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The optimal management of renewable resources under the risk of potential regime shift

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ABSTRACT

Complex dynamic systems can undergo changes in feedbacks between system components causing a rapid and persistent shift in system behavior ("regime shifts"), and potentially reduce welfare from declining provision of important ecosystem services. In this paper, we provide an analytical condition that determinfilefs whether the threat of a potential regime shift causes management to be more aggressive or more precautionary. In numerical simulations we find that aggressive management can occur for reasonable parameter values, which is counter prior results that the potential for harmful regime shift always leads to precautionary management.

1. Introduction

Complex systems, such as ecosystems or market economies, are characterized by interactions among multiple components (e.g., interactions among species or among multiple producers and consumers). Such complex systems can undergo changes in feedbacks between system components causing rapid and persistent shifts in system behavior. Examples of such regime shifts in ecological systems include shifts in coral reefs between coral-dominated and algal-dominated systems (Hughes et al., 2003), and in shallow lakes between oligotrophic and eutrophic conditions (Scheffer, 2004). In financial markets, where the expectations of other traders influence returns, shifts in investor sentiment lead to shifts between bull and bear markets (Scharfstein and Stein, 1990; Banerjee, 1992). Similarly, changes in expectations can lead to shifts between multiple potential equilibria in the entire economy (Azariadis, 1981; Cass and Shell, 1983). Regime shifts can also occur in social systems (e.g., consumer fads) and in political systems with changes in governments (literally regime shifts).

Regime shifts are characterized not only by relatively rapid shifts in system behavior but also by hysteresis. Once a regime shift has occurred it may be difficult or impossible to reverse the process and recover the original regime.

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In ecological systems, an increase in phosphorus inputs into shallow lakes can trigger a shift from oligotrophic to eutrophic conditions but it may take a far greater reduction in phosphorus inputs over an extended period of time to shift the lake back from eutrophic to oligotrophic conditions (Scheffer et al., 2001). Similarly, it may take prolonged good or bad economic news before a sufficient number of people shift expectations and generate a new equilibrium.

A regime shift may have either positive or negative effects on welfare. Of greatest concern for management are cases where a regime shift causes a decline in welfare. For example, a shift from coral-dominated to algal-dominated reef may reduce tourism and fish harvests, and a shift from a bull to a bear market can reduce wealth and potentially trigger a financial crisis. In this paper we analyze the case where a potential regime shift results in lower welfare.

Early research on regime shifts in resource economics focused on catastrophic collapse with zero utility post regime shift. Cropper (1976) analyzed potential system collapse triggered when the state variable exceeds an uncertain threshold. Reed (1987, 1988) used the Pontryagin maximum principle to transform Cropper's stochastic problem into a deterministic problem to find an analytical solution. With an exogenous probability of catastrophic collapse, optimal environmental management is more aggressive compared to the case with no threat of collapse. The potential to lose the resource in the future gives more incentive to use the resource in the current period rather than save for the future ("use it or lose it"). When the risk of collapse is endogenous, optimal management is contingent on the shape of the hazard function and the magnitude of disutility induced by the collapse and can be either aggressive or precautionary (Clarke and Reed, 1994).

More recent research has analyzed the effect of regime shift that reduces stock but not to zero, changes the growth dynamics of the stock, or shifts preferences. This literature has generally found that the threat of regime shift causes optimal management to be more precautionary. Tsur and Zemel (1998) studied a model of pollution in which "reversible events" lead to a reduction in post event welfare. They conclude that "reversible events always imply more conservation" (p. 968), which is equivalent in our terms to the threat of potential regime shift always leading to precautionary management. This result follows from the assumption that the hazard rate and the penalty inflicted by the regime shift are non-decreasing functions of the pollution level. Polasky et al. (2011) developed unambiguous results for a potential regime shift that reduces the natural growth of a renewable resource. With a linear benefit function, they found that a potential regime shift has no effect on the optimal management when the risk is exogenous, and induces precautionary management when the risk is endogenous. Precautionary management is also found by de Zeeuw and Zemel (2012) in the context of pollution control where a regime shift causes a structural change in preferences but does not affect the pollution decay rate. Numerical simulations by Gjerde et al. (1999) and Keller et al. (2004) in a potential regime shift for climate change also suggest precautionary management.

This paper builds from Polasky et al. (2011) in which a regime shift reduces the natural growth of a renewable resource. We use a general utility function rather than a linear function as in Polasky et al. (2011). We use dynamic programming methods to evaluate the changes in value of harvesting the resource caused by biophysical change in the resource growth function. This change in value is captured by a damage function based on the value functions before and after the regime shift. As found in the early literature (Clarke and Reed, 1994; Tsur and Zemel, 1998), the shape of the damage function is crucial to determine how a potential regime shift influences optimal management.

In contrast with the previous research in which the shape of the damage function is given by assumptions (Clarke and Reed, 1994; Tsur and Zemel, 1998), we use general forms of utility function, natural growth function and hazard function to study the shape of the damage function analytically. We show that damage function can be either increasing or decreasing in resource stock. Therefore, the threat of potential regime shift can make the management more aggressive (when the damage function increases in stock) or more precautionary (when the damage function decreases in stock) compared to management without threat of regime shift.

We find that a potential regime shift affects optimal management through multiple effects, which have not been fully captured by the existing literature. If lowering exploitation of the resource lowers the risk of a regime shift, the resource manager will take precautionary measures and lower exploitation compared to a case without potential regime shift. We call this effect the "risk reduction effect." The risk reduction effect occurs when the probability of a regime shift is endogenous. The risk reduction effect is the only effect that occurs when the utility function is linear (Polasky et al., 2011).

However, there are two additional effects from a potential regime shift with general forms of utility function and resource growth function. First, a regime shift will cause future resource availability to be lower, which lowers post-regime shift harvest and raises post-regime shift marginal utility of harvest. A forward looking manager will take this into account by reducing the initial exploitation rate thereby saving more stock to increase future harvests ("consumption smoothing effect").

Second, a regime shift reduces the resource growth rate and makes saving the resource a poorer investment because it will have a lower rate of return. A forward looking manager will take this effect into account by increasing the current exploitation rate and saving less stock for the future ("investment effect").

The investment effect causes optimal management to be more aggressive, but the risk reduction effect and the consumption smoothing effect cause optimal management to be more precautionary. We provide a condition under which the investment effect outweighs the other two effects, leading to more aggressive management in the face of a potential regime shift compared to the case without threat of potential regime shift. With aggressive management a potential regime shift will increase current resource exploitation and reduce resource stocks as compared to the case with no potential regime shift. This result is surprising in light of the previous literature in which the potential for a regime shift was thought to cause optimal management to be more precautionary.