Economics of Forest Resources

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The MIT Press
Cambridge, Massachusetts
London, England

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This book was set in Palatino on 3B2 by Asco Typesetters, Hong Kong.
Printed and bound in the United States of America.

Library of Congress Cataloging-in-Publication Data

Amacher, Gregory S., 1962–
Economics of forest resources / Gregory S. Amacher, Markku Ollikainen, and Erkki Koskela.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-262-01248-5 (hardcover : alk. paper) 1. Forests and forestry—Economic aspects.
I. Ollikainen, Markku, 1952– II. Koskela, Erkki, 1946– III. Title.
SD393.A46 2009
338.1′349—dc22 2008032762

10 9 8 7 6 5 4 3 2 1

Organization of the Book

This book is organized around a presentation of historical and classic core models that every serious student or researcher of forest economics must know. These models, along with numerous recent extensions of them, are discussed in part I (Basic Models). Part II (Policy Problems) is devoted to choice of policy instruments, deforestation, conservation of biodiversity, and age class-based forest modeling that builds upon the core models. Part III (Advanced Topics) surveys a rapidly expanding area of forestry problems, including uncertainty and stochasticity, and dynamic approaches to modeling forestry problems.

Most of the material in parts I and II of the text can be followed by someone with an understanding of multivariate calculus that beginning graduate students and advanced undergraduates in economics, agricultural and environmental economics, and forest and natural resource economics should have. Chapters 9–12 are the most advanced, but the material is generated from first principles to bring readers to the level needed to follow the main results. In addition, a mathematics review at the end of the book presents several concepts that will help in following proofs and interpretations in the text. A graduate course in microeconomics is not a necessary precursor to reading this book, although such training will obviously aid in understanding the more advanced concepts.

Because space is always finite when it comes to books, we have omitted some topics from consideration. We do not focus specifically on operations research (linear, goal, and some other programming-intensive) approaches to forestry problems, although many of these have been based on modifications of the models and policy problems we do discuss. Further, we do discuss in detail dynamic programming and both dynamic and static Lagrange and Kuhn-Tucker problems that are obviously related to the operations research literature. Comprehensive books devoted to operations research and numerical methods in forest economics on both intertemporal and spatial scales are Buongiorno, J., and K. Gilless, *Decision Methods for Forest Resource Management* (2003, Elsevier Science, London), and Hof, J., and M. Bevers, *Spatial Optimization in Ecological Applications* (2002, Columbia

University Press, New York). We also do not focus on econometric applications used to study forest markets or landowner behavior. This also means that the valuation of nonmarketed goods such as ecosystem services is not treated in any real detail. However, we do make extensive use of public goods values in our treatments of different forestry problems. A useful recent book that touches on many empirical areas in forest economics is E. Sills and K. Abt, editors, *Forests in a Market Economy* (2003, Kluwer, London).

The empirical relevance of the theories we survey in these pages should not be difficult for readers to see. It is our hope that the material in this book will open a range of new empirical applications that follow from more sophisticated modeling of forest landowner, market, and government decisions. It would certainly be impossible to cover every area of forest economics thought in one volume. Still, the chapters of this book cover nearly all of the economics-based models proposed within the past two decades to describe forest policy design, forest landowner behavior, or predict the effects of policy instruments on the bahavior of forest landowners.

Questions of policy and landowner behavior have occupied the minds of foresters and resource economists for more than 150 years, indeed even to the extent that one of the earliest contributions to modern forest economics, by the German, Martin Faustmann, in 1849, was conceived as a way of developing "fairer" taxation systems. We may never have another set of theoretical contributions to equal those that Faustmann's analysis has given us, but we are fairly sure that the value of any theory developed in the future will be worthless if it is not examined at some point using real data.

Part I Basic Models

These chapters provide the basic and historically important models and problems that any student or researcher of forest economics should be familiar with. We briefly discuss the early history of forest economics in chapter 1. It is interesting to see the number of iterations concerning the same basic idea of choosing an optimal rotation age that were developed during the dawn of economic thinking. We will focus on three periods of debate: the prehistory of economic analysis concerning the optimal rotation age, the birth of the optimal rotation decision as a separate framework, and what is called the Faustmann revival period. Any serious student or researcher must have an appreciation of where the field originated if they want to eventually shape where the field will go.

