

**Investigating the Cooperative Behavior of Nonindustrial Private Forest Landowners
When Stands are Spatially Interdependent**

by

Melinda M. Vokoun

Dissertation submitted to the Faculty of the
Virginia Polytechnic Institute and State University
In partial fulfillment of the requirements for the degree of

Doctor of Philosophy

in

Forest Economics

Dr. Gregory Amacher

Dr. Jay Sullivan

Dr. Stephen Prisley

Dr. Jeffrey Alwang

Dr. David Wear

March 7, 2005
Blacksburg, VA 24061

Keywords: spatial interdependence, adjacent, coordination, amenity services, nonindustrial landowners, externality

**Investigating the Cooperative Behavior of Nonindustrial Private Forest Landowners
When Stands are Spatially Interdependent
Melinda M. Vokoun**

Abstract

This research examines how the harvesting behavior of nonindustrial private forest landowners, and their use of forestland for non-timber amenities, is affected by adjacent landowner behavior. The uncertainty an individual landowner has regarding adjacent landowners' preferences, and how the production of non-timber amenities on their own stands relies on the condition of adjacent stocks, is specifically addressed. Economic characterizations of substitutes and complements are employed to investigate the differences in optimal stock levels at the steady state in the production of amenities under various levels of cooperation among landowners. It is shown that there are externalities present when landowners do not coordinate management actions when parcels are spatially interdependent. The effects of spatial interdependencies on landowner behavior are further explored using data from a survey of forest landowners in Central Virginia. Findings suggest that forest landowners are willing to coordinate activities, and such decisions are determined by similar characteristics that function in predicting landowner behavior regarding timber harvesting. Further, landowners' decisions to use own and adjacent parcels were correlated, hinting at the spatial interdependencies of stocks in amenity valuations. Both the theoretical and empirical analyses suggest that the lack of coordination among landowners and its effects on stock management would be best addressed through the use of incentives to drive spatially efficient outcomes.

Acknowledgements

I would like to thank my advisor, Dr. Greg Amacher, for his support and encouragement throughout this endeavor. Yes, there is a light at the end of the tunnel, as you were wise to reiterate throughout this challenging task. With the tools that I have acquired along the way, as well as an infectious enthusiasm for the field of economics that you have inspired, I feel most prepared to pursue greatness in the world of academia.

I would also like to thank Dr. Jay Sullivan, for his encouragement and guidance in times of what seemed like desperation and much confusion. I am grateful Dr. David Wear for the opportunity to collaborate with him and members of his unit in the summer of 2004. I benefited greatly from the experience and from a change of scenery. I would like to express my gratitude to Dr. Jeff Alwang, whose course benefited me greatly in this effort and who provided valuable opinions on this work. Also, hats off to Dr. Stephen Prisley, whose “noneconomic” perspective and past experiences also contributed greatly to revisions of this work.

I am deeply indebted to several others who had a hand in this work. To Sue Snow and Laura Eanes for putting up with my endless questions regarding proper forms to fill out and survey related business. Thanks to Shawn Baker, Hylton Haynes, Amy Haynes, Paige Parrish, and Nathan Smith for their comments and review of early versions of the survey instrument.

I would like to thank my family for their continued support and encouragement throughout the completion of this dissertation, especially as my efforts have taken me so far away from home. I owe a sincere amount of gratitude and kudos to my husband, James, for putting me back on track the many times that I tried to depart. His endless ability to encourage me and make me laugh made this pursuit endurable, and for that I dedicate this work to him.

Table of Contents

Title Page.....	i
Abstract.....	ii
Acknowledgements.....	iii
Table of Contents.....	iv
Table of Figures.....	vi
Chapter 1: Introduction.....	1
1. Problem summary.....	1
2. Review of prior studies.....	3
Review of basic economic theory of forest land use.....	4
Theoretical analyses of stand interdependencies.....	5
Empirical literature.....	11
3. Contribution of research in this dissertation.....	15
4. Avenues for extension.....	17
Chapter 2: A model of landowner interaction.....	19
1. Introduction.....	19
2. Model of adjacent landowners.....	25
Single landowner problem.....	27
Defining the distribution of adjacent forest stocks.....	35
3. Landowner cooperation.....	38
Landowner cooperation affects price.....	39
Landowner cooperation occurs in the production of non-timber benefits.....	46
Landowner cooperation affects both prices and non-timber benefits.....	51
4. Strategic behavior between adjacent landowners.....	55
5. Costs from not coordinating.....	62
6. Conclusion.....	65
Chapter 3: Econometric analysis of adjacent landowner behavior.....	69
1. Introduction.....	69
2. Methods.....	73
3. Econometric model.....	77
4. Descriptive statistics.....	83
5. Logit estimation results.....	87
Willingness to enter into a joint plan for future forest management.....	88
Harvest at the same time as neighbor(s) given a 20% increase in price for timber.....	91
Willingness to enter into a joint agreement to forego harvesting to create wildlife cover ...	93
Willingness to not harvest a portion of forest to create an area for recreation.....	95
Willingness to enter into a joint agreement to manage land use activities, excluding harvest.....	97
Likelihood ratio tests.....	99
6. Bivariate probit estimation results.....	100
Decision to cooperate in past and enter into a joint agreement for future forest management.....	102
Prior cooperation and joint agreement to not harvest a portion of land for wildlife.....	103
Prior cooperation and joint agreement to not harvest a portion of land for recreation.....	104
Prior cooperation and joint land management activities, excluding timber harvesting.....	105

Decision to use own and adjacent lands for hunting related activities	106
Decision to use own and adjacent lands for non-hunting recreation	106
7. Conclusion	107
Chapter 4: Conclusion.....	113
1. Introduction.....	113
2. Theory results.....	115
Future work on landowner behavior models	122
3. Empirical results	124
Future work in empirical analysis.....	129
Literature Cited.....	146
Appendix 1: Existence of a steady state in the single landowner problem.....	151
Appendix 2: Proof of a stable equilibrium when there is cooperation in price.	152
Appendix 3: Proof of a steady state when there is cooperation in the production of non-timber benefits.....	154
Appendix 4: Proof of a stable Nash equilibrium.	156
Appendix 5: Survey Instrument.....	157
Curriculum Vita	165

Table of Figures

Table 1: Descriptive statistics of selected variables for survey on the effect of adjacent parcel management on land management and use decisions of Virginia NIPF landowners.	133
Table 2: Logit estimation results of landowner willingness to enter into a joint agreement with neighbors for future forest management.	134
Table 3: Logit estimation results of predicting landowner willingness to harvest at the same time as neighbor(s) with a 20% increase in the price received for timber.	135
Table 4: Logit estimation results of landowner willingness to enter into a joint agreement with neighbors to not harvest a portion of land to create a forested area for wildlife.	136
Table 5: Logit estimation results of landowner willingness to enter into a joint agreement with neighbors to not harvest a portion of land for the purpose of creating a forested area for recreation.	137
Table 6: Logit estimation of landowners' decision to jointly plan land management activities, such as, trail building, stream quality improvement, wildlife habitat development, and farming, with neighboring landowner(s).	138
Table 7: Results of likelihood ratio test when groups of variables are removed from the initial logit estimations of landowner decisions regarding entering into cooperative arrangements with neighbors.	139
Table 8: Landowner decisions to cooperate in land management activities in the past and to coordinate timing of harvest under the condition of an offered price incentive.	139
Table 9: Landowner cooperation in past land management activities and future forest management with neighbors estimated with bivariate probit model.	140
Table 10: Landowner cooperation in past land management activities and willingness to enter into an agreement with neighbors to not harvest on a portion of land to create an area for wildlife.	141
Table 11: Landowner decisions to cooperate in past land management and to forego harvest on a portion of land to create an area for recreation.	142
Table 12: Landowner decisions to coordinate with neighbors in past land management and future land management, excluding harvesting, activities estimated with bivariate probit.	143
Table 13: Landowner use of own and adjacent parcels for consumptive recreation (hunting) to assess spatial interdependencies using a bivariate probit model.	144
Table 14: Estimation of landowner use of own parcel and adjacent parcels for activities other than hunting using a bivariate probit model.	145

Chapter 1: Introduction

1. Problem summary

The sustainability of forests, in terms of the ability to produce multiple timber and non-timber outputs far into the future, has been a topic of debate for years. Standing forests provide many services that are not traded in typical market settings, such as maintenance of watersheds, wildlife habitat, carbon sequestration, and others. It is not individual forest stands functioning independently that fosters production of many of these services, but more often than not, the interaction of forest stands across a landscape is important. Public forest planning in this country has been under the directive of multiple-use management since 1960 in recognition that forests are not only sources of timber but also sources of other benefits to society. There has been increasing debate regarding whether the directive should shift to one of multiple stand ecosystem management (Sample and Sedjo 1996).

Despite the private nature of property rights in this country, it is possible that individual landowners receive amenity benefits from adjacent properties in terms of many services that forests provide. Adjacent landowners may affect the management behavior of other private forest landowners, and the lack of coordination among landowners could be costly. However, studies regarding the harvesting behavior of private individuals, who hold the majority of forest resources in this country, have only recently begun to account for the spatial interdependencies between forest parcels in terms of amenity benefit production and the social costs that may result from lack of coordination among landowners. A more thorough understanding of the spatial interdependencies in the production of non-timber benefits and how individual decision makers

account for the effect of their management decisions on the welfare of surrounding (proximate) landowners is needed in order to best address many current landscape level forest sustainability issues.

In this dissertation, I address the effects of adjacent owners on individual landowner behavior, specifically considering the spatial interdependencies between parcels in the production of amenity services. I employ a dynamic model characterizing the substitutability and complementarity of adjacent stands to characterize the interaction of stands in the production of non-timber benefits. My analysis specifically addresses the uncertainty an individual landowner has regarding an adjacent landowner's preferences and how the production of non-timber benefits on their own land depends on adjacent stand conditions. When landowners cooperate in either land management or land use activities with adjacent owners, some of the uncertainty regarding the effects of individual actions is alleviated. A determination of how adjacent stand management affects an individual landowner's decisions and use of their own timber resources is necessary to best address many landscape level forest sustainability issues. Comparison of the outcomes of coordination for stands that are complementary in different ways will allow for an assessment of the costs resulting from the lack of coordination among landowners.

This chapter presents a review of previous research on stand interdependencies and cooperative landowner behavior, and provides the context for this study. A theoretical model incorporating landowner uncertainty and investigating the outcomes of different levels of coordination at the steady state is developed in the second chapter. An empirical study of landowner behavior that specifically concentrates on cooperation in land use and management activities is explored in the third chapter. Lastly, a summary of the conclusions regarding the

new models of landowner decision making are presented in the final chapter. These chapters encompass a thorough examination of how adjacent stands affect an individual landowner's behavior, with particular focus on the interdependencies of stands in the production of amenities.

2. Review of prior studies

This chapter reviews prior research on coordination of resource extraction among distinct owners, with a particular emphasis on forestry issues. Forests are of particular concern, because forest conditions yield many services that not restricted to an individual landowner. The interrelationship between parcels in the provision of services is particularly important in addressing many of the current factors threatening forest sustainability, such as fragmentation, invasive species, and fire. Most of these factors are not restrained by property boundaries but affect entire landscapes. With increasing forest fragmentation and a majority of land held by non-industrial private forest (NIPF) owners, an understanding of the relationship among individual owners and stands is crucial to developing policies to combat landscape level threats to forest sustainability and also will allow for more comprehensive predictions of timber supplies from these lands into the future.

Previous research regarding the interrelationship of resource quantities in the production of benefits and the effect that this has on the optimal use decision of individual landowners managing forest stocks range from survey based studies focusing on the concepts of ecosystem management, to complex theoretical analyses that examine landowner behavior. The theoretical models (Bowes and Krutilla 1985, Swallow and Wear 1993, Koskela and Ollikainen 2001, Amacher et al. 2004) incorporate the relationship between neighboring parcels in the production

of amenities into a single-stand type formulation that has been extensively employed in analyses of non-industrial private forest (NIPF) landowner behavior.¹ Statistical methods have been used to analyze data from survey-based studies to characterize landowner interest in participating in joint management projects (Stevens et al. 1999, Jacobson et al. 2000, Klosowski et al. 2001, Jacobson 2002). Gains from cooperation have also been examined empirically (Uusivuori and Kuulivainen 2001, Kurttila et al. 2001, Eid et al. 2001, Smith and Shogren 2001, Parkhurst et al. 2002). There have also been analyses of the interdependencies of stands in the production of conditions that affect forest ecological functions (Csuti et al. 1997, Ando et al. 1998, Polasky et al. 2000).

Review of basic economic theory of forest land use

An issue that has been examined frequently in forest economics in one form or another has been the determination of the optimal forest rotation schedule, a quantification of the elapsed time between timber harvests, on a single forested stand. The scheduling of forest harvests was a point of contention between the biologists and economists for years. Biologists' advocated harvesting timber when the long-run growth of timber was maximized referred to as maximum sustained yield. This schedule of timber harvests does not account for the marginal economic rents generated from forest use. Economists have suggested that the determination of the optimal single-stand rotation should account for marginal land rents from forest use. This type of approach began with Martin Faustmann in 1849.

