Ecological Economics 107 (2014) 133–144

Contents lists available at ScienceDirect

Ecological Economics

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

Analysis

Optimal investment in ecological rehabilitation under climate change

Anke D. Leroux [a,*], Stuart M. Whitten [b]

[a] Department of Economics, Monash University, Melbourne, Australia
[b] CSIRO Ecosystem Sciences, Canberra, Australia

ARTICLE INFO

Article history:
Received 28 May 2013
Received in revised form 27 May 2014
Accepted 21 July 2014
Available online 29 August 2014

Keywords:
Bid ranking
Cost-efficiency
Real options
Conservation
Risk
Extinction debt
Box Gum Grassy Woodlands

ABSTRACT

Ecological rehabilitation is subject to a variety of risks affecting the likely return on investment. We propose an options approach to allocating scarce conservation funds that explicitly allows for the irreversibility of investment and risks to investment payoffs. The approach captures ecosystem dynamics from extinction debt, as well as ecological and climatic risks at the project scale. Climatic risks are introduced through three channels: the effects of climate change on species loss, future rehabilitation benefits and frequency of catastrophic events. Our results suggest that allocating voluntary rehabilitation contracts on the basis of real options criteria increases cost-efficiency and delivers greater value for money for the Government when compared with the conventional cost-effectiveness criterion as it is illustrated for the case of Box Gum Grassy Woodland rehabilitation in Australia.

1. Introduction

Large-scale land conversions have critically endangered many indigenous ecological communities. In an effort to reverse this trend, there has been substantial investment by individuals, governments and non-government organizations in ecological conservation and rehabilitation.[1] One example is the voluntary USDA Conservation Reserve Program, which provides $1.8 billion annually to contracted landholders to control soil erosion, improve the quality of water and enhance wildlife habitat on its 27 million enrolled hectares (USDA, 2013). Within this context the *cost-effective* allocation of scarce conservation budgets is a key concern. The use of competitive tender processes for the allocation of conservation contracts has been instrumental in reducing information asymmetries, thereby increasing the conservation value that is being derived from such policies (Latacz-Lohmann and Van der Hamsvoort, 1997; Claassen et al., 2008). Moreover, conservation projects have long investment horizons and are subject to a variety of risks that can prevent the achievement of conservation objectives. As rehabilitation investments are not recoverable, an important, but less well understood problem is how project-specific risks could be evaluated for the purpose of achieving a more *cost-efficient* allocation of conservation funds across competing projects.

We contribute to the literature on conservation investment by developing an alternative ranking method of competing conservation projects that makes the irreversibility of investment explicit and distinguishes between a variety of risks to successful rehabilitation. This is done in two steps. We start by specifying a real options model to evaluate the effects of ecosystem dynamics and ecological and climatic risks on individual rehabilitation projects. In particular, we model three distinct channels through which climate change affects rehabilitation success, project value and optimal investment threshold for an individual project. Secondly, we show how option pricing can be used to rank competing bids for conservation contracts in a cost-efficient way. It is shown that the outcome is superior to the conventional cost-effectiveness criterion as it facilitates the allocation of scarce rehabilitation funds according to sound investment rules that incorporate critical investment thresholds and value the option of delaying some types of rehabilitation into the future. We provide a carefully worked application of this approach to Box Gum Grassy Woodland rehabilitation in Australia.

The role of budget constraints in determining optimal conservation strategies has been recognized in many contexts, including the dynamic selection of reserve sites (Costello and Polasky, 2004) and the choice of optimal strategies to prevent species extinctions under climate change (Wintle et al., 2011). Joseph et al. (2009) are among a number of ecologists, who rightfully argue that the scarcity of conservation budgets calls for the prioritization of conservation actions according to biodiversity benefit, cost and probability of success.

The ranking of competitive bids for conservation contracts according to each bid's environmental benefit index and bid price follows the philosophy of cost-effectiveness prioritization. Environmental benefit

* Corresponding author.
E-mail address: anke.leroux@monash.edu (A.D. Leroux).

[1] We take conservation to be the protection of existing ecological assets and rehabilitation to be the assisted recovery of ecosystems from degraded conditions.

http://dx.doi.org/10.1016/j.ecolecon.2014.07.012
0921-8009/

indices used for bid ranking are based primarily on ecological outcome measures with risk, if at all, featuring as an aggregate measure. As such, the ranking mechanism cannot distinguish between risks that occur on different scales. For example, site specific land use history and management may aid or hinder the achievement of rehabilitation objectives. Across the landscape, the extent to which genetic material has been lost due to landscape fragmentation and habitat loss will affect rehabilitation success. Hence, the probability of conservation success is determined by a combination of risks, each affecting the investment decision in its distinct way. This distinction becomes particularly important when considering climate change. Depending on the severity of change, none, some or all risks may intensify resulting in a non-uniform effect on rehabilitation success within and across projects.

The investment framework we are proposing differentiates among site and landscape specific risk and is sufficiently flexible to allow for the additional complexity imposed by climate change. It is based on a continuous-time real options model of sequential investment by Majd and Pindyck (1987), which is adapted to optimal investment in rehabilitation. We build on the extensive economic literature that applies continuous time real options models to determine optimal natural resource management under conditions of risk and uncertainty.[2] To specify and calibrate the real options model we draw on a large body of literature in ecology that deals with the dynamics of ecological systems using state and transition models pioneered by Westoby et al. (1989). Of these, the McIntyre and Lavorel's (2007) Box Gum Grassy Woodland State and Transition Model is most relevant to this study as it describes a wide range of land use implications for ecosystem condition and maps potential rehabilitation pathways and their impediments.