In chapter 2, the focus is on the most basic rotation-based decision models. The rotation age problem was originally developed for a single stand as one of maximizing the timber volume produced on a given forest site over time. The pure

focus on forest growth led economists to denounce this solution from the beginning. Economists have tended to side with the Faustmann solution to define an optimal rotation age, but this is quite different than the one historically adopted by foresters. Forests are a long-term economic asset, capable of jointly producing revenue and other benefits periodically. As we will see, the economically optimal rotation age strikes a balance between harvest revenue derived from timber yields and the opportunity costs forgone by delaying harvesting and effectively tying up capital in forestry (standing timber and land) instead of investing this money in other assets. Economic thinking essentially replaces the foresters' "biological" capital theory with financial capital theory. As we develop the Faustmann model, we will compare its solution with earlier solutions to illustrate of the debate and confusion that originally surrounded early thinking in the field.

Perhaps the most important part of chapter 2 concerns modifications to the basic Faustmann model. There have been literally several hundreds of articles written using this framework, and applications continue to show up in the literature even today. Some of the more interesting modifications we examine include a cost function approach that uses duality theory, and the decision landowners face concerning choices among competing land uses. A relatively new extension to Faustmann models, one that considers rotation age decisions simultaneously with consumption and savings decisions, is also studied. These have been developed in response to some evidence that the harvest decisions of landowners depend on owner-specific preferences and characteristics such as nonforest income and wealth. The idea is that landowners may have incentives to use their forest as a means of financing consumption expenditures, and this can be used to determine how binding financial constraints affect decisions about their forests.

Chapter 2 concentrates largely on rents from harvesting that forest users can capture through markets. However, it is well known that forests also provide flows of important public goods, known in the economics literature as "amenities" or "nontimber" goods. These include wildlife habitat, biodiversity, flood prevention, recreation, fishing and hunting opportunities, landscape aesthetics, and carbon sequestration, among others. Generally these are goods and services that may not generate income-based rent, although some may depend on harvesting. All are potentially important to the welfare of forest recreation users and nonusers, as well as landowners. Amenity services have two common features. First, in most cases we can think of them as public goods that are not priced in markets. Second, the time path of amenity production during the age of a stand depends on the amount of standing timber present through time. Hence, amenities are jointly produced with timber in the forest production technology. When a stand is harvested, the flow of amenity services changes in a corresponding and possibly complicated manner.

Chapter 3 builds upon chapter 2 by introducing amenities into the landowner decision problem. As in the previous chapter, we also return to the question of forest taxation and its importance in shaping landowner decisions when there are social costs present because landowners and society do not have the same preferences. Two theoretical generalizations developed within the past few years are then presented. First we consider a case where stands in a given area form a forest landscape and are potentially interdependent in producting amenity services over time and space, and second, we return to our examination of models that combine rotation age decisions with consumption and savings decisions from chapter 2, extending them to the case where amenities are present.

Chapter 4 addresses life-cycle models of forest management decisions. The central feature of these models is to maximize the net present value of forest rents over two periods, current and future. These theories follow from combinations of the classical fishery-relevant biomass model and the traditional Fisherian two-period model widely applied elsewhere in economics. The life-cycle model has proven useful in studying short-term timber supply questions and has simplified the analysis of uncertainty, capital market imperfections such as landowners facing borrowing constraints, and amenities that invalidate the traditional Fisherian (and Hartman) assumption of separability between the preferences of resource users and production decisions. The effects of forest policies and the development of timber supply within this framework are also considered, as are extensions to longer-run models of overlapping generations. These models accommodate the notion that timber and money transfers can be made across generations through either timber bequests or sales. It also allows an examination of various long-run forest steady states that have important implications for forest policy. Of special value in this chapter is a comparison of the results derived with those of rotation models because this comparison has often been confused within the literature.

Part II Policy Problems

Chapter 5 turns to the problem of policy design from the perspective of a government or social planner, with an emphasis on identifying the socially best instruments for the forest sector. In examining this problem, the policy maker must always answer two basic questions: First, what types of tax instruments are "best," and second, what is the appropriate level for each instrument? Obviously, these choices depend on the target function maximized or minimized by the policy maker, as well as any constraints regarding the set of available instruments. The policy maker must also be able to anticipate the reaction of landowners to any choice of instruments. Often the known fact that private landowners and other agents may make decisions inconsistent with a social planner, or the fact

that policy makers face several constraints on their actions, creates special scope for policy design.