¹ For thorough reviews of single-stand NIPF landowner behavior literature see Amacher et al. (2003), Pattanayak et al. (2002), and Alig et al. (1990).

The Faustmann formula, as it is commonly referred to, has been utilized and modified by many economists, but it has stood the test of time (see Newman 2002). The extension of the Faustmann model that is most familiar is that of Hartman (1976), who proposed that amenity benefits factor in the determination of the optimal scheduling of timber rotations for a single forest stand. In his analysis, Hartman (1976) suggested that if the stand were part of a larger forested plot, then the management of the adjacent stands on the plot would most certainly affect optimal management of the single stand under consideration when amenity benefits were included as factors in the decision making. Planners in governmental forests have long been directed to consider services other than timber that are produced when managing their forest planning areas, which are typically divided into several stands based on composition and age of the timber resources.² It was this multiple-use directive on public forest lands that was first analyzed in terms of its affect on the optimal rotation age in the mid 1980's.

Theoretical analyses of stand interdependencies

Bowes and Krutilla (1985) were the first to propose a theory to address the issue of multiple-use management of a single forested stand incorporating the concept of spatial interdependence of stands in the production of amenity benefits. The model developed by Bowes and Krutilla (1985) analyzed the optimal rotation age decision of a single landowner faced with managing a homogeneous forest area in terms of timber production and amenity services, where production of services was related to the condition of the forest stand delineated by age class. Using data derived from Douglas-fir growth tables, Bowes and Krutilla (1985)

² Passage of the Multiple-Use Sustained Yield Act (1960) and the National Forest Management Act (1976) directed planners to consider the various resources of the forests and held forest planners accountable to the public, respectively.

examined the policy implications of various stand management schemes, determining that there was no simple rule to describe harvest patterns under multiple-use objectives. Snyder and Bhattacharyya (1990) extended this analysis and incorporated the cost associated with maintenance of amenity services into their determination of optimal rotation for forests under multiple-use directives. Under the assumption that the quality of amenity services decreased over time, but subject to efforts to maintain amenity services, Snyder and Bhattacharyya (1990) examined the forest management objectives of a single forest manager maximizing the present value of net returns from timber (both harvested and unharvested). The relative size of marginal maintenance costs, determined by age of the stand and present value of these costs, determined the difference in rotation period between the model of Snyder and Bhattacharyya (1990), where maintenance costs were incorporated, and previous models such as that of Hartman (1976).

Swallow and Wear (1993) further studied spatial interdependencies in production of amenity services, where the individual decision maker considered amenities produced on adjacent stands. The model of optimal rotation age proposed by Swallow and Wear (1993) retained the locational identity of stands and examined the behavior of the manager of a single-stand, where the rotation of a nearby stand was an exogenous factor to the landowner's decision. By modeling amenity benefits from stands in this manner, Swallow and Wear (1993) explored the possibility that stands could be substitutes or complements in production of amenity services that factor in the optimal rotation decision of the individual landowner. Swallow and Wear (1993) utilized data from a National Forest in Montana in simulations and concluded that a range of potential optimal harvest plans were possible that depended on benefits to the manager and initial stand conditions. Vincent and Binkley (1993) utilized a production possibilities frontier to determine the economic implications of multiple use directives from the perspective of a single

owner who allocated management effort between two identical stands. Based on their theoretical analysis, Vincent and Binkley (1993) determined that management effort should become specialized when a single landowner manages two identical stands that produce both timber and non-timber outputs, however this was only the case when diminishing marginal returns were not taken into account. In the case of diminishing net returns, there were externalities at the landscape level presented when management of stands is specialized by product, thus less specialization by the manager became optimal (Vincent and Binkley 1993).

The interdependencies of stands in the production of amenity services were further investigated by Swallow et al. (1997), who focused on the optimal rotation age decision of a landowner faced with managing an entire forest ecosystem and accounted for the locational identity of stands. Amenity benefits produced on neighboring stands, dependent on their condition, were internal to the individual manager's decision (Swallow et al. 1997). Simulation models were utilized by Swallow et al. (1997) to compare outcomes of different scenarios using sensitivity analysis. They found, similar to Bowes and Krutilla (1985), that there were no strict rules of thumb for schedule of harvests that can be followed by the landowner who addressed management at the ecosystem level. Swallow et al. (1997) surmised that the optimal harvest schedules when management was addressed at an ecosystem level by a single landowner cannot coincide with typical single-stand models where rotations occur in constant intervals, but rather rotation decisions must adjust to the condition of the adjacent forest stands.

More recently, Koskela and Ollikainen (2001) considered the interdependence among adjacent stands in the provision of amenity services in their examination of optimal public rotation age. The economic characterization of complements and substitutes was formally incorporated into a model of the rotation age decision of a landowner, who considered the spatial

relationship of stands in the production of benefits, yet the actions of neighboring landowners were exogenous to this decision (Koskela and Ollikainen 2001). Koskela and Ollikainen (2001) derived rules to solve for a socially optimal level of public harvesting, under the assumption that the public agency was a first-mover in a Stackelberg game. These rules were dependent on the relationship among public and private parcels in the production of benefits. They were also based on the evolution of the degree of complementarity and substitutability between public and private forests in the production of amenity services over time, the relationship between the age of forest stands and amenity production, and the extent of access to forest stands for the purpose of recreation on private lands (Koskela and Ollikainen 2001).

Amacher et al. (2004) extended Koskela and Ollikainen (2001), studying the behavior of adjacent landowners under various game theoretic scenarios. Amacher et al. (2004) incorporated the economic characterization of complements and substitutes into their analysis of adjacent landowner behavior where (1) decisions were made simultaneously and landowners played a Nash game, (2) a Stackelberg game was played where one landowner moved first, or (3) decisions were made by a sole owner who accounted for the interdependence of all stands. These outcomes were compared at the steady state equilibrium to determine the increase in social welfare that resulted from coordination. When stands were independent with regards to how the degree of substitutability and complementarity in the production of amenity service changed over time, referred to as temporal independence, the rotation ages under all of the game theoretic behaviors were identical (Amacher et al. 2004). However if the stands were temporally dependent, then the difference between the optimal rotation age under sole ownership to those found under the Nash or Stackelberg scenarios depended on the spatial relationship of the parcels. Amacher et al. (2004) also analyzed the qualitative properties of the rotation ages under

different levels of landowner cooperation to determine the effect of various policy instruments. The effects of policy parameters were found to differ from those determined in a typical single-stand analysis and depended on the spatial interdependence and temporal dependence of stands, which landowner was affected by the parameter change, and the ability of landowners to effectively commit to a cooperative management scheme (Amacher et al. 2004).

Others have also considered the role that the spatial distribution of land has in forest management behavior, but these analyses were typically undertaken from the perspective of a single owner/manager. Albers (1996) examined the decisions regarding land use faced by a multitude of landowners in the tropics. These landowners' decisions were irreversible and there was uncertainty with regard to land tenure and benefits from preservation of land in forest use. The model of optimal land use decisions was constructed under the assumption of a single manager faced with a choice among four land uses for an equivalent number of plots over three time periods (Albers 1996). Albers (1996) incorporated the benefits created from the spatial distribution of parcels when preservation parcels were established in contiguous blocks, or when managed land was near preserved plots, which accounted for spatial interdependencies between parcels in the production of amenity values. Landowners in Albers' (1996) model were assumed to face uncertainty with regards to the benefits produced from preservation of land. In her analysis, Albers (1996) emphasized that landowners would benefit more from flexibility and knowledge of the implications of spatial patterns than from sustainable land uses that were less adaptive to future gains in information and to alternative uses. Zhang (2001) modeled the uncertainty landowners' face with regards to their ability to harvest when faced with the possibility of regulatory actions taken to protect endangered species. The probability of loss of harvesting ability to regulatory action depended on the characteristics of both own and adjacent

stands, where adjacent stand conditions were exogenous to the individual landowner's management decisions (Zhang 2001). The above are just two examples of how the interdependencies of stands were included in models of individual forest manager decisions, when adjacent management behaviors were modeled as an exogenous factor.

The interdependency among adjacent stocks was also investigated in other resource use problems. Zeitouni and Dinar (1997) examined the interrelationship between distinct supplies of water resources in a study of two adjacent aquifers and the outcomes under joint and independent management. The aquifers were physically related in that the direction and magnitude of flow between them was determined by the quantity of water in each aquifer, while the quality of water in each aquifer also affected management decisions (Zeitouni and Dinar 1997). Thus, management decisions were constrained by the quantity of water in each aquifer, in a sense that if the higher quality source was depleted, the remaining high quality water was compromised from flow from the lower quality source (Zeitouni and Dinar 1997). Under the assumptions that the aquifers differed in the quality of water and their capacity for natural renewal, Zeitouni and Dinar (1997) determined that independent management of the interrelated aquifers was optimal only when the differences in quality were sufficiently small or when recharge in the renewable aquifer of good quality prevented flow from the poor quality aquifer, otherwise joint management of the aquifer improved overall social welfare. However, the determination of optimal management from a social perspective did not account for the transactions costs associated with joint management that resulted from the coordination of use among several parties (Zeitouni and Dinar 1997).

Empirical literature

Survey-based analyses that assess probability of landowners' participation either independently or jointly with neighbors in ecosystem management type programs comprise most of the empirical literature. A survey of non-industrial private forest (NIPF) landowners in 11 states by Brunson et al. (1996) was the first to address individual landowner attitudes toward ecosystem management. Probability of participation in collaborative partnerships for the purpose of ecosystem management varied among the regions studied, with definite interest shown in 14% percent of Indiana respondents and 23% of respondents from Utah and the Southeast (Brunson et al. 1996). Those respondents that were uncertain about participation in collaborative partnerships indicated that they would rather observe a partnership at work, or would require certain conditions in place before the indicated their probability of participation (Brunson et al. 1996). Stevens et al. (1999) extended this work through utilization of conjoint analysis to evaluate landowner attitudes towards cooperative management. Landowners were asked to rate four possible management scenarios for either an individually managed parcel, or an area owned by three separate owners (including themselves) (Stevens et al. 1999). The probability of landowner participation in one of the cooperative management alternatives was not different when compared with identical individual management alternatives, *ceteris paribus* (Stevens et al. 1999). As expected, Stevens et al. (1999) also found that increased costs of program implementation and fewer positive attributes reduced the likelihood of landowner interest in participation.

In another survey-based study, Jacobson et al. (2000) examined South Carolina landowner interest in joint management. Five various groups of landowner characteristics and

attitudes were analyzed for their significance in determining participation in a joint management projects (Jacobson et al. 2000). Factors found to be significant at the 5% level in the models of individual groups were then combined in a final model to determine which characteristics had the most influence on landowner interest in joint planning (Jacobson et al. 2000). Jacobson et al. (2000) surmised that knowledge, beliefs, and attitudes or opinions of individual landowners were more indicative of interest in joint management than spatial, demographic, or land planning characteristics. In an extension of this work, Jacobson (2002) utilized a pair-wise statistical method to examine the importance of variables that would factor in the level of interest toward joint and ecosystem management. The demographic characteristics of age and education were found to be significant to a landowner's interest in joint management (Jacobson 2002). Similarly, interest in joint management was associated with those landowners who allowed hunting on their land, had a management plan, or were involved in agricultural cooperatives (Jacobson 2002). Jacobson (2002) concluded that education, technical assistance, and financial assistance could greatly improve attitudes and interest of landowners toward both joint and individual ecosystem management type projects.

In a similar vein, Klosowski et al. (2001) analyzed the effect of economic incentives on the probability of involvement in coordinated management programs by NIPF landowners. The effect of economic incentives on the (1) rank of programs, (2) landowner interest, and (3) probability of program participation were determined using conjoint analysis. The small sample of study participants prevented broad application of the results of this study (Klosowski et al. 2001). Results were fairly intuitive, in that probability of participation in any of the programs offered decreased with extent of commitment and increased economic value of timber enrolled, while it increased with offered incentives (Klosowski et al. 2001).

Sullivan et al. (2005) examined cooperative behavior of Southwest Virginia landowners, in the form of individuals ceding rights to forest management to a non-governmental organization (NGO) when presented with an annual payment (a banking type system). In this case, forest development rights would transfer to the NGO, which would then act as a sole owner in managing enrolled parcels. A referendum-based survey was implemented to assess individual landowner's willingness to accept guaranteed financial returns that would result from foregoing management rights on their land (Sullivan et al. 2005). Probability of bid acceptance was increased by increased bid offers, the extent of roads on the parcel, whether landowners owned more than one parcel, and whether the parcel was greater than 20 acres in size, while females and those landowners with interest in bequeathing land had a decreased probability of accepting a bid to forego forest management on their land (Sullivan et al. 2005). The above studies focused on estimating *whether* landowners would participate in a joint management program, but generally did not assess how adjacent parcel management affected management decisions of landowners.

