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Regeneration decisions in forestry under climate change related uncertainties and risks: Effects of three different aspects of uncertainty

Erik Schou [a,*], Bo Jellesmark Thorsen [b,c], Jette Bredahl Jacobsen [b,c]

[a] Department of Geosciences and Natural Resource Management, University of Copenhagen, Rolighedsvej 23, DK-1958 Frederiksberg, Denmark
[b] Department of Food and Resource Economics, University of Copenhagen, Rolighedsvej 23, DK-1958 Frederiksberg, Denmark
[c] Centre for Macroecology, Evolution and Climate, University of Copenhagen, Rolighedsvej 23, DK-1958 Frederiksberg, Denmark

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ABSTRACT

Future climate development and its effects on forest ecosystems are not easily predicted or described in terms of standard probability concepts. Nevertheless, forest managers continuously make long-term decisions that will be subject to climate change impacts. The manager's assessment of possible developments and impacts and the related uncertainty will affect the combined decision on timing of final harvest and the choice of species for regeneration. We analyse harvest of a Norway spruce stand with the option to regenerate with Norway spruce or oak. We use simulated variations in biophysical risks to generate a set of alternative outcomes, investigating effects on decision making of three aspects of uncertainty: (i) the perceived time horizon before there will be certainty on outcome, (ii) the spread of impacts across the set of alternative outcomes, and (iii) the subjective probability (belief) assigned to each outcome. Results show that the later a forest manager expects to obtain certainty about climate change or the more skewed their belief distribution, the more will decisions be based on ex ante assessments — suggesting that if forest managers believe that climate change uncertainty will prevail for a longer period of time, they may make sub-optimal decisions ex ante.

1. Introduction

Large scientific efforts worldwide aim at increasing our understanding of the nature of climate change and its possible impacts. While our knowledge is steadily increasing, the issue remains nevertheless surrounded by significant uncertainty, in particular concerning long run impacts. Uncertainty is not only due to lack of knowledge about cause and effect or measurement errors, but is also due to more complex issues, like the uncertainty on political efforts to reach agreements on greenhouse gas emissions. Climate change may affect absolute and relative production performances of forest tree species, through effects on growth, health, and risk agents. Forest managers are operating under this uncertainty and routinely make decisions reaching far into the future, most prominently when deciding on species for regeneration. Because of the nature of the long term uncertainty surrounding climate change, decisions are likely to be affected not only by scientific knowledge and uncertainty, but also by public debate and information flows. As stressed by Yousefpour et al. (2012), it may be useful to address the issue of uncertainty in terms of the forest manager's belief in particular climate developments, allowing aggregation of both scientific and subjective measures of uncertainty as assessed by the manager.

* Corresponding author. Tel.: +45 35336268; fax: +45 35331508.
E-mail address: eschou@ign.ku.dk (E. Schou).

Long term effects of possible climate change are a major source of uncertainty for forest management, due to the long production time in forestry. Species must not only be suitable for present, but also for future growth conditions, which in 50 years might be considerably different. Thus, the regeneration decision is important and irreversible, and highly sensitive to climate change. Mixing of species has been proposed as one way to mitigate this uncertainty, providing the forest manager with flexibility on the final choice through selective thinnings as more is learned about climate development (Jacobsen and Thorsen, 2003). However, for silvicultural reasons mixing is not always a feasible strategy, and in this paper we instead address the issue of adaptive decision making in the form of final harvest timing and subsequent species selection in forest regeneration.

The purpose of this paper is to investigate how the forest manager's optimal combined decision on harvest timing and choice of species for regeneration is affected by three aspects of climate change uncertainty:

1. At what time the forest manager expects to be certain about the direction and impact of climate change
2. The spread of economic impacts across possible alternative climate change scenarios
3. The weight that the forest manager assigns to each alternative climate change scenario ex ante, i.e. the subjective probability or belief (Yousefpour et al., 2014).

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We do not explicitly model climate change development and impacts over time. Rather, we rely on existing evidence, debates and prognoses in constructing a limited set of possible scenarios or outcomes of different climate change developments in order to focus on and assess how these features of uncertainty may change present-day decisions with respect to the three abovementioned aspects. To that end we assume that uncertainty about climate change and its impact is resolved at a specific point in time, using a small model with a limited set of time periods. This allows us to identify and separate the effect of the three different aspects of uncertainty from e.g. the form of the forest manager's learning or the many different specific aspects of climate change and impacts that often cloud the results of more complicated simulations (e.g. Yousefpour et al., 2013, 2014). Resolving the uncertainty gradually which is more realistic will make the effects smaller. We discuss the implications in the discussion section.

The problem is illustrated using the general case of deciding simultaneously on the final harvest timing and the regeneration species, when maximising expected net present value (NPV) of timber production. We consider two alternative species that are likely to show very different climate change sensitivity, but are still possible alternatives in forest management in the Danish case that serves as our empirical fundament. These are Norway spruce (*Picea abies* (L.) Karst.) and Pedunculate oak (*Quercus robur* L.). Norway spruce is expected to suffer from health problems in a warmer climate (Larsen et al., 2011), as well as from more frequent storm damage caused by a possible higher storm frequency. According to the most recent National Forest Inventory in Denmark (Johannsen et al., 2013), Norway spruce covers 16% of the forest area. 52% of the stands are below 40 years of age, i.e. they still have at least 10 years to go before final harvest. Many stands are situated on poor soils, where oak is one of the only alternatives among species not expected to suffer from climate change.