In chapter 6 we consider the important global problem of deforestation, delving into property rights risks and illegal logging activities. Deforestation of temperate forests was very rapid in the industrial world up through the 1940s and since then, this activity has shifted largely to tropical forests in Africa, Asia, and Latin America. These forests play a special global role because they contain more than 80% of the Earth's biodiversity. Our focus in the chapter is on policies aimed at reducing incentives for forest users to harvest forests unsustainably. The policy choice environment here is quite different from the one studied in chapter 5. Both empirical evidence and the literature have made it clear that any policy design must take into account many institutional and economic factors prevailing in underdeveloped tropical countries. Imperfect credit and labor markets distort agents' decision making in tropical fringe areas. Insecure property rights often lead to illegal logging, and there is sometimes land clearing and suboptimal investments in plantation forestry. Poor and inefficient governments raise money through royalties applied to a concessions process, but there are nearly always improperly designed royalty systems and lack of monitoring. Corruption among public officials is also ever present. This, combined with migration pressures and other poorly designed government policies, imposes constant pressure on the world's remaining native forests.

Using two common frameworks, this chapter shows how these issues provide challenges for forest policy design. The first is a concession model in which we analyze how the size of concessions, royalty instruments, and enforcement should be designed jointly to raise royalties to finance government budgets but also to abate illegal logging and control deforestation. The modifications to policy instruments necessary in the presence of corruption among public officials is also examined. The second framework discussed is the land-use rent-based model. This type of model reveals how migration pressure, insecure property rights, and risks concerning illegal logging and expropriation affect both land use and deforestation.

Chapter 7 analyzes biodiversity conservation. Biological diversity is multifaceted and important to life in all possible forms on Earth. To make the concept operative, biologists typically distinguish among diversity of species, diversity of habitats, and genetic diversity with regard to number, composition, and relationships. Regardless of how it is defined, the provision of biodiversity by forests is a public good. The socially optimal level of conservation for forest land depends on the social benefits and costs of providing the biodiversity. While the loss of tropical forests is a major drain on these public goods, many challenges lie ahead for conserving biodiversity in boreal and temperate forests. Most important, the

management decisions of individual forest landowners may not be consistent with practices designed to maintain or increase biodiversity. To wit, intensive forest management practices, such as planting single-species stands, improving timber stands, suppressing fires, and frequent harvesting have all replaced the natural disturbance dynamics that have driven forest renewal and helped to maintain the diversity of habitat for centuries.

This chapter focuses on forest species and habitat conservation in three parts. First, we review ideas from ecology concerning forest habitat networks based on modeling of site selection. Following the spirit of this book, we then examine two key policy questions in biodiversity conservation. First, we investigate how a green auction approach can be used to promote the voluntary participation of private landowners in building biodiversity conservation reserves on forest land. These approaches are becoming more common and are already in place in many countries. Second, we examine how forest policies can be used to promote biodiversity maintenance in commercial forests; our special focus here is on retention of green trees as a means of increasing the dead and decaying wood needed for threatened old-growth forest habitat. Finally, we discuss some other aspects of biodiversity and forests, including genetic diversity and invasive foreign species.

Chapter 8 turns to age class-based models in forest economics. These models allow the inclusion of multiple tree ages within a landowner decision model. An important question in modeling age classes has been an investigation of several long-run steady states that might be important to forest management. The efficiency of one steady state in particular, a normal forest, is also examined. The desirability of normal forests has long been a controversial subject within the forestry and economics literature. In this chapter we present recent research that sheds some light upon these debates. Second, we discuss policy design problems where age class-based frameworks should be applied, such as carbon sequestration and using forest structure to enhace forest amenities.

Part III Advanced Topics

These chapters focus on the many types of uncertainties involved in forestry and their implications for policy. The long-term nature of forest production means that landowners may never know the value of all parameters when they make management decisions in current time periods. The future price of timber is probably the easiest type of uncertainty to envision, but there is uncertainty in real interest rates and the pattern of forest growth, all of which are important to forest management decisions. There is also the possibility that a landowner is uncertain about several parameters simultaneously when making decisions. Furthermore, there are many natural hazards that landowners face in any rotation, but for

which there is imperfect information concerning their arrival over time. These "catastrophic" risks come in many forms, such as fires, ice and wind storms, and pest attacks.