Still other studies examined the relative costs and gains from cooperation among landowners. Uusivuori and Kuulivainen (2001) determined that landowners who cooperate in forest management efforts could offset welfare losses that resulted from imperfections in capital markets. Financial gains from collaboration between forest managers depended on the value of growth in the stands brought into the agreement, as well as the differences between interest rates for borrowers and lenders, and the apparent inflexibility of the borrowing constraint (Uusivuori and Kuulivainen 2001). Other types of gains from collaboration, in terms of increased amenities, or spatial interdependencies were not accounted for in Uusivuori and Kuulivainen's analysis. Similarly, there was no consideration for the effect that implementation of sustainable harvesting regimes have on overall social welfare in an analysis by Eid et al. (2001). Sustainable

harvesting regimes were analyzed under both individual and cooperative management schemes, where it was assumed that the objective of management was to maximize net present value (NPV) with linear programming algorithms applied to data from eight productive forest areas in Norway (Eid et al. 2001). Eid et al. (2001) concluded that although the NPV of the forest area would increase under cooperative management, compared with individual management, the returns to cooperation might not be enough to cover the transaction costs associated with cooperation (Eid et al. 2001).

Other studies have examined landowner behavior when faced with incentives designed to concentrate preservation areas adjacent to others in the same use (Smith and Shogren 2002, Parkhurst et al. 2002). Smith and Shogren (2002) and Parkhurst et al. (2002) examine the strategic behavior of individuals offered a financial bonus when acreages retired from active management were located adjacent to other retired acres. They found that such an incentive increased the propensity to preserve forest acres in large blocks. However, there were multiple equilibrium possibilities that resulted from the financial incentives offered in these simulation studies, which served to increase the potential for players to select a reserve pattern that was less effective in creation of favorable wildlife habitat (Parkhurst et al. 2002). When communication between players was allowed prior to selection of reserves it increased the probability of realization of the first-best outcome (Parkhurst et al. 2002).

3. Contribution of research in this dissertation

Despite what seems to be a large body of research on the interdependencies of parcels in the provision of amenities, and individual landowner attitudes toward cooperation, there is still a need for empirical examinations of the effect adjacent landowners have on the behavior of individual non-industrial landowners. The research in this dissertation provides insights into the factors underlying cooperative type behaviors among landowners, and whether or not landowners account for affects of management on adjacent parcels or try to anticipate future actions on surrounding lands in their behavior. However, if landowners exhibit behavior that does not account for adjacent landowners, then there may indeed be a cost that results from lack of coordination depending on the interdependencies among parcels in the production of amenity services among nearby owners. The role that adjacent parcels play in an individual landowner's forest management decisions is important when developing policies to alleviate these costs from lack of coordination or address many of the landscape level forest sustainability issues discerned in the past decade. In the following chapters, both a theoretical and empirical analysis of the spatial interdependencies among parcels and their effects on landowner behavior will be undertaken. These analyses will focus on the various forms of cooperation among landowners and the resulting effect on individual behavior and overall social welfare. Such an analysis contributes to a range of disciplines within forestry.

This work extends economic methodology by examining the implications of coordinated versus uncoordinated landowner behavior. The spatial relationship between stands, in terms of amenity production, has very different effects on the outcomes of management, both coordinated and uncoordinated. If a landowner values amenity benefits produced by own standing timber

stock, k_i , and adjacent standing stock, k_j , the utility relation can be expressed as $N(k_i, k_j)$. The landowner's marginal amenity valuation of each parcel indicates the spatial interdependencies of the parcels. That is, when stands are spatial complements, the landowner's marginal amenity valuation of each stand increases with the level of stock on the adjacent stand, that is,

$$\frac{\partial N(k_{it}, k_{jt})}{\partial k_{it} \partial k_{jt}} > 0, \forall t = 0, 1, 2, \dots, s.$$

This is often the case when individuals' value habitat for certain wildlife species that would prefer greater cover that would be provided by increasing stock levels. Similarly, when stands are spatial substitutes, the landowner's marginal amenity valuation of each stand decreases with the level of stock on the adjacent stand,

$$\frac{\partial N(k_{it}, k_{jt})}{\partial k_{it} \partial k_{jt}} < 0, \forall t = 0, 1, 2, \dots, s.$$

This is often the case when individuals value a particular aspect that is not necessarily specific to a particular forest, for instance if landowner just values having timber nearby for aesthetic purposes, increasing levels of stock on an adjacent parcel could easily substitute in this particular individual valuation. Under the assumption of the existence of a steady state, the outcomes of different levels of coordination for stands that are complementary in different ways should be compared in order to identify and quantify costs that result from uncoordinated individual private management.

There are also policy implications of this research. Policies addressing timber management across a landscape that rely on the evaluation of landowner behavior in a single-stand type analysis are misspecified without information on landowner and parcel interactions at a landscape level. With this knowledge, policies can be focused on the extent of interaction necessary to reach the best social outcome, especially considering the relation between stands in the production of amenity services. This research is also important to landowner modeling, as it provides empirical evidence of spatial interdependencies of parcels in the production of amenity

benefits to individuals across a landscape. Simulations of the various levels of coordination and of the effects of changes in the landscape and landowners could assist policy makers and forest managers, as well as provide predictions for timber supply well into the future.

4. Avenues for extension

An understanding of how adjacent management affects an individual landowner's behavior increases the possibilities for addressing landscape-level forest sustainability issues. An interesting extension of this work would be incorporation of the models of landowner behavior, like those in the following chapters that provide an initial assessment of the spatial interdependencies among parcels in the production of amenity benefits, with models of land use change. These integrated models could be employed in simulations to predict changes in forest cover and timber supply resulting from changes in timber markets, landowner preferences, and landscape characteristics.

Another interesting extension of the analysis of the effects of adjacent landowners on individual landowner behavior would involve an examination of behavior regarding management of invasive species. The outcomes of individual and joint invasive species management by landowners could be compared in order to determine the social costs, if any that stem from independent management behavior. Such an analysis would be further improved by studying the effect of various levels of information on landowner behavior towards management of invasive species and the effect of improved information on attitudes towards cooperative management. Research on adjacent landowner effects on NIPF behavior could also be applied to fire risk management. The outcomes of individual and joint actions to reduce fuel loading could be

analyzed to determine the need for policies to assist landowners in mitigating fire risk, which might be less costly than current fire suppression methods. The adjacent landowner research would not just apply to these topics, however, as it could be applied to a variety of current landscape level forest sustainability issues, such as water quality issues and determination of the benefits and costs associated with surface mining.

Chapter 2: A model of landowner interaction

1. Introduction

In forestry, management is typically considered from the perspective of an individual forest stand or landowner. Forest stands are delineated based on species composition and calendar age of the standing timber. However, forest stands come together to produce conditions that might be beneficial to areas larger than a single stand; for instance consider wildlife or watershed services. Spatial interdependence is the measure of the reliance of one parcel on another in the production of services that are anthropocentric or bio-centric in nature. The heterogeneity of forest stands is essential for some wildlife species whose survival depends on a mix of timber species and age classes. A forest output that is more anthropocentric in focus is the dependence on the interaction or coordinated management of several stands in the production of recreation services. The concept of ecosystem management, which focuses heavily on managing ecological properties of an area and thereby emphasizes the multiple uses of the landscape, also encompasses an area larger than a single parcel (Brunson et al. 1996). Similarly, many of the current forest sustainability threats, such as, managing watersheds, reducing areas of fire risk, and stemming the spread of invasive species, are issues that would be better addressed not at the level of an individual forest stand, but at a landscape level.

Typically, the study of forest management has been addressed at a forest stand level, without consideration of the interaction of stands in the provision of services and the effect that adjacent landowners have on individual amenity values. With increasing fragmentation of the forest landscape currently occurring in many regions where private forest ownerships are

prevalent, it is important to understand how forested parcels function in the production of services to both an individual landowner and to surrounding landowners.

When considering forest management decisions of a non-industrial private forest (NIPF) landowner, prior studies have not specifically considered the effects of individual landowner management on the values that adjacent landowners derive from that particular forest stock or the effect of adjacent owner decisions have on an individual landowners values derived from standing forest stock on their own parcel.³ Prior to the 1980s, it was common to assume that a landowner's objective in timber management was to maximize timber revenues generated from the stand (Amacher et al. 2003). Recently the common assumption is that an individual landowner manages timber resources with the objective of maximizing utility generated from the sum of benefits of timber revenues and services that do not have a specific market value, such as those generated from recreation on the stand, the existence of timber for bequest purposes, and others that are often referred to as non-timber benefits (Binkley 1981, Hyberg and Holthausen 1989, Conway et al. 2003). In examining management of an individual landowner, it is thought that the individual acts in order to maximize his or her own utility. However, if stands are spatially interdependent in the production of benefits, then an individual landowner managing land without considering the effect of their actions on the values of adjacent owners represents an externality.

Surrounding (proximate) landowners may also have amenity values that differ from those of an individual owner; for instance there are hunters of certain game that may have amenity functions that decrease with increasing conditions of forest stock. There are currently no incentives in place to reconcile the differences in management of proximate landowners and an

³ For a thorough review of literature on the timber harvesting behavior of NIPF landowners see Alig et al. (1989), Pattanayak et al. (2002), and Amacher et al. (2003).

individual for interdependent forest stands that would achieve the socially best outcome for stand management. If an individual manages land without considering the effects of their actions on the values place on amenities by adjacent landowners, then there is an externality created by the individual management of timbered stands, in that the individual may harvest timber stock at a level that is either lower or higher than what is optimal for all individuals in the effected region.

Few studies have examined the optimal management of several forest stands under multiple use management schemes. Hartman (1976), who was the first to consider amenity values when modeling harvest-scheduling decisions of landowners, suggested that management of a single stand within the boundaries of a parcel consisting of multiple stands would affect the value of the remaining timber stands on the parcel. Bowes and Krutilla (1985, 1989) were the first to examine optimal harvest scheduling of multiple stands using a specification of an amenity function that incorporated the concept of adjacent stand interdependence. In their analysis of landowner harvest scheduling, Bowes and Krutilla (1985) assume that the management of neighboring stands is endogenous to the problem, and thus they assume that a single owner manages a parcel of multiple stands where each stand has homogeneous productivity for multiple uses. Snyder and Bhattacharyya (1990) evaluated the optimal harvest-scheduling problem of an owner with multiple use objectives in a manner similar to that of Bowes and Krutilla (1985), but explicitly accounted for the costs associated with the provision of non-timber benefits by a competitive firm.

The specific spatial relationship of stands was also considered in the estimation of optimal harvest scheduling by Swallow and Wear (1993) and Swallow et al. (1997). Swallow and Wear (1993) analyzed management of a single stand identified by location under the assumption that a landowner behaved in order to maximize his/her own utility received from

standing and harvesting timber, where neighboring parcels were considered exogenous to the decision-making process. This differs from the approach of Swallow et al. (1997), who studied the management of an entire forest ecosystem in their analysis of optimal harvest scheduling in a multiple-use environment. Swallow et al. (1997) also track the spatial identity of forest stands, using location of the stand, and follow stand management over time. The management of neighboring stands is endogenous to the landowner's own problem of maximizing the utility derived from multiple uses within the forest ecosystem (Swallow et al. 1997). The substitution and wealth effects of stand management are accounted for by both Swallow and Wear (1993) and Swallow et al. (1997), who employ numerical simulations to analyze the spatial interdependence of stands, specifically concentrating their efforts on National Forest planning data. In their consideration of the efficiency of multiple use management of forest resources, Vincent and Binkley (1993) assumed a single forest owner allocated management effort between two identical forest stands. Vincent and Binkley (1993) studied how the production of two distinct products, timber and non-timber values, for two homogenous stands induced changes in management decision, finding that land use specialization was optimal.

Koskela and Ollikainen (1999) solved for the optimal rotation of public lands considering the interdependence of public and private forests in the production of amenities across a landscape in a two-period framework, under the assumption that adjacent management was endogenous to an individual landowner's decision. The work of Swallow and Wear (1993) and Swallow et al. (1997) was extended by Koskela and Ollikainen (2001) to formally examine the economic concept of complementarity and substitutability in the production of amenity services between a single stand and the adjacent stands that comprise a landscape or ecosystem. Private rotation age was evaluated using the concepts of both spatial and temporal interdependence,

where the latter measures the effects on complementarity and substitutability of stands when an individual rotation age was altered (see Koskela and Ollikainen 2001). Koskela and Ollikainen (2001) described the interaction between private and public agents in forest management under the assumption of a particular game theoretic behavior, where the public agency acted as a Stackelberg leader and the private landowner chose rotation age in the second stage of the game. Amacher et al. (2004) evaluated the economic concepts of complementarity and substitutability further through examination of other game theoretic possibilities for forest management. They assumed that benefits received by landowners were dependent on the rotation age of adjacent stands and the existence of unique steady state equilibrium and evaluated assumptions regarding timing and execution of adjacent landowner decisions under equivalent rotation ages (see Amacher et al. 2004).

This chapter serves to address several issues that have been examined in the economic management of interdependent forest stands and extend upon them to specifically evaluate the effects on welfare generated from the extent (or lack) of coordination among individual landowners. I follow the studies of Koskela and Ollikainen (1999, 2001) and Amacher et al. (2004) by including the economic concepts of spatial interdependence in the provision of goods or services by standing forest stock, and under the assumption of a unique steady state examine various assumptions about timing of adjacent landowner decisions. The work here is unique in that it assumes that landowners receive timber and non-timber benefits that depend not on the rotation ages of own stand and adjacent stand(s), but on the *in situ* stock of these stands. By accounting for benefits from forest stands in this manner, both even-aged and uneven-aged forest management possibilities can be evaluated, without the restrictive assumption of identical rotation ages as in Amacher et al. (2004).