After introducing the formal framework in Section 2, the model is calibrated and optimal investment rules for the base case are derived in Section 3. The effects of climate change on optimal rehabilitation investment are analyzed in Section 4. The efficiency gains from using bid ranking criteria that are based on option pricing are demonstrated in Section 5. A discussion and concluding comments are provided in Section 6.

2. A Real Options Model of Box Gum Rehabilitation

Box Gum Grassy Woodland ecosystems are of national importance to Australia. With less than five percent remaining in good condition (AGDEH, 2006; TSSC, 2006), their rehabilitation is a priority under the Australian Government's Caring for Our Country Environmental Stewardship Program (AG, 2012). Rehabilitation on private land occurs on a voluntary basis and is incentivized through conservation contracts that are allocated by a government agency via a conservation auction, equivalent to the one described in Stoneham et al. (2003). Before placing their bids, landholders are advised of the type of conservation and rehabilitation actions that would be most appropriate on their land and are invited to put in a competitive bid for funding of a rehabilitation project that reflects their costs of providing these recommended actions.

The design of proposed rehabilitation projects is driven primarily by ecological concerns. Advice on beneficial management activities closely follows the prescriptions of a state and transition model that was developed for this ecological community by McIntyre and Lavorel (2007). As shown in Fig. 1, the Box Gum Grassy Woodland State and Transition Model is divided into five ecological states. The arrows represent transitions from one state to another that are driven by changes in land use. For example, livestock grazing triggers a shift from State 1 to State 2, while fertilization triggers a shift from State 2 to State 3. We take the ecological value that is attached to each state and proxied by endemic species richness to decrease from States 1 to 5. The ultimate objective of rehabilitation is the eventual return of ecological condition to that of Grassy Woodlands (State 1). The stewardship program invests in 'native pastures' (State 2) and 'fertilized pastures' (State 3) for which the transition pathways are considered most ecologically feasible.

Targeted rehabilitation requires cessation of particular activities such as fertilization and removal of fallen logs and branches. In addition, proactive measures may be necessary to facilitate ecological transitions, including the adoption of specific grazing regimes, ongoing weed control or adding carbon to expedite nutrient release (Prober and Thiele, 2005). The completion of a rehabilitation pathway requires a significant period of time to allow nutrients to be leached and ecological processes to re-establish. This process can be highly non-linear and subject to significant variation, making it difficult to determine the precise point in time at which a state transition has occurred. Similarly, determining the marginal benefit from rehabilitation investment is problematic. Accordingly, the Environmental Stewardship Program prefers to invest in fixed 15-year contracts that are paid in annual installments, so as to allow for sufficient time for a single state level transition to occur.[3] Not all of the funded rehabilitation projects turn out to be successful and the likelihood of successfully transitioning to the next preferred state is expressed in terms of a transition probability.

As a first step, we now specify a real options model of sequential investment with the purpose of evaluating a single Box Gum Grassy Woodland rehabilitation project. The framework makes the importance of time and ongoing efforts for rehabilitation success explicit, as well as allowing for multiple rehabilitation risks and the irreversibility of investment. We start with the premise that a given Box Gum rehabilitation project incurs a fixed budget, K_{max}, which is equal to its bid price and reflects the total cost of the expended rehabilitation effort over the 15-year contract. The implementing government agency invests this budget optimally until exhausted. The objective of investment is to achieve a single state level transition to the next preferred state, which has a higher ecological value than the initial state due, for example, to having more observed endemic species. Hence, the benefit from rehabilitation, denoted V, is the difference in ecological value between the initial and the targeted state and can also be thought of as the present value of the stream of recovered ecological value or ecological value added due to rehabilitation. In line with the ecological transition concept, this rehabilitation benefit, V, will only be realized upon project completion. Current rehabilitation benefits are known with certainty, whereas the benefits from rehabilitation projects completed in the future are subject to trend and uncertainty dynamics.

The task of the agency is to maximize the value of the rehabilitation project, denoted F, by choosing the optimal level of rehabilitation effort, k, measured in terms of the amount of the budget spent on rehabilitation, in the next instant. The Bellman equation for this problem, which assumes that all future effort expended is also optimal, is (Majd and Pindyck, 1987)

$$F(V,K) = \max_k \left\{ -kdt + \frac{1}{1+\rho dt}(F(V,K) + E[dF]) \right\}, \tag{1}$$

where dt represents a small time period and where K is the total remaining expenditure required to complete the project and is representative

[2] See, for example, investigations into optimal land development (Scheinkman and Zariphopoulou, 2001; Bulte et al., 2002; Leroux et al., 2009), harvesting (Morgan et al., 2007; Insley, 2002) and species preservation (Kassar and Lasserre, 2004) under ecological uncertainty. Using a combined Brownian motion and Poisson process as in this paper, Baranzini et al. (2003) model the effects of increasing climate variability and catastrophic events on optimal greenhouse gas abatement.

[3] A State 3 to State 1 transition is considered unlikely within this fifteen-year time frame.