Uncertainty in timber markets may change the ways forest taxation affects incentives for a landowner to provide timber and amenity services. As we discuss in many places within this book, governments can influence these incentives through policy choices. Thus we will ultimately consider in many of these cases how uncertainty should be taken into account when a government designs forest policies. The basic question here is whether forest policies can be tailored in ways that correct for the possible biases uncertainty causes in the decisions of private landowners. Answering this question requires understanding how uncertainty enters the objective function of the government, and whether the government should be regarded as risk averse or risk neutral when forming its policies.

In chapter 9 we explore how uncertainty has been studied within the two-period life-cycle model of chapter 4. Several types of uncertainties, including those associated with the forest stock and economic parameters, are shown to affect harvesting behavior, timber supply, and amenity production in the short run. We also examine how government policies can be used to correct the distortions that uncertainty induces in landowner decisions, if it is desired by the policy maker. We make extensive use of the economic theory of risk-bearing behavior, which dates back at least four decades to initial work in expected utility theory. However, we will take a slightly different and more recent approach that uses analytically simple and economically intuitive classes of models based on nonexpected utility theory. One important advantage of these models, aside from their ease of interpretation, is the fact that they can easily incorporate the risk attitudes of both forest landowners and policy makers.

Chapter 10 continues our presentation of risk and uncertainty for a different class of models. Here we examine catastrophic natural events such as fires, wind, ice, and pests. Such events often cause large, discrete jumps in the rents that forest owners can capture during a rotation. These events have always been part of the forest landscape, and in many ways they play an important ecological role. By destroying trees, natural catastrophes create open space to promote both regeneration and biological diversity. The chapter begins by reviewing the types of catastrophic risks that are normally present for forest land, and then begins a study of the models used to incorporate these risks into forest management decision making. An important piece of this modeling involves specifying a workable description of how catastrophic natural events arrive during a rotation. We consider both the case where amenities are not valued and the case where amenities are important, and we consider cases where the arrival of the natural hazard depends on the age of the forest and on costly protection efforts that the landowner may

engage in. The chapter ends with a discussion of the large set of literature that has followed the first treatments of this problem in forest economics. Chapter 10 serves as an introduction to the more complex modeling of stochastic processes and forest management that arises from economic parameters, such as forest stand value, timber prices, and interest rates.

The incorporation of general economic risks as a real options problem is discussed in chapter 11. This chapter introduces a research area in forest economics active since the 1990s. This work reflects the fact that forest management involves other risks besides catastrophic single-loss events. Often, uncertainty in market and biological parameters evolves over time, so that changes in rents do not involve one-time jumps, and there is often volatility in certain parameters that takes on special forms. This is most typically the case for market prices and interest rates, where demand and supply tend to dampen fluctuations over time. The typical way of modeling this type of problem is to use stochastic processes to describe how unknown parameters change through time. In this chapter we examine a class of problems known as optimal stopping, where the landowner can either irreversibly harvest the stand and capture revenues, or continue to let it grow and retain the option of stopping to harvest in the future. A critical part of these models is specifying a workable description for both the trend and the volatility of economic parameters. Several types of stochastic processes are therefore considered, and the use of stochastic processes in single- and multiple-rotation problems is discussed. This chapter amounts to a rigorous survey of optimal stopping and real options models as they have been applied to understanding forest decision making under uncertainty.

The book culminates with a study of dynamic forest models in chapter 12. We try to cover in this chapter material that could comprise an entire book in and of itself. We discuss myriad applications of dynamic optimization to understanding problems of forest resource economics. There are two main purposes here: First, we show how the problems studied and the scope for results in dynamic forestry models compare with rotation-based models. Over the past 20 years, several important articles have been written using either optimal control or dynamic programming, covering such areas as stand management, land use, timber supply, strategic behavior among landowners, deforestation, forest preservation and old-growth features of forest stands, and carbon sequestration. Dynamic programming is increasingly being used to study complex questions involving uncertainty. The stochastic control and real options models discussed in chapter 11 present a way of modeling uncertainty in a stopping problem, which provides a close bridge to harvesting decisions in rotation models. However, these approaches restrict attention to uncertainty as a diffusion process that evolves over time. Our second objective is therefore to give the reader an appreciation for the

link between dynamic models and practical questions involving the dynamics of forest stands and markets.