I also incorporate uncertainty that an individual landowner has regarding adjacent landowner preferences, and how non-timber benefits on their own stands depend on adjacent stand conditions. Under the assumption of the existence of a unique steady state, I examine various degrees of cooperation that are possible between landowners. In examining the outcomes of various behavioral responses for stands that are spatially interdependent in different ways, i.e., substitutes, complements, or independent in the production of non-timber amenities, it is possible to determine which behavior produces the socially best outcome through comparison.

The main findings of this analysis can be characterized as follows. When decisions are made without regards to their effects on adjacent landowners, landowners are effectively behaving under strategic assumptions typified by a Nash game. In a Nash game, an individual landowner assumes that decisions occur simultaneously with neighbors. The forest stock level decision is also examined under cooperative regimes that result in outcomes similar to those of a sole owner that accounts for the interdependence among neighboring stands when making decisions regarding forest management. In these cooperative regimes, I examine situations where landowners cooperate in managing stands to receive a better price for timber, cooperate in the production of non-timber benefits, and cooperate fully in their actions. Comparing the outcomes of simultaneous and various cooperative behaviors shows the importance of coordination in management; this provides insight into the cost from lack of coordination among landowners when determining the management of forests.

The remainder of this chapter is organized as follows. In the next section, I introduce the model of forest management in a dynamic utility-based framework and evaluate the decisions of a single landowner. Section 3 examines the various levels of cooperation among adjacent landowners in the timing of decisions regarding the forest stock. Section 4 presents an analysis

of landowner behavior under the assumption that all decisions are made simultaneously. Section 5 compares outcomes when landowners make decisions simultaneously with those resulting from cooperation, thus providing an initial assessment of the cost (if any) from lack of coordination among landowners. Finally, some concluding remarks are presented in Section 6.

2. Model of adjacent landowners

Consider a landscape populated by $i=1, \dots, n$ landowners. Each individual landowner, i , is bordered by $1 \dots n-1$ adjacent landowners. The utility each landowner receives is assumed to be separable in income and non-timber benefits, following in the spirit of Hartman (1976). An individual landowner maximizes utility at any point in time by making harvesting choices that determine the amount of stock in their stand in the current period.

Non-timber benefits (N) received by each landowner are assumed to depend on the landowner's own forest stock and on adjacent forest stocks, i.e. adjacent landowner forest management decisions. Examples of non-timber benefits include recreation, wildlife habitat, bequest values, and protection of water quality. I define the 'focal' landowner to be the landowner of interest, and the 'adjacent' landowners to be those from the set of $n-1 \equiv j$ landowners who have land adjoining or neighboring the focal landowner. Information is revealed at the beginning of the period, thus the landowner in period t will know the actions of adjacent landowners in that period. However, the landowner may not know the behavior of adjacent landowners in future periods ($t+1, \dots, t+s$) with certainty and the landowner may not fully know how the production of non-timber amenities on their own stand(s) depend on the

condition of adjacent stock(s). Uncertainty here arises because the adjacent forest stock is unknown to the focal landowner - it depends on future decisions of the adjacent owner.

There are two types of landowner decision making considered in this chapter: (1) harvesting where the landowner does not consider the actions of adjacent landowner, and (2) harvesting where landowners make decisions strategically. The latter requires solving a dynamic Nash equilibrium between adjoining landowners, many of whom may not have the same preferences or behavior regarding harvesting. The prospect that landowners make strategic decisions and the exact behavior of landowners in this equilibrium will depend on how non-timber benefits depend on adjacent landowner decisions. In all types of models the individual landowner chooses the level of harvesting (stock removal) undertaken in the current period. Therefore, given some period t , forest stock held by the adjacent landowner in the next period could be a random variable from the perspective of the individual landowner.

In the following model, I also reasonably assume that the actions taken by any adjacent landowner affect non-timber benefits obtained by the focal landowner. These adjacent landowner actions represent a random variable each period to the focal landowner's decision making. The random variable has a distribution that only depends on the current time period and the values of the state variables in the current time period, i.e. it is time invariant. The probability of adjacent stock harvest is assumed to be independent of previous harvesting of stocks on adjoining land parcels. The probability distribution in the current time period depends only on the current values of the state and control variables, but not on past or future decisions (Léonard and Van Long 1992).

Single landowner problem

The focal landowner receives utility in each period equal to the sum of harvesting income, if harvesting occurs, plus non-timber benefits accruing to remaining forest stock, where utility is assumed separable in consumption and non-timber benefits,

$$V_t = \max_{x_{it}} U(c_{it}; \Omega) + N(k_{it}, k_{jt}), \forall i \neq j. \quad (1)$$

Assuming that the landowner wants to maximize utility over time, the following Bellman equation can be used to explain the landowner's objective,

$$V_t = \max_{x_{it}} U(c_{it}; \Omega) + N(k_{it}, k_{jt}) + \beta EV_{t+1}(c_{it+1}, k_{it+1}, \tilde{k}_{jt+1}). \quad (2)$$

The expression in equation (2) states that, at any point in time t , utility derived from forest services is a function of rents from period t plus discounted future utility, conditional on all past decisions that determine the forest stock at time t . Utility from timber production also depends on the individual's preferences, such as bequest motives, income, etc., which are represented by the vector Ω . This formulation accounts for the present value of standing timber, in terms of both income and non-timber values, as well as the opportunity costs of using the land for forestry by accounting for the effect of decisions made in the present on marginal returns obtained from this use of land in the future. Also, in the above formulation, the k variables are representative of *unharvested* forested stock in each period, as there are no amenity values associated with harvested forest stock (see Hartman 1976).

The Bellman equation is written with the interaction of adjacent landowners in mind. The Bellman equation represents the present value of all decisions starting at time t , thus future utility is discounted by the constant rate β ($0 < \beta < 1$). The term k_{it} is the stock held by the focal landowner at the beginning of time period t . The beginning stock at time zero is defined by the

endowment of forest stock at time zero, i.e., $k_{i0} = Q_0$. In (2), the term k_{jt} then represents a vector of time t forest stocks on adjacent land held by $n-1$ landowners. This stock can be considered a random variable from the perspective of the focal landowner; where a general continuous distribution, $D(K)$, is assumed. The random variable has a distribution that is time invariant, i.e., at time t it only depends on the time t value of the parameter, adjacent forest stock. I return to a consideration of the distribution of the random variable later in this chapter.

The term c_{it} in (1) and (2) represents the focal landowner's consumption at time t . Current and future consumption by a landowner are given by the following equations,

$$c_{it} = Px_{it} + M_{it} - S_{it}, \text{ and}$$

$$c_{it+1} = Px_{it+1} + M_{it+1} + (1+r)S_{it} - S_{it+1}. \quad (3)$$

Where x_{it} is the quantity of timber stock harvested at time t by the individual landowner, S_{it} is landowner's monetary savings at time t , and M_{it} represents exogenous income from sources other than timber at time t . For the time being, the individual landowner is assumed to take prices, P , as exogenous to consumption.

The landowner's maximization problem is also subject to the following equation of motion for the forest stock:

$$k_{it+1} = g(k_{it} - x_{it}) + k_{it} - x_{it}, \quad (4)$$

where the left hand side represents landowner i 's beginning of period $t+1$ stock $\forall t=0, 1, 2, \dots, s$. The level of stock at the beginning of period $t+1$ is thus determined by the growth of the stock remaining from the previous period, determined by the initial stock minus any stock harvested, added to the remaining stock from the previous period.

The above equations (2), (3), and (4), state that an individual landowner maximizes utility from forest resources, in terms of timber consumption dependent upon his/her own preferences,

and in terms of non-timber benefits accruing from his/her own standing forest stock and adjacent stocks (j) over time. The non-timber benefit possibilities depend on adjacent landowner stocks, but I assume that the forest growth possibilities of each landowner do not depend on adjacent forest stocks; which is reasonable given the small growing space of a tree. This assumption is consistent with other work on adjacent stand management (Swallow and Wear 1993, Swallow et al. 1997, Amacher et al. 2004). The expectation term is a result of the uncertainty the focal landowner has with regards to how adjacent landowners will manage land in the future (i.e., adjacent preferences), as well as a lack of information regarding how the production of non-timber benefits on their own parcels depend on adjacent stand conditions.

It proves useful to work with the control formulation of the Bellman equation and substitute from the equations of motion into (2). This is accomplished under the simplifying assumption that forest growth is given by

$$g(k_{it} - x_{it}) = \Delta(k_{it} - x_{it}), \quad (5)$$

where Δ is a constant. Using this assumption and taking the equation of motion forward by one period,

$$x_{it+1} = \Delta(k_{it+1} - x_{it+1}) + k_{it+1} - k_{it+2}, \quad (6)$$

it is possible to solve for x_{it+1} as a function of x_{it} . Substituting (4) into (6), obtain an expression for x_{it+1} as a function of x_{it} ,

$$x_{it+1} = \frac{-k_{it+2} + (1+\Delta)^2(k_{it} - x_{it})}{(1+\Delta)} = \psi. \quad (7)$$

Using equation (7) in (2) allows us to express the Bellman equation as a function of terms in the current control variable x_{it} . Given that utility is separable in timber and non-timber benefits, the uncertainty regarding future adjacent forest stocks is realized through the path of future benefits captured by the focal landowner in the next period.

Using the above derivations and assumptions, equation (2) is now rewritten:

$$V_t = \max_{x_{it}} U(c_{it}; \Omega) + N(k_{it}, k_{jt}) + \beta(E[U(c_{it+1}; \Omega) + N(k_{it+1}, \tilde{k}_{jt+1})]). \quad (2')$$

Using equation (2) and (2') and substituting from (3) and (7), I obtain,

$$V_t = \max_{x_{it}} U(Px_{it} + M; \Omega) + N(k_{it}, k_{jt}) + \beta[E\{U(P\psi + M; \Omega)\} + E\{N(k_{it+1}, k_{jt+1})\}]. \quad (2'')$$

Sufficient conditions for existence of a solution are that the utility at any time must be real valued, continuous, concave, and finite (Mas-Colell et al. 1995). The state space must also be compact and concave. The first requirement is satisfied given that $N(0,0) < \infty$. The second is satisfied given that $\beta < 1$. Continuity and concavity are satisfied because the growth function and non-timber benefit functions are differentiable and continuous.

The first order condition with respect to x_{it} is,

$$V_{x_{it}} = PU_{c_{it}}(\cdot) + \beta \frac{\partial E}{\partial} \left[\frac{U(P\psi; \Omega)}{x_{it}} \right] + \beta \frac{\partial E}{\partial} \left[\frac{N(k_{it+1}, \tilde{k}_{jt+1})}{x_{it}} \right] = 0. \quad (8)$$

Differentiating equation (7) and the equation of motion (4) with respect to x_{it} results in:

$$\frac{\partial x_{it+1}}{\partial x_{it}} = \frac{\partial k_{it+1}}{\partial x_{it}} = -(1 + \Delta). \quad (9)$$

Recall the assumption that \tilde{k}_{jt+1} is a random variable with distribution $D(K)$ defining whether the stock has been harvested or not in the next period by the adjacent landowner. Using this assumption a more general expression for the optimal harvesting rule over time is obtained,

$$V_{x_{it}} = PU_{c_{it}}(\cdot) + \beta \int_0^1 \frac{\partial U(\cdot)}{\partial x_{it}} dD(X) + \beta \int_0^1 \frac{\partial N(\cdot)}{\partial x_{it}} dD(K) = 0. \quad (8')$$

The expression in equation (8') can further expanded using the chain rule to obtain,

$$V_{x_{it}} = PU_{c_{it}}(\cdot) + \beta \int_0^1 \frac{\partial U(\cdot)}{\partial c_{it+1}} \frac{\partial c_{it+1}}{\partial x_{it+1}} \frac{\partial x_{it+1}}{\partial x_{it}} dD(X) + \beta \int_0^1 \frac{\partial N(\cdot)}{\partial k_{it+1}} \frac{\partial k_{it+1}}{\partial x_{it}} dD(K) = 0. \quad (8'')$$

Substituting (9) into equation (8'') results in the following,

$$V_{x_{it}} = PU_{c_{it}}(\cdot) - \beta \int_0^1 (1 + \Delta) PU_{c_{it+1}}(\cdot) dD(X) - \beta \int_0^1 (1 + \Delta) \frac{\partial N(k_{it+1}, \tilde{k}_{jt+1})}{\partial k_{it+1}} dD(K) = 0. \quad (8''')$$

Equation (8''') equates the marginal benefit of delaying harvest, $PU_{x_{it}}(\cdot)$, to the expected discounted opportunity cost of delaying harvest. Timber harvesting behavior of a landowner is thus determined through an assessment of the present value of benefits resulting from harvesting, as well as the expected costs generated from delaying harvest for an additional year,

$$\beta \int_0^1 (1 + \Delta) PU_{c_{it+1}}(\cdot) dD(X) - \beta \int_0^1 (1 + \Delta) \frac{\partial N(\cdot)}{\partial k_{it+1}} dD(K). \text{ The expected costs of delaying harvest are}$$

derived from both timber and non-timber values, where the latter is determined by the present stock on the landowner's own parcel, as well as on adjacent stands. A landowner would only undertake harvesting when the marginal benefit of delaying harvest is equal to the opportunity costs of delaying harvesting, which are essentially the expected costs of delay of harvest to the landowner in terms of lost timber and non-timber benefits from letting the stock grow an additional year.