We simulated the economic consequences of changes in biophysical risks for Norway spruce and used the simulations to generate a set of illustrative alternative climate dependent outcomes for a new spruce stand — relative to a fixed performance of oak. The decision problem was thus an optimal stopping problem with fully exclusive alternatives (Malchow-Møller et al., 2004). In the decision model, the forest manager expects that within a finite number of periods, information that reveals the actual climate development will emerge. The expected NPV, conditional on each climate scenario, is known, and the manager holds a set of subjective ex ante beliefs about the likelihood of each scenario materialising, relative to the other scenarios. The expected NPV is maximised based on these subjective probabilities and hence risk neutrality is assumed.

Results included the standard findings from the real option literature that the larger the spread of outcomes, the larger is the value of waiting and the bigger the impact on decisions, i.e. it becomes optimal for a larger set of states to postpone final harvest and species choice. We find that the further into the future the forest manager perceives uncertainty to be resolved, the more decisions are based on ex ante assessments and the less willing the forest manager will be to wait for ex post evidence. Finally, we show that the more skewed the forest manager's belief is towards a particular scenario, the more weight is put on ex ante assessments and the less likely the postponement of decisions becomes, essentially because the belief reflects a much lower degree of (subjective) uncertainty about future outcomes.

The rest of the paper is organised as follows: In Section 2, we briefly relate our approach to the relevant part of the literature on climate change and decision making under uncertainty. In Section 3, we outline the background of our case and the material on which, we rely for simulating possible scenarios for Norway spruce. We use this in Section 4, where the model framework is set up including the simulation parameters. Results of simulations are presented in Section 5 and discussed in Section 6. We briefly conclude the study in Section 7 with some perspectives on the results from a research as well as a practical forest management point of view.

1.1. Decision making in forestry, uncertainty and climate change

Reviews of decision making under climate change (Yousefpour et al., 2012), of the modelling of natural hazards in forest management (Hanewinkel et al., 2010) and of real option studies in forestry (Hildebrandt and Knoke, 2011) present a comprehensive overview of the literature on decision making under uncertainty. We do not repeat this but focus on some of the similarities and differences between our study and the studies most closely related to it.

This study builds on the real option literature (Dixit and Pindyck, 1994; MacDonald and Siegel, 1986) and adds to the literature on optimal decision making under uncertainty, when forthcoming information on future states of the world may imply a real option. In forestry such studies have focused on, e.g. the use of reservation prices to handle price variation over time (Brazee and Mendelsohn, 1988), which as shown by Plantinga (1998) is a variant of the optimal stopping and real option problems addressed by McDonald and Siegel (1986). Numerous studies have addressed various real option issues in forest management, from general investment scaling and timing issues (Conrad, 1997; Insley, 2002; Thorsen, 1999a; Tee et al., 2014) to other issues of harvest timing (Malchow-Møller et al., 2004; Thorsen, 1999b). Among them we also find studies which in terms of model framework are even closer related to ours. These include Jacobsen (2007) on the regeneration decision and Jacobsen and Thorsen (2003) on the advantages of mixed species stands under climate development uncertainty.

All these real option type studies, however, share the common feature of having uncertainty specified and modelled quite specifically in the form of a stochastic process, which continues to vary and evolve over time, with parameters known to the decision maker. While this may be appropriate for some types of uncertainty, e.g. on price development, it is less so for the long perspective climate development that may be better understood as uncertainty about which new dynamic climate variation pattern will be emerging (Jacobsen et al., 2010). Furthermore, by nature, it is also less feasible to rely on past experience in assessing the likelihood of alternative future climate developments.

Assigning probabilities to climate change scenarios is difficult, as important conditions in classical probability theory are not met, i.e. lack of mutual exclusiveness between outcomes and a possible incomplete state space description. The use of imprecise probabilities as described by Tonn (2005) is seen as a solution to these problems. Dessai et al. (2005) describe the applicability of probability weighted scenarios in adaptation planning, stressing the importance of the decision maker's risk attitude, when investigating the sensitivity of decisions to choice of weights. According to Hall et al. (2007) it is much debated, if the use of probabilities is necessary for dealing with decision making under uncertainty, i.e. that rational decisions imply access to some probability estimates. Whether or not this is the case, it is of interest to analyse the implications if people more or less directly assign probabilities or beliefs to various outcomes — and act accordingly. Even if one rejects the use of probabilities for theoretical reasons when dealing with climate change uncertainty, subjective probabilities or perceptions of uncertainty might still to some extent explain behaviour. Thus, we follow Yousefpour et al. (2014) in addressing perceived uncertainty in terms of the beliefs, or subjective probabilities of the forest manager.

The use of Bayesian updating of beliefs as a way to model and simulate a forest manager's learning on climate change development has recently been investigated in related studies (e.g. Yousefpour et al., 2013, 2014). However, to arrive at mean measures of behaviour and outcomes, the method requires the forward simulation of numerous climate development draws, combined with assumptions on initial beliefs and updating rules. This complicates the quantification of the effects of uncertainty aspects on decisions, and rules out backward induction dynamic programming solutions. The simplifying assumptions made here allow the use of this dynamic programming approach and more precisely identify the effects of the three aspects which are central to this study. Furthermore using the subjective

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