The primary dynamic optimization methods applied to forestry problems have been optimal control and dynamic programming. Dynamic programming has been used mostly for stand management problems and landowner's decision making under uncertainty, while optimal control models have been used for perhaps a wider variety of nonstochastic problems, including policy design problems. The main goal of this chapter is to introduce these approaches in a way that links them to other parts of the book, showing alternative ways that problems can be studied by abandoning the rotation model. The chapter begins with some preliminaries concerning dynamic optimization, using forestry problems as illustration. Second, optimal control is considered and four areas are studied: Faustmann and Hartman interpretations, old-growth forest and native forest interpretations, land-use interpretations, and other interpretations, such as carbon sequestration and biodiversity. Third, we take up dynamic programming approaches using both perfect foresight and stochastic interpretations.

An important component of this book is the summary at the end of each chapter. Taken together, these summaries not only point out where we have come as a scholarly field, but they also reveal certain weaknesses in current approaches or research. In the summaries we have tried to provide some hints as to where we think research is going or should go in these areas.

Suggestions for Use

The chapters and parts of this book can be tailored to reader preferences. Readers interested in an advanced undergraduate and beginning graduate survey of basic theories in general forest economics should concentrate on chapters 1–4. Those interested in the design of policy instruments should read chapters 1–8. Readers interested in a thorough survey of uncertainty and stochasticity should concentrate on chapters 9–11 and the latter parts of chapter 12, while readers seeking to understand the types of dynamic problems that have been studied in forest economics should focus on chapters 11 and 12.

We have used the material in this book for both master's and doctoral-level courses in natural resource and environmental economics, forest economics and management, risk and uncertainty, and dynamic optimization. The book could easily serve as a graduate textbook in forest economics, but our hope is that it will be used as a supplemental textbook for any natural resource or environmental economics course where the instructor intends to give a serious or current treatment of forestry problems.

Acknowledgments

It is probably impossible to thank everyone who helped us through the many years it took to write this book. Obviously our families deserve the most thanks for enduring our seemingly unending hours spent working on this project at their expense. Without encouragement from them it is hard to imagine we would have succeeded. We also involved countless graduate students at Virginia Tech and Helsinki Universities. Names that come to mind are Maria Bowman, Fanfan Weng (who checked many of our equations for us), Erivelthon Lima, Melinda Vokoun, Simone Bauch, Jani Laturi, Jenni Miettinen, Kimmo Ollikka, and Karoliina Pilli-Sihvola. We also are indebted to the all other students who waded through this book in courses where the chapters were tested. Several colleagues were also there throughout the process to hear our complaints and fears and to suggest important directions. Amacher especially thanks his good friends and colleagues Jay Sullivan and Arun Malik, who constantly dealt with questions concerning whether this book was worth writing, and who provided important suggestions throughout for content. Ollikainen thanks his collaborators Artti Juutinen, Mikko Puhakka and Timo Pukkala, as well as Jari Kuuluvainen, Ville Ovaskainen, Olli Tahvonen, Jussi Uusivuori and Lauri Valsta for valuable insights in various topics discussed in this book over the years. Amacher and Ollikainen jointly thank Chiara Lombardini-Riipinen, who kindly checked and further developed the empirical boxes present in several chapters, and Artti Juutinen and Jussi Uusivuori for comments on the material in chapters 7 and 8, respectively. Finally, we owe great gratitude to the tireless and highly professional staff at the MIT Press in Cambridge, Massachusetts. It's no wonder they have the reputation they do among economics authors. First, we thank John Covell whose encouragement from day one has been immeasurable and irreplaceable. Katie Helke has also been invaluable in helping us sort through the steps involved in publishing this book. Ruth Haas, the copy editor who read through our manuscript, was absolutely outstanding and led to a much better product than we originally submitted. Katherine Almeida also deserves thanks for fielding our numerous questions and moving the process along. This all said, any remaining errors are certainly our own.