Using the implicit function theorem, it is possible to determine how the steady state level of harvesting responds to a change in the expectation of adjacent stock (see Appendix 1 for specification of the steady state). Here, it becomes convenient to express the parameter \tilde{k}_{jt+1} explicitly using a mean preserving spread,

$$\tilde{k}_{jt+1} = \alpha(\tilde{k}_{jt+1} + h(\tilde{k}_{jt+1} - \bar{k})). \quad (10)$$

This form can then be used to express overall utility as a function of harvesting by the focal landowner at time t (the control variable) and of the parameters α and h as $V(x_{it}; \alpha, h)$. It is then possible to determine how an individual landowner's steady state level of stock changes with a

change in either α (the mean) or h (a term related to the variance) by totally differentiating the first order condition (8'''), again making use of the envelope theorem and the existence of a steady state (see Appendix 1 for proof of existence):

$$V_{x_{it}x_{it}} \partial x_{it} + V_{x_{it}\alpha} \partial \alpha + V_{x_{it}h} \partial h = 0, \quad (11)$$

where the following define the derivatives in (11),

$$V_{x_{it}x_{it}} = P^2 U_{c_{it}c_{it}}(\cdot) + \beta \left[\int_0^1 (1+\Delta)^2 P^2 U_{c_{it+1}c_{it+1}} dD(X) + \int_0^1 (1+\Delta)^2 \frac{\partial^2 N(\cdot)}{\partial k_{it+1}^2} dD(K) \right] < 0, \quad (12a)$$

$$V_{x_{it}\alpha} = \beta \int_0^1 (-1-\Delta) \left[\tilde{k}_{j_{t+1}} + h(\tilde{k}_{j_{t+1}} - \bar{k}) \frac{\partial N_{t+1}(\cdot)}{\partial k_{it+1} \partial \tilde{k}_{j_{t+1}}} \right] dD(K) >, <, = 0, \text{ and} \quad (12b)$$

$$V_{x_{it}h} = \beta \int_0^1 (-1-\Delta) \left[\alpha(\tilde{k}_{j_{t+1}} - \bar{k}) \frac{\partial N_{t+1}(\cdot)}{\partial k_{it+1} \partial \tilde{k}_{j_{t+1}}} \right] dD(K) >, <, = 0. \quad (12c)$$

Use equation (11) to derive expressions for the comparative statics of the system at the steady state. The comparative static results are given by:

$$\frac{\partial x}{\partial h} = - \frac{V_{x_{it}h}}{V_{x_{it}x_{it}}}, \text{ and} \quad (13a)$$

$$\frac{\partial x}{\partial \alpha} = - \frac{V_{x_{it}\alpha}}{V_{x_{it}x_{it}}}, \quad (13b)$$

where equations (12a-c) define the terms in the numerator and denominator. In equations (13a) and (13b) the denominator is just the second order condition for equation (8'''), which from equation (12a) is negative (see Appendix 1). Therefore, the sign of the left hand side expressions in both equation (13a) and (13b) depend on the sign of the numerator.

From equations (12b) and (12c) the numerator can have multiple signs, determined by the sign of the $\frac{\partial N_{t+1}(\cdot)}{\partial k_{it+1} \partial \tilde{k}_{j_{t+1}}}$ term, if harvesting by the individual is a discrete decision, while the

$(-1 - \Delta)$ has the effect of altering the sign when harvesting is a continuous action. This term is representative of the spatial interdependence of stands, an assessment of how an individual's amenity valuation for own stock and adjacent stock responds to the level of adjacent stock. The focal landowner therefore determines their management with an expectation of the behavior of adjacent landowners. For instance, if amenity valuation of forest stocks on own land and adjacent parcels are increasing with the level of adjacent stock, the stands are spatial

complements, that is $\frac{\partial N_{t+1}(\cdot)}{\partial k_{it+1} \partial \tilde{k}_{jt+1}} > 0$. In responding to a shift in one of the parameters, equations

(12a) and (12b), the landowner attempts to mitigate this shift by returning back to the acceptable level of amenity production between stands, in order to reach his/her own steady state level of timber stock. For instance, when stands are spatial complements, a shift in one of the parameters

would effectively increase the steady state level of harvest, $\frac{\partial x_{it}}{\partial h}, \frac{\partial x_{it}}{\partial \alpha} > 0$ and offset the

landowner's timber management at the point of shift.

Spatial interdependence of the parcels is determined by whether the landowner's amenity values for own stock and adjacent stock increase, decrease, or remain constant with increasing levels on the stands. The direction of amenity valuation determines whether the stands are complements, substitutes, or independents, respectively. The stands are spatial complements in the production of the individual's amenity values when the marginal amenity valuation of both

own and adjacent stocks increases with the level of adjacent stock, $\frac{\partial N(k_{it+1}, \tilde{k}_{jt+1})}{\partial k_{it+1} \partial \tilde{k}_{jt+1}} > 0$. In this

case, any individual parcel provides a particular benefit when considered along with adjacent parcels that form the landscape, and thus is more valuable to the landowner as stock levels increase. On the other hand, when the focal landowners marginal amenity valuation of the

stocks decreases with increasing level of adjacent stocks, $\frac{\partial N(k_{it+1}, \tilde{k}_{jt+1})}{\partial k_{it+1} \partial \tilde{k}_{jt+1}} < 0$, the stands are

considered to be spatial substitutes in the production of amenity benefits. In this case, a landowner can harvest his/her own stand and still receive amenities from adjacent stocks that are still standing. When the condition of adjacent stocks has no effect on an individual landowner's

amenity benefits, $\frac{\partial N(k_{it+1}, \tilde{k}_{jt+1})}{\partial k_{it+1} \partial \tilde{k}_{jt+1}} = 0$, the stands are spatially independent. Now, the landowner's

marginal amenity valuation remains constant with changes in the level of the adjacent stock. In this case, actions by the adjacent landowner would not alter the individual landowner's forest management. A landowner may try to anticipate the actions of adjacent landowners; by harvesting increased or decreased levels of stock when stands are spatially interdependent than would be the case if they were aware of adjacent landowner preferences for standing timber.

An individual landowner's timber-harvesting behavior therefore depends on the spatial relationships of the focal landowner's forest stand with forest stands held by adjacent landowners, and also on the expectation of adjacent landowner behavior and the pattern of adjacent forest stocks. Recall, in the current set-up the assumption is that the focal landowner takes the adjacent forest stock as exogenous. The focal landowner expects that the condition of adjacent stocks and adjacent forest management be not affected by the landowner's own management actions.

Spatial relationships of stands with regard to non-timber benefits include several cases. Following Swallow and Wear (1993), suppose that there is a geographic area composed of just a focal stand and one adjacent stand. The focal landowner values both timber production and wildlife habitat provided by the stands, and wildlife roam freely between the stands. Now suppose that the adjacent landowner has a stand that consists of mostly cover habitat for wildlife,

while the focal landowner has a stand that produces a particularly good food source for wildlife. Suppose that the adjacent landowner harvests his timber, effectively decreasing cover. Due to the decrease in wildlife habitat, the focal landowner may then increase timber production, as now their non-timber benefits for their own standing timber have become less valuable due to loss of wildlife habitat on the adjacent stand; this is an example of spatial complements.

Now suppose both stands supply cover and food for wildlife. If the adjacent landowner harvests, effectively decreasing their timber stock, then this may increase the dependence of wildlife on the focal stand to meet habitat needs. The focal landowner's amenity values for their own stand increases, resulting in a decrease in emphasis on timber production. This is an example of spatial substitutes. If the stands are spatially independent, then the focal landowner only considers the non-timber benefits obtained from his/her own timber stock when making forest management decisions, resulting in a modified (in terms of utility) Hartman equation.

Defining the distribution of adjacent forest stocks

An alternate method for solving the Bellman equation, and one that makes it easier to consider an econometric form of the model is to rewrite equation (2) using a specific distribution for the adjacent timber stock random variable. Suppose, for example, the adjacent stock is a random variable with a binary distribution, i.e., either it is present or not present. Equivalently, this relates to a case where harvesting on adjacent land either occurs or does not occur in future periods. Define the probability that adjacent stock is present by $\Pr(\tilde{k}_{j+1} > 0) \equiv \eta$, and the probability that adjacent stock is not present by $\Pr(\tilde{k}_{j+1} = 0) \equiv 1 - \eta$. Recall, the assumption that

utility from non-timber benefits has an upper bound, i.e., $N(0,0) < \infty$. Thus, this probability assumption can be used to rewrite the last term in equation (2''), $E\{N(k_{it+1}, \tilde{k}_{jt+1})\}$, as,

$$\eta[N(k_{it+1}, \tilde{k}_{jt+1})] + (1 - \eta)[N(k_{it+1}, 0)]. \quad (14)$$

Substituting 14 into (2'') results in a modified Bellman equation,

$$V_t = \max_{x_{it}} U(Px_{it} + M; \Omega) + N(k_{it}, k_{jt}) + \beta\{EU(P\psi + M; \Omega) + \eta[N(k_{it+1}, \tilde{k}_{jt+1})] + (1 - \eta)[N(k_{it+1}, 0)]\} \quad (15)$$

Following a procedure similar to the one used before, the first order condition for the steady state level of harvesting becomes,

$$V_{x_{it}} = PU_{c_{it}}(\cdot) - \beta \left[\int_0^1 (1 + \Delta) PU_{c_{it+1}}(\cdot) dD(X) + \eta \left\{ (1 + \Delta) \frac{\partial N(k_{it+1}, \tilde{k}_{jt+1})}{\partial k_{it+1}} \right\} + (1 - \eta) \left\{ (1 + \Delta) \frac{\partial N(k_{it+1}, 0)}{\partial k_{it+1}} \right\} \right]. \quad (16)$$

Observe that equation (16) is simply a modified equation (8'''). The economic interpretation of equation (16) is that the single landowner will harvest when the marginal amenity benefits from delaying harvest, $PU_{c_{it}}(\cdot)$, are equal to the marginal costs of delay, in terms of negated future benefits generated from preserving the stock an additional period,

$$\beta \left[\int_0^1 (1 + \Delta) PU_{c_{it+1}}(\cdot) dD(X) + \eta \left\{ (1 + \Delta) \frac{\partial N(k_{it+1}, \tilde{k}_{jt+1})}{\partial k_{it+1}} \right\} + (1 - \eta) \left\{ (1 + \Delta) \frac{\partial N(k_{it+1}, 0)}{\partial k_{it+1}} \right\} \right]. \quad \text{Here, it is}$$

evident that these marginal opportunity costs are given by the expected benefits from invested current timber revenues and non-timber amenity production that would begin in the present period and evolve over time, as opposed to delaying a new cycle of amenity production on the land. The expected benefits the landowner receives from non-timber related products depend on the levels of both their own stock and the probability that adjacent stocks maintain their pre-existing levels. The landowner would thus harvest when there are no additional benefits

accruing to standing timber from growth of the stock, either in the form of timber or non-timber related valuations.

Expressing the parameter \tilde{k}_{jt+1} again with a mean preserving spread, the total differential terms are:

$$V_{x_{it}x_{it}} = P^2 U_{c_{it}c_{it}}(\cdot) + \beta \left[\int_0^1 (1+\Delta)^2 P^2 U_{c_{it+1}c_{it+1}}(\cdot) dD(X) \right] + \beta \left[\eta \left((1+\Delta)^2 \frac{\partial^2 N(k_{it+1}, \tilde{k}_{jt+1})}{\partial k_{it+1}^2} \right) + (1-n) \left((1+\Delta)^2 \frac{\partial^2 N(k_{it+1}, 0)}{\partial k_{it+1}^2} \right) \right] < 0, \quad (17a)$$

$$V_{x_{it}\alpha} = \beta \left[\eta \left(-(1+\Delta) (\tilde{k}_{jt+1} + h(\tilde{k}_{jt+1} - \bar{k})) \frac{\partial N(k_{it+1}, \tilde{k}_{jt+1})}{\partial k_{it+1} \partial \tilde{k}_{jt+1}} \right) \right] >, <, = 0, \text{ and} \quad (17b)$$

$$V_{x_{it}h} = \beta \left[\eta \left(-(1+\Delta) (\alpha(\tilde{k}_{jt+1} - \bar{k})) \frac{\partial N(k_{it+1}, \tilde{k}_{jt+1})}{\partial k_{it+1} \partial \tilde{k}_{jt+1}} \right) \right] >, <, = 0 \quad (17c)$$

The comparative static terms can again be expressed as in equations (13a) and (13b). The sign of the left hand side of the comparative static equations $\frac{\partial x_{it}}{\partial \alpha}$, $\frac{\partial x_{it}}{\partial h}$ depend on the sign of the numerator of the right hand side term. Using equations (17a) – (17c), it is more apparent that the sign of the numerator hinges on the spatial interdependence of stands in the production of amenity benefits represented by $\frac{\partial N(k_{it+1}, \tilde{k}_{jt+1})}{\partial k_{it+1} \partial \tilde{k}_{jt+1}}$. An expected shift in the mean (or variance) of

the condition of adjacent stock would serve to increase, decrease, or have no effect on the steady-state level of harvesting. A negative value for the term representing spatial interdependence

$\frac{\partial N(k_{it+1}, \tilde{k}_{jt+1})}{\partial k_{it+1} \partial \tilde{k}_{jt+1}} < 0$ indicates that the stands are spatial substitutes in the individual's amenity

valuation. That is the landowner's marginal amenity benefit received from own stock decreases

with an increase in the level of adjacent stock, and thus the landowner would decrease the steady state level of own stock in response to a shift in either the mean level of adjacent stock or the variance in the level of adjacent stock. While an increase in the marginal amenity valuation of own stock and adjacent stock with an increase in the level of adjacent stock indicate the stands are complements, $\frac{\partial N(k_{it+1}, \tilde{k}_{jt+1})}{\partial k_{it+1} \partial k_{jt+1}} > 0$, and the landowner would be expected to decrease the level

of his/her own stock in response to a shift in one of the parameters describing adjacent stock. If the shift is neutral, that is the stands are spatially independent $\frac{\partial N(k_{it+1}, \tilde{k}_{jt+1})}{\partial k_{it+1} \partial k_{jt+1}} = 0$, then there

would be no change in the landowners amenity valuation of their own stand in response to a shift in the level of adjacent stock. These are properties that are site specific and do not depend on the stock level between harvests. When the stands are spatially independent, the focal landowner derives amenity benefits solely from his/her own stock and thus has no concern about the exogenous change in the adjacent stock when determining his/her own forest management behavior.

