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The value of adaption: Climate change and timberland management

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ABSTRACT

Adaptation to exogenous change occurs on both intensive and extensive margins. Whether and how one accounts for human adaptation directly affects estimates of the economic consequences of environmental change, estimates that are both critical in informing policy decisions and notoriously difficult to value. This paper introduces and applies an analytical framework for placing an economic value on adaptation. We explore the issue first in a stylized model that facilitates making concrete generalizations about the kinds of adaptations that generate high or low economic value. We then test the soundness of our insights by incorporating learning and adaptive decision-making into a structural dynamic forestry model where climate change is imposed exogenously and agents respond optimally. Using downscaled climate projections integrated with site- and species-specific timber productivity data, we estimate the economic value of adaptation to climate change within the California timber industry. We find on the intensive margin, changing the rotation intervals will yield a low value of adaptation, but on the extensive margin, replanting more suitable tree species can yield significant value.

1. Introduction

Extreme weather events, catastrophic fires, sea level rise, ocean acidification, species range shifts, floods, famine, and infestations are just a few of the hundreds of documented consequences of climatic change. For policy analysis, a fundamental contribution of economics is to estimate the economic impacts of environmental changes, which are then used as inputs into cost benefit calculations for policy design [56,41,36,58,18] . Regardless of the cause or specific context, many environmental changes share underlying patterns. First, environmental change is dynamic; the external stimulus of environmental change, whether it be a land management practice or pollution, has an intertemporal path. The stimulus then causes different outcomes within the ecological systems over time due to lags and adjustments. Second, the market response to environmental change is dynamic, as individual economic agents, firms, and governments make adaptive decisions. Due to these two underlying characteristics, the economic effects of climate change are extremely difficult to quantify, as seen in the wide range of impact estimates [60].

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That humans will adapt to exogenous change seems uncontroversial; predicting human behavior is a cornerstone of microeconomic theory. Clearly, failing to properly account for adaptation is a concern because impact estimates depend fundamentally on whether and how adaptation is accounted for. Damages will be overstated (and benefits understated) if adaptation is ignored. While it seems intuitive that impact assessments may hinge critically on if and how adaptation is incorporated, this expectation has not been formally evaluated. This paper introduces an analytical framework for measuring the *economic value of adaptation* given different types of dynamic adjustment. We define adaptation as a behavioral change or economic investment made to avoid or limit economic damages (if the environmental change is deleterious) or to enhance welfare (if the environmental change is welfare-enhancing). A central focus of this analysis is to distinguish between adaptation on the intensive margin (where behavioral changes adjust to a continuous choice variable) and extensive margin (where discrete changes are made). We use the model to derive several theoretical insights about the conditions under which adaptation will have high or low value. We apply the framework to a more sophisticated structural dynamic decision problem within forestry in the presence of exogenous environmental change and stochastic timber prices. We find results from the simple model are highly consistent with those from the fully dynamic decision problem. In combination, this analysis provides empirical estimates of the practical value of adaptation, general theoretical insights regarding adaptive behavior, and a new perspective on assessing impacts of environmental change.

The forestry sector provides an ideal case to test our theory. One hundred and fifty years ago, the German forester Martin Faustmann derived a formula to calculate the present value of income streams over an infinite cycle of forest rotations. Modern work concerning the optimal rotation has increasingly focused on risk and uncertainty analysis, given size-dependent stochastic growth [10,44] and stochastic timber prices, either using a reservation price policy, assuming prices can be modeled as independent draws from a known distribution [6,32,21], or taking a real options approach to the valuation of forest resources [7,10,39,57,43,42,27,4].

Climate change further introduces interesting dynamics into this story by changing site characteristics over time. Rainfall, temperature, or humidity are expected to shift in predicable ways over time and space, thus changing the suitability of any given site for growing any given species. The forester now faces a substantially more complex tradeoff because he must optimize the management of the tree stand with time-dependent growth and economic parameters in addition to uncertainty about future timber prices. Foresters are equipped with two fundamental adaptive responses to these kinds of changes. On the intensive margin, adaptation consists of adjusting the rotation period, the classical control variable in forestry. On the extensive margin, adaptation involves harvesting ones' tree stock and replanting a different species of tree altogether [50]. Sohngen and Mendelsohn [52] use optimal control theory to calculate the optimal harvesting of timber species, while comprehensively accounting for species selection, dieback, and salvage harvests. They estimate welfare outcomes with a steady state response and with dynamic adjustments. We extend their work by focusing specifically on adaptive decisions, being careful to distinguish between the intensive and extensive margins. We develop a model of a forester's choice set at any point in time in the form of a Bellman equation. Pioneered by Provencher [43] and Plantinga [42], the application of dynamic programming to the forestry sector is useful for determining option value and is well-suited to modeling a full range of adaptation options on both margins. This paper contributes to the literature first, by integrating the Bellman approach to the Faustmann problem with climate change dynamics, second, by comparing theoretically and in an example the value of different types of dynamic adaptations, and third, by incorporating Bayesian learning about future timber price paths into a decision-making model under market uncertainty.

1.1. Literature on adaptation in the context of climate change

While adaptation is incorporated in ad hoc examples, there is little consistency in the literature on the definition of adaptation or on how to properly treat it. Economists either refer to adaptation as the learning process by which an agent's demand function is determined [33,12,25,8], as a hedonic treadmill where expectations rise in tandem with changes in fortune [38,31], or as a natural selection mechanism used to theoretically explain the size dynamics and distribution of firms [48,11]. In the environmental literature, adaptation is often treated indirectly as a possible decision to invest in a new energy or agricultural technology [28,26,20,5,17], or it is described as an adjustment cost attributed to the time it takes for inputs to change in the short run [29]. Within the specific context of climate change, adaptation is treated differently within the various impact models.

Few studies have considered dynamic responses of economic agents to steadily increasing concentrations of greenhouse gases. The economics literature on climate change mostly consists of impact assessments and traditionally follows a top-down approach where global greenhouse emission concentrations are fed into climate models, which deliver estimates of future climate conditions (mainly temperature and precipitation attributes) at a coarse spatial scale. Downscaling the global climate model to local climate conditions, researchers use this information to predict impacts. At this final stage, various degrees of adaptation might be introduced as part of an impact model.

The impacts literature treats adaptation in four classes: no adaptation, arbitrary adaptation, observed adaptation (analogues), and modeled adaptation. While much attention has been paid to the ecosystem dynamics of environmental change, many prominent economics papers implicitly assume either no adaptive response or perfect adaptation without investigating specifically which one was most appropriate [14,47,3,15,18,41,58,59]. Later authors use observed adaptation to match temporal and spatial analogues. Spatial analogues compare cities A and B in the same period but different locations in order to predict how town A will change in a different time. This takes into account real adaptation as carried