populations may prevent entry by potential invaders, whereas depleted native populations may create room for entry. The opposite is true for native prey species, which would include susceptible hosts for pathogens.

[6] Analyses of ex ante management in the invasive species context are less common than those of ex post management (e.g., Knowler and Barbier, 2005; Horan et al., 2011; Olson and Roy, 2002; Perrings, 2005; Fenichel et al., 2010; Fenichel and Horan, 2007).

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