3. Landowner cooperation

Suppose the initial assumption that landowners' behave independently taking adjacent stocks to be exogenous to their decision is relaxed and the possibility exists for landowner cooperation. It will be assumed throughout this section that the landowner is able to commit to the action (type of cooperation) investigated. A common form of cooperation involves landowners jointly managing harvests in order to obtain higher prices from a logger (see Kittredge (2001) for an example of this practice in Sweden). Consider the following example in the model above: At

the beginning of period t , the focal landowner considers his/her harvesting options. One of the factors that the landowner can take into account is cooperation, in terms of coordinating future harvests, with a neighboring landowner. Such cooperation could be beneficial to both landowners in terms of bringing a better price for timber from a logger who harvests both tracts at one time, given that the logging economies of scale and greater access should lower the cost of harvesting (Jacobson 2002). Another possible type of cooperation would be for adjacent landowners to schedule harvests in order to provide suitable habitat for a jointly valued wildlife species. The individual landowner would then consider the level of harvesting and cooperation that would maximize their own utility from forest management. Here the situation is simplified for ease of notation to examine cooperation between two landowners. The behavior of a single landowner is evaluated. A number of cases are examined, including: cooperation affecting prices, cooperation affecting non-timber benefit production, and cooperation affecting both prices and non-timber benefit production.

Landowner cooperation affects price

Suppose that future period prices, beyond time t , are a function of landowner cooperation undertaken in period t $\tilde{P} \equiv P_{t+1}(\gamma_i | \bar{\gamma}_j)$, where γ_i denotes the degree of the focal landowner's cooperation. This can be either an indicator of the focal landowner's cooperation ($\gamma_i = 0,1$) or a

measure of the level of cooperation undertaken. It is assumed throughout this analysis that $\frac{\partial \tilde{P}}{\partial \gamma_i} > 0$ and $\frac{\partial^2 \tilde{P}}{\partial \gamma_i^2} = 0$. The price in future periods is therefore a function of cooperation of the focal

landowner conditional on the expectation of cooperation with adjacent landowner, and assumes that the landowner can commit to cooperation in terms of synchronizing harvests with neighboring landowners.

The new dynamic programming model, from an individual landowner's perspective, for this type of cooperation has two control variables: the current level of harvesting and the degree of cooperation. Formulating the new Bellman equation for this case:

$$V_t = \max_{x_{it}, \gamma_{it}} U(P_t x_{it} + M; \Omega) + N(k_{it}, k_{jt}) + \beta U(\tilde{P} x_{it+1}, \Omega) + E[N(k_{it+1}, \tilde{k}_{jt+1})]. \quad (18)$$

The first order conditions of (18) are:

$$V_{x_{it}} = P_t U_{c_{it}}(\cdot) - \beta \left[(1 + \Delta) \tilde{P} U_{c_{it+1}}(\cdot) \right] - \beta \left[\int_0^1 (1 + \Delta) \frac{\partial N(\cdot)}{\partial k_{it+1}} dD(K) \right] = 0, \text{ and} \quad (19a)$$

$$V_{\gamma_{it}} = \beta \psi \tilde{P}_{\gamma_{it}} U_{c_{it+1}}(\cdot) = 0, \quad (19b)$$

where equation (19a) is similar to equation (8''') with the inclusion of a few substitutions and the new price term, thus it has the same mathematical interpretation. The economic

interpretation is that the individual landowner equates the marginal benefit from delaying

harvest, in terms of the present value of harvesting timber $PU_{c_{it}}(\cdot)$, to the marginal opportunity

costs of delaying harvest, $\beta \left[(1 + \Delta) \tilde{P} U_{c_{it+1}}(\cdot) \right] - \beta \left[\int_0^1 (1 + \Delta) \frac{\partial N(\cdot)}{\partial k_{it+1}} dD(K) \right]$. This latter term, along

with the expected non-timber benefits associated with delay, now includes a price effect resulting

from the level of cooperation that multiplies the timber benefit from delay. This price effect

serves to alleviate some of the uncertainty associated with future timber benefits. Equation (19b)

states that the discounted product of the marginal utility with respect to cooperation, $\beta U_{c_{it+1}}(\cdot)$,

and the marginal price that results from cooperation, $\psi \tilde{P}_{\gamma_{it}}$, of the focal landowner must equal

zero. That is the landowner will be indifferent toward entering a cooperative that functions to improve the price of timber when the gains from cooperation in terms of price are offset by the transaction costs the landowner incurs from cooperation, in terms of offsetting timber benefits.

There is an externality evident in the last term on the right hand side of equation (19a). The focal landowner seeks to maximize their own utility from cooperation in timber harvesting that result in a higher price from timber and the expectation of non-timber amenities that they receive from their own stand and adjacent stands. The landowner in this situation still has no incentive to consider the effects of their actions on the non-timber benefits accruing to adjacent stands, or the utility and behavior of the adjacent landowner.

Now, under the existence of a steady state (see Appendix 2 for proof) it is possible to examine the how the steady-state levels of the control variables over time, cooperation and current period harvest, respond to changes in the parameters α and h , which are the mean of adjacent stock and a term related to the variance in adjacent stock levels, respectively. Totally differentiating the necessary conditions, in the steady state, produces the following,

$$V_{x_{it}x_{it}} \partial x_{it} + V_{x_{it}\gamma_i} \partial \gamma_i + V_{x_{it}\alpha} \partial \alpha + V_{x_{it}h} \partial h = 0, \quad (20a)$$

$$V_{\gamma_i x_{it}} \partial x_{it} + V_{\gamma_i \gamma_i} \partial \gamma_i + V_{\gamma_i \alpha} \partial \alpha + V_{\gamma_i h} \partial h = 0, \quad (20b)$$

$$\text{where } V_{x_{it}x_{it}} = P^2 U_{c_{it}c_{it}}(\cdot) + \beta \left[(1+\Delta)^2 \tilde{P}^2 U_{c_{it+1}c_{it+1}}(\cdot) \right] + \beta \left[\int_0^1 (1+\Delta)^2 \frac{\partial^2 N(\cdot)}{\partial k_{it+1}^2} dD(K) \right] < 0, \quad (21a)$$

$$V_{x_{it}\alpha} = \beta \int_0^1 (-1-\Delta) (\tilde{k}_{jt+1} + h(\tilde{k}_{jt+1} - \bar{k})) \frac{\partial N(\cdot)}{\partial k_{it+1} \partial \tilde{k}_{jt+1}} dD(K) >, <, = 0, \quad (21b)$$

$$V_{x_{it}h} = \beta \int_0^1 (-1-\Delta) (\alpha(\tilde{k}_{jt+1} - \bar{k})) \frac{\partial N(\cdot)}{\partial k_{it+1} \partial \tilde{k}_{jt+1}} dD(K) >, <, = 0, \quad (21c)$$

$$V_{\gamma_i \gamma_i} = \beta \left[\psi^2 \tilde{P}^2 U_{c_{it+1}c_{it+1}}(\cdot) + \psi \tilde{P} \psi_{\gamma_i \gamma_i} U_{c_{it+1}}(\cdot) \right] < 0, \quad (21d)$$

$$V_{\gamma_i \alpha} = V_{\gamma_i h} = 0, \text{ and} \quad (21e)$$

$$V_{\gamma_i x_{it}} = V_{x_{it} \gamma_i} = \beta \left[(-1 - \Delta) \tilde{P}_{\gamma_i} \{U_{c_{it+1}}(\cdot) + \psi \tilde{P} U_{c_{it+1} c_{it+1}}(\cdot)\} \right]. \quad (21f)$$

Equations (21b) and (21c) are similar to equations (12b) and (12c), which describe the effects of adjacent stock on own steady-state level of stock. Equations (21a), (21d), (21e), and (21f) are representative of the effect of cooperation in price. Also note that the term $\tilde{P}_{\gamma_i \gamma_i} = 0$ by assumption, allows modification of equation (21d). The second term on the right hand side of equation (21d) thus falls out and using the assumption that utility function for consumption is concave it is possible to sign this expression.

The above equations can be solved using Cramer's rule, for the comparative statics of a change in the steady state level of harvesting with respect to either a change in the mean level of adjacent stock (α) or a change in the parameter that is similar to the variance in the level of adjacent stock (h),

$$\frac{\partial x_{it}}{\partial \alpha} = - \frac{\begin{vmatrix} V_{x_{it} \alpha} & V_{x_{it} \gamma_i} \\ V_{\gamma_i \alpha} & V_{\gamma_i \gamma_i} \end{vmatrix}}{\begin{vmatrix} V_{x_{it} x_{it}} & V_{x_{it} \gamma_i} \\ V_{\gamma_i x_{it}} & V_{\gamma_i \gamma_i} \end{vmatrix}} = - \frac{V_{x_{it} \alpha} V_{\gamma_i \gamma_i} - V_{\gamma_i \alpha} V_{x_{it} \gamma_i}}{|J|}, \quad (22a)$$

$$\frac{\partial x_{it}}{\partial h} = - \frac{V_{x_{it} h} V_{\gamma_i \gamma_i} - V_{\gamma_i h} V_{x_{it} \gamma_i}}{|J|}, \quad (22b)$$

$$\frac{\partial \gamma_i}{\partial \alpha} = - \frac{\begin{vmatrix} V_{x_{it} x_{it}} & V_{x_i \alpha} \\ V_{\gamma_i x_{it}} & V_{\gamma_i \alpha} \end{vmatrix}}{|J|} = - \frac{V_{x_{it} x_{it}} V_{\gamma_i \alpha} - V_{x_{it} \alpha} V_{\gamma_i x_{it}}}{|J|}, \text{ and} \quad (22c)$$

$$\frac{\partial \gamma_i}{\partial h} = - \frac{V_{x_{it} x_{it}} V_{\gamma_i h} - V_{x_{it} h} V_{\gamma_i x_{it}}}{|J|}. \quad (22d)$$

Where the denominator in equations (22a)-(22d) is just the determinant of the Jacobian (J) matrix explicitly stated in (22a), which, as shown in Appendix 2, is negative semi-definite and thus is a

positive number. As in equations (13a) and (13b), the sign of the comparative static terms on the right hand side of equations (22a)-(22d) are determined by the sign of the respective numerators. In this case, the second term in the numerators of equations (22a) and (22b) is zero. Therefore, the sign of the numerators of the equations (22a) and (22b) are determined by the products of the numerators in equations (13a) and (13b) and the second derivative of the Bellman equation with respect to cooperation.

Accordingly, the numerators in equations (22a) and (22b) are easily signed, as $V_{\gamma_i \gamma_i}$ is negative from equation (21d). The comparative static results are similar to those found when cooperation of this type was not considered, because the landowner now also assumes that the adjacent level of cooperation is an exogenous factor in determining their management objectives.

When stands are spatial complements $\frac{\partial N(.)}{\partial k_{it+1} \partial k_{jt+1}} > 0$ a shift in the mean (variance) results in a positive shift in the steady state level of stock. An individual landowner's marginal amenity valuation of both the focal and adjacent standing stock increases with the level of adjacent stock when stands are spatial complements, leading to this increase in the steady state level of stock. The marginal amenity valuation of each stand decreases with increases in adjacent stock levels when the stands are spatial substitutes, $\frac{\partial N(.)}{\partial k_{it+1} \partial k_{jt+1}} < 0$. A sudden and unexpected shift in adjacent stock levels when stands are spatial substitutes would result in a decrease in the steady state level of harvesting. When the stands are spatial independent $\frac{\partial N(.)}{\partial k_{it+1} \partial k_{jt+1}} = 0$, a shift in one of the parameters does not affect the steady state levels of stock. Such a result is intuitive, spatially independent stands are site-specific amenities and do not rely on the condition of standing timber stock.

In equations (22c) and (22d), note that the first term in the numerator is zero, as $V_{\gamma,\alpha} = V_{\gamma,h} = 0$, resulting in an overall expression on the right hand side that is positive. However, the sign of the expressions on the left hand side of equations (22c) and (22d), $\frac{\partial \gamma_i}{\partial \alpha}$ and $\frac{\partial \gamma_i}{\partial h}$, are still determined by the sign of the numerator of the expression on the right hand side. The sign of the numerators on the right hand side in equations (22c) and (22d) are difficult to determine without making assumptions about the cross-partial derivatives (21f).

For the purpose of signing equation (21f), assume that utility is linear in consumption,⁴

$$V_{\gamma_i x_{it}} = V_{x_{it} \gamma_i} = \beta \left[-(1 + \Delta) \tilde{P}_{\gamma_i} (U_{c_{it+1}}(\cdot)) \right] < 0. \quad (21f')$$

With the additional assumption that the harvesting choice of the individual is discrete, the $(-1-\Delta)$ term falls out and the sign of equation (21f') becomes positive. Under these assumptions, the comparative static expressions involving cooperation (equation 22(c-d)) have the same sign as those involving harvesting (equation 22(a-b)). The sign of the comparative static terms are also determined by the spatial interdependence of the stands.

When stands are spatial substitutes, $\frac{\partial N(\cdot)}{\partial k_{it+1} \partial k_{jt+1}} < 0$, the steady state level of cooperation decreases with a change in either the mean level of adjacent stock or the variance in the level of adjacent stock. The effect on the steady state level of cooperation responds in the opposite direction that is it increases, when the stands are spatial complements. Therefore, there is less incentive to coordinate harvesting to obtain a higher price for timber when there is a shift in the mean (variance) of the conditions of neighboring stocks when stands are complements,

$\frac{\partial N(\cdot)}{\partial k_{it+1} \partial k_{jt+1}} > 0$. An individual's marginal amenity valuation for each stand increases with

⁴ This is a case of a risk neutral landowner and will be returned to later in this chapter.

increasing levels of adjacent stocks when stands are spatial complements. A shift in the conditions of neighboring lands would thus increase the landowner's overall value of amenities and thus increase their incentive to cooperate at all.

When there is a sudden shift in the mean (variance) of non-timber amenity values under stands are spatial substitutes $\frac{\partial N(\cdot)}{\partial k_{it+1} \partial k_{jt+1}} < 0$, the steady state level of cooperation decreases.

When stands are substitutes in production of amenities, landowners cooperating in price have marginal valuations for standing timber on their own and adjacent parcels that decrease with the increasing condition of adjacent stock. Thus, substitutability decreases with increases in the level of adjacent stock, an unexpected shift in the level of adjacent stock causes the landowner to respond by decreasing the level of cooperation in order to better suit their own preferences for amenity benefits that have been affected by changes in the adjacent stock. When an individual's amenity valuation of the landowner's own parcel and the adjacent parcel does not depend on the condition of neighboring stock, i.e., the stands are spatially independent, $\frac{\partial N(\cdot)}{\partial k_{it+1} \partial k_{jt+1}} = 0$, then there is no effect on steady state level of cooperation resulting from a sudden shift in the non-timber amenity values obtained from adjacent stands.

Recall that the previous analysis only investigates a single landowner's behavior when faced with the decisions to harvest and cooperate in harvesting in order to receive a better price for timber. This type of cooperation between landowners could also be investigated under the assumption that landowner decisions are made simultaneously. Simultaneous decision-making behavior of landowners will be further addressed in section 4.

Landowner cooperation occurs in the production of non-timber benefits

In this case, I revert to the assumption that landowners are price takers. Specification of the dynamic programming model, in this case, allows for the non-timber benefits the landowner receives to be a specific function of future landowner cooperation, perhaps reflecting an understanding by the landowner of how benefit production on their own stand depends on the condition of adjacent stock. Thus, here the individual landowner has amenity values for his own and adjacent stocks and these benefits are a function not only of the existing stock on each stand, but also of the level of cooperation the landowner is willing to undertake. Using this assumption, the non-timber benefit terms (as the landowner has amenity values associated with both own stands and neighboring stands) can be rewritten as $N^i(k_{it+1}, k_{jt+1}^s, \gamma_i | \bar{\gamma}_j)$, where the i and j terms can be interchanged to define the amenity valuation the landowner has for a specific adjacent stand. It is assumed throughout this analysis that non-timber amenity values are concave in the

level of cooperation, that is, $\frac{\partial N^{i,j}(\cdot)}{\partial \gamma_i} > 0$ and $\frac{\partial^2 N^{i,j}(\cdot)}{\partial \gamma_i^2} < 0$. Under the assumption that the

landowner only accounts for amenity production by his/her own stand and one adjacent parcel

and is able to commit to some level of amenity production on his/her own stand, the new

Bellman equation is now written,

$$V_t = \max_{x_{it}, \gamma_i} U(Px_{it} + M; \Omega) + N^i(k_i, k_j) + N^j(k_j, k_i) + \beta EU(P\psi_i + M; \Omega) + \beta \{N^i(k_{it+1}, k_{jt+1}^s, \gamma_i | \bar{\gamma}_j) + N^j(k_{jt+1}, k_{it+1}^s, \gamma_j | \bar{\gamma}_i)\}. \quad (23)$$

The corresponding first order conditions are,

$$V_{x_{it}} = PU_{c_{it}}(\cdot) - \beta(1 + \Delta) \left[\int_0^1 PU_{c_{it+1}}(\cdot) dD(X) \right] - \beta(1 + \Delta) \left[\frac{\partial N^i(\cdot)}{\partial k_{it+1}} + \frac{\partial N^j(\cdot)}{\partial k_{it+1}} \right] = 0, \text{ and} \quad (24a)$$

$$V_{\gamma_i} = \beta \left[\frac{\partial N^i(\cdot)}{\partial \gamma_i} \right] = 0, \quad (24b)$$

where equation (24a) is again similar to equation (8''') and thus has the same mathematical interpretation.

The economic interpretation of equation (24a) is that the landowner harvests when the marginal benefit from delaying harvest, $PU_{c_{it}}(\cdot)$, equals the marginal opportunity cost from

delaying harvest $\beta(1+\Delta) \left\{ \left[\int_0^1 PU_{c_{it+1}}(\cdot) dD(X) \right] + \left[\frac{\partial N^i(\cdot)}{\partial k_{it+1}} + \frac{\partial N^j(\cdot)}{\partial k_{it+1}} \right] \right\}$. In this case the marginal

opportunity costs of delaying harvest are the additional revenues received from harvesting in the present, in terms of non-timber benefits accruing to a newly established stand, and the effects on the evolution of non-timber benefits produced by the adjacent stand and expected timber revenue from harvest. The level of coordination is now a factor in the individual's assessment of the former, and the landowner is aware of how his/her own valuation of amenities depends on the condition of own and adjacent stock. The focal landowner harvests when they are indifferent between the future value of timber harvests resulting from delay in the current period and the opportunity costs of delaying harvest. Harvesting at any other time would produce an inefficient outcome, for instance, if the landowner harvests when the net present value of delaying timber harvest is higher than the opportunity costs of harvesting, then the landowner is not acting to maximize the net benefits they receive from their standing forest stock. Equation (24b) states that the discounted marginal non-timber amenity valuation for own standing timber resulting from cooperation $\beta \left[\frac{\partial N^i(\cdot)}{\partial k_{it+1}} \right]$ has to equal zero. The landowner is indifferent to cooperation

when there are no additional marginal benefits accruing to valuation of own stock resulting from such an agreement.

There is still an externality present in equations (24a-b). An individual landowner does not have incentive to consider the effects of their own management on the behavior of the adjacent landowner. For instance, the focal landowner could have amenity values that increase with increasing forest stock, which are so strong that the landowner would never consider harvesting their property within their lifetime. However, the only access to an adjacent forested parcel may be through the focal landowner's parcel via the establishment of an easement. The easement may result in harvest of a small portion of the timber from the focal stand, but may improve the adjacent landowner's overall welfare in that the action would provide a source of income. A harvest by an adjacent landowner may also serve to improve the overall landscape through creating variation in the conditions of the two stands. The individual landowner in this case, however, has no incentive to account for the adjacent landowner's preferences for timber benefits.

Like before, I am interested in how the steady state levels (see Appendix 3 for proof of existence) of the two choices, cooperation and current period harvest, respond to a change in the one of the parameters, α and h , which again describe the mean level of adjacent stock and the variance in adjacent stock levels, respectively. Totally differentiating the necessary conditions results in the following,

$$V_{x_{it}x_{it}} = P^2 U_{c_{it}c_{it}}(\cdot) + \beta \left[\int_0^1 (1+\Delta)^2 P^2 U_{c_{it+1}c_{it+1}}(\cdot) dD(X) \right] + \beta(1+\Delta)^2 \left[\frac{\partial^2 N^i(\cdot)}{\partial k_{it+1}^2} + \frac{\partial^2 N^j(\cdot)}{\partial k_{it+1}^2} \right] < 0, \quad (25a)$$

$$V_{x_{it}\alpha} = \beta \left[-(1+\Delta)(\tilde{k}_{jt+1} + h(\tilde{k}_{jt+1} - \bar{k})) \right] \left[\frac{\partial N^i(\cdot)}{\partial k_{it+1} \partial \tilde{k}_{jt+1}} + \frac{\partial N^j(\cdot)}{\partial k_{it+1} \partial \tilde{k}_{jt+1}} \right] >, <, = 0, \quad (25b)$$

$$V_{x_{it}h} = \beta \left[-(1+\Delta)(\alpha(\tilde{k}_{jt+1} - \bar{k})) \right] \left[\frac{\partial N^i(\cdot)}{\partial k_{it+1} \partial \tilde{k}_{jt+1}} + \frac{\partial N^j(\cdot)}{\partial k_{it+1} \partial \tilde{k}_{jt+1}} \right] dD(K) >, <, = 0, \quad (25c)$$

$$V_{\gamma_i \gamma_i} = \beta \left[\frac{\partial^2 N^i(\cdot)}{\partial \gamma_i^2} \right] < 0, \quad (25d)$$

$$V_{\gamma_i \alpha} = \beta \left[(\tilde{k}_{jt+1} + h(\tilde{k}_{jt+1} - \bar{k})) \frac{\partial N^i(\cdot)}{\partial \gamma_i \partial \tilde{k}_{jt+1}} \right] >, <, = 0, \quad (25e)$$

$$V_{\gamma_i h} = \beta \left[\alpha(\tilde{k}_{jt+1} - \bar{k}) \frac{\partial N^i(\cdot)}{\partial \gamma_i \partial \tilde{k}_{jt+1}} \right] >, <, = 0, \text{ and} \quad (25f)$$

$$V_{x_{it} \gamma_i} = V_{\gamma_i x_{it}} = \beta \left[-(1 + \Delta) \frac{\partial N^i(\cdot)}{\partial k_{it+1} \partial \gamma_i} \right] >, <, = 0. \quad (25g)$$

With cooperation affecting the future non-timber benefit function, there are now expressions for the cross partial of cooperation and α (equation (25e)) and the cross partial of cooperation and h (equation (25f)), as opposed to the case where cooperation affected only price and these terms were equal to zero (equation (21e)). The comparative statics expressions are the same as those presented in equations (22a)-(22d). However, the signs of some of these expressions differ due to the fact that landowner's steady state level of cooperation is now affected by changes in the parameters describing the level of adjacent stock.

When stands are spatial complements, $\frac{\partial N^n(\cdot)}{\partial k_{it+1} \partial \tilde{k}_{jt+1}} > 0, n = i, j, i \neq j$ the steady state level of stock increases with shifts in the mean level of adjacent stock or the variance in adjacent stock levels. Recall, the marginal benefit that an individual landowner receives from standing timber on both his/her own parcel and the adjacent parcel increases with the increasing adjacent stocks, a shift in one of the parameters shifts the valuation of amenity benefits that could complement those existing on the landowner's own parcel, thus resulting in an increase in the steady state level of stock. In this case the landowner has to delay harvest while the adjacent stock levels increase to simulate the benefits that he/she receives from own stock, that is as stands become

increasingly substitutable in the production of amenities. When the marginal benefit that an individual landowner receives from standing timber on both his/her own parcel and the adjacent parcel decreases with increasing adjacent stock, $\frac{\partial N^n(\cdot)}{\partial k_{it+1} \partial \tilde{k}_{jt+1}} < 0$, the stands are spatial substitutes and the direction of the shift in the steady state level of stock is *a priori* ambiguous. That is, without further information on the relative weights of the expressions in equations (25a-g), it is not possible to sign the effect that changes in the mean (variance) of adjacent stock levels has on harvesting, when the stands are spatial substitutes and an individual's non-timber amenity values decrease with increases in the adjacent forest stock levels.

The steady state level of cooperation also increases with changes in the parameters describing adjacent stock when stands are spatial complements $\frac{\partial N^n(\cdot)}{\partial k_{it+1} \partial \tilde{k}_{jt+1}} > 0$, if the cross partial of amenities in the level of cooperation and level of adjacent stock is increasing. Thus a shift in the mean (variance) of non-timber amenity values attained from adjacent stocks when stands are spatial complements depends on the direction of this cross partial derivative. If the mean (variance) of non-timber amenity value from adjacent stock suddenly and unexpectedly decreased, the landowner would adjust their steady state level of stock to balance their preferences for timber and amenities. In the case when stands are spatial complements, this would lead a landowner to decrease the steady state level of harvesting. A positive shift in one of the parameters of adjacent stock would effectively alter the marginal amenity valuation of the landowner for both own and standing stock, and the landowner would increase their own steady state level of cooperation in order to combat further shocks to overall amenity valuation of the proximate landscape when stands are spatial complements. When the individual landowner's marginal benefits from having standing timber increase with the condition of own and adjacent

stocks as is the case when stands are spatial complements, a shift in the mean (variance) of non-timber amenity values increases the level of cooperation the landowner would undertake at the steady state.

However, when stands are spatial substitutes $\frac{\partial N^n(\cdot)}{\partial k_{it+1} \partial \tilde{k}_{jt+1}} < 0$, the change in the steady

state level of cooperation is *a priori* ambiguous in response to a shift in adjacent stock levels.

That is, without information on the relative weights of the degree of substitutability among stands and the strength of the cross partial of non-timber utility with respect to cooperation and adjacent stock levels, it is not possible to sign the effects of an unexpected change in adjacent stock levels on the level of cooperation. This is expected, as when stands are substitutes in the landowner's amenity valuation, the marginal valuation of own and adjacent parcels decreases with increases in adjacent stand conditions, and thus landowners would not have an innate incentive to cooperate with a neighbor in an agreement that delays their own harvest plans.

When the stands are independent in the production of amenities on the landowner's own and adjacent parcels, shifts in the level of amenities produced on adjacent stands have no effect on the owner's harvesting or incentive for cooperation. There is no incentive to anticipate behavior of adjacent landowners in the interest of attaining some level of amenities produced by parcels on the landscape, as the marginal valuation of amenities remain constant for the focal landowner with changing conditions of the stocks.

Landowner cooperation affects both prices and non-timber benefits

Lastly, consider the dynamic programming model under the assumption that both prices and non-timber benefits over time are a function of landowner cooperation. This type of behavior would

be expected if landowners were to fully cooperate in management of forested stocks, thus behaving as a sole owner of the resource. Consider, for ease of notation, that there are two landowners that are able to fully commit themselves to enter into such an arrangement. Full cooperation among landowners would mimic the behavior of a sole owner, who now must consider the utility of both landowners in management of the stocks.

The adjacent landowner's consumption and equation of motion must be defined before addressing the management objectives of the sole owner. These are similar to equations (3) and (4') in section 2, with the following modifications:

$$c_{jt} = Zx_{jt} + M_{jt} - S_{jt}, \text{ and } c_{j,t+1} = Zx_{j,t+1} + M_{j,t+1} + (1+r)S_{jt} - S_{j,t+1}, \text{ and} \quad (26)$$

$$k_{j,t+1} = (1+\Delta)(k_{jt} - x_{jt}). \quad (27)$$

It is reasonably assumed that the price of timber on adjacent and focal lands differ, as such disparities could be the result of differences in the composition of the stock (specifically species of timber or quality of timber) or level of stock. The implicit assumption in this analysis is that the discount rates of the landowners are equal, which would indeed be the case for a sole owner, but may not be the case if the landowners had different preferences for the future. It is also again assumed that both owners manage their stands with the objective of maximizing utility from timber and non-timber benefits that is behavior of landowners is symmetric in their objective functions. As a result of the assumption of full cooperation among the landowners, the levels of cooperation between the two owners (parcels) are equal, that is $\gamma_i = \gamma_j$.

The resulting Bellman equation becomes,

$$V_t = \max_{x_{it}, x_{jt}} U(Px_{it} + Zx_{jt} + M; \Omega) + N^i(k_i, k_j) + N^j(k_j, k_i) + \beta U(\tilde{P}\psi_i + \tilde{Z}\psi_j + M; \Omega) + \beta N^i(k_{it+1}, k_{jt+1}^s) + \beta N^j(k_{jt+1}, k_{it+1}^s). \quad (28)$$

Where the M term in the utility functions is the sum of individual exogenous income factors, i.e., $M=M_{it}+M_{jt}$. Thus, the sole landowner considers the effects of management actions taken on one stand on the non-timber amenities and potential revenue generated from the neighboring stand in their objective function.

Proceeding as before, the necessary conditions for this problem can be obtained as,

$$V_{x_{it}} = PU_{c_{it}}(\cdot) - \beta(1+\Delta)[\tilde{P}U_{c_{it+1}}(\cdot)] - \beta(1+\Delta)\left[\frac{\partial N^i(\cdot)}{\partial k_{it+1}} + \frac{\partial N^j(\cdot)}{\partial k_{it+1}}\right] = 0, \text{ and} \quad (29a)$$

$$V_{x_{jt}} = ZU_{c_{jt}}(\cdot) - \beta(1+\Delta)[\tilde{Z}U_{c_{jt+1}}(\cdot)] - \beta(1+\Delta)\left[\frac{\partial N^j(\cdot)}{\partial k_{jt+1}} + \frac{\partial N^i(\cdot)}{\partial k_{jt+1}}\right] = 0. \quad (29b)$$

The economic interpretation of equation (29a,b) is that the sole landowner is indifferent between harvesting and preserving stock on a stand when the marginal benefits from delaying harvest

$PU_{c_{it}}(\cdot), ZU_{c_{jt}}(\cdot)$ equal the marginal costs from letting stock stand,

$$\beta(1+\Delta)\left[\tilde{P}U_{c_{it+1}}(\cdot) + \frac{\partial N^i(\cdot)}{\partial k_{it+1}} + \frac{\partial N^j(\cdot)}{\partial k_{it+1}}\right], \beta(1+\Delta)\left[\tilde{Z}U_{c_{jt+1}}(\cdot) + \frac{\partial N^j(\cdot)}{\partial k_{jt+1}} + \frac{\partial N^i(\cdot)}{\partial k_{jt+1}}\right]. \text{ Here, cooperation}$$

factors into both the utility from timber and non-timber production and the resulting effect on adjacent stocks are accounted for in the necessary conditions. A sole owner equates the marginal value of benefits from delaying timber harvesting to the opportunity costs from delay, in terms of the additions to timber and non-timber benefits on both the stand being considered for management and the adjacent stand that would occur over time. The sole owner manager will address the effects of delaying harvest on any stand in the current period on the management plan for the entire area, in terms of offsetting timber and non-timber benefits production on each stand. In the simple case of two stands, there are no externalities present in equations (29a) and

(29b), as the sole owner accounts for the effects of actions taken on one stand on the flow of benefits that are generated by both that stand and the adjacent stand.

The responses of the steady state levels of stock on each parcel to a change in the actions taken on the adjacent stand determine the stability and uniqueness of equilibrium in this case.

The resulting second order conditions are expressed in the following:

$$V_{x_{it}x_{it}} = P^2 U_{c_{it}c_{it}}(\cdot) + \beta(1+\Delta)^2 [P^2 U_{c_{it+1}c_{it+1}}(\cdot)] + \beta(1+\Delta)^2 \left[\frac{\partial^2 N^i(\cdot)}{\partial k_{it+1}^2} + \frac{\partial^2 N^j(\cdot)}{\partial k_{it+1}^2} \right] < 0, \quad (30a)$$

$$V_{x_{jt}x_{jt}} = Z^2 U_{c_{jt}c_{jt}}(\cdot) + \beta(1+\Delta)^2 [Z^2 U_{c_{jt+1}c_{jt+1}}(\cdot)] + \beta(1+\Delta)^2 \left[\frac{\partial^2 N^j(\cdot)}{\partial k_{jt+1}^2} + \frac{\partial^2 N^i(\cdot)}{\partial k_{jt+1}^2} \right] < 0, \text{ and} \quad (30b)$$

$$V_{x_{it}x_{jt}} = V_{x_{jt}x_{it}} = PZU_{c_{it}c_{jt}}(\cdot) + \beta(1+\Delta)^2 [PZU_{c_{it+1}c_{jt+1}}(\cdot)] + \beta(1+\Delta)^2 \left[\frac{\partial N^i(\cdot)}{\partial k_{it+1} \partial k_{jt+1}} + \frac{\partial N^j(\cdot)}{\partial k_{it+1} \partial k_{jt+1}} \right]. \quad (30c)$$

Equations (30a) and (30b) and the following equation,

$$\Psi^{SO} = V_{x_{it}x_{it}} V_{x_{jt}x_{jt}} - V_{x_{it}x_{jt}} V_{x_{jt}x_{it}} > 0, \quad (30d)$$

must hold for a stable equilibrium to exist. The assumption is that these conditions hold, otherwise the sole manager would not be accounting for the rents accruing to their choice of land use.

Further economic interpretations of the first order conditions follow. When stands are substitutes in the production of amenities to the sole owner, that is marginal amenities decrease with increasing levels of adjacent stock $\frac{\partial N^j(\cdot)}{\partial k_{it+1}}, \frac{\partial N^i(\cdot)}{\partial k_{jt+1}} < 0$, decreasing the amenity valuation the landowner has for his/her own stock and adjacent stocks. This implies that the sole owner would harvest lower levels of stock when the stands are substitutes, when compared with the steady state condition of stock resulting in the single landowner or the partial cooperation cases. In the latter cases, the spatial interdependencies of parcels do not play a role in determining the optimal

harvesting rules. However, when considering harvest in the case of full cooperation, the landowner not only considers the effect on the overall evolution of conditions on the one stand, but also on the conditions that foster amenity and timber production on the adjacent stands. For stands that are spatial complements, the marginal amenity value increases with increasing

condition of the stands $\frac{\partial N^j(\cdot)}{\partial k_{it+1}}, \frac{\partial N^i(\cdot)}{\partial k_{jt+1}} > 0$, and is accounted for by the sole owner. The sole

landowner when managing the stands considers this spatial relationship and its evolution over time and thus may delay harvest on one stand longer than that which would occur if the stands were managed by a single landowner or under partial cooperation agreements between landowners. The sole owner adjusts their management behavior depending on the current and future production of both timber and amenities on both stands. Now, the focus will turn to addressing the strategic behavior among adjacent landowners.

4. Strategic behavior between adjacent landowners

Certain forms of strategic behavior between adjacent forest landowners can also be studied. Strategic behavior might be expected because the focal landowner may be able to free ride off of an adjacent landowner's forest stock in terms of the public nature of services provided from standing timber. In Section 3, there were possibilities for this type of behavior when cooperation between landowners was not complete. Revisiting the example of a landowner that values both timber and wildlife provides some insight into how "free riding" might be possible when stands are spatially interdependent in the production of amenities. Suppose the focal landowner's marginal amenity value for his/her own stand and an adjacent stand decreases with increasing levels of adjacent stock, as the adjacent stock acts as a substitute in the production of habitat for

the valued wildlife species, that is as stock levels increase, the adjacent stand provides similar conditions as the landowner's own parcel for the wildlife that is valued. If the focal landowner expects that adjacent stock will not change, then he/she will have incentive to harvest his/her own stock without concern for how the condition of adjacent parcels are affected by this decision. This is an example of free-riding behavior that could result from individual management when adjacent parcels are taken as exogenous, as standing timber provides many services that are public in nature.

The most common form of strategic outcome is to assume that adjacent landowners play a Nash game in determining their harvesting rules, and thus each landowner assumes that the actions of others are determined simultaneously with their own. Thus, each landowner makes choices as in the single landowner model of Section 2, and then the first order conditions of adjacent landowners are solved simultaneously to characterize the equilibrium. They do so taking the adjacent landowner forest stocks (adjacent management behavior) as given. In other words, each landowner in the game would choose their private harvesting rule to maximize their individual Bellman equation subject to their own equation of motion, and therefore implicitly assuming that the actions (forest stocks) of adjacent landowners are exogenous to their decision.

The first order conditions defining harvest rules from the Bellman equation for each landowner define the reaction function of that landowner to the forest harvesting (and forest stock) choices of the adjacent landowners. This system of reaction functions in principle could be solved for the Nash outcome, assuming that one existed. It is expected that the solution to this problem would be quite different than the coordinated and partially coordinated outcomes defined above.

In Nash equilibrium, players take action with the best response of other participants in mind, that is, the management behavior of other players is completely exogenous to the determination of the individual's behavior. In this sense, the individual landowners in a Nash game also do not account for the effect of the condition of their stock on the utility and behavior of adjacent landowners. Such behavior would not affect landowners when stands are spatially independent $\frac{\partial N(\cdot)}{\partial k_{it+1} \partial \bar{k}_{jt+1}} = 0$, that is an individual's own non-timber values are not affected in this case by the condition of adjacent parcels and how conditions change over time. However, when stands are spatial complements or spatial substitutes $\frac{\partial N(\cdot)}{\partial k_{it+1} \partial \bar{k}_{jt+1}} > 0$, that is the changing conditions in stands affects the valuation of amenities by proximate individuals, then there are externalities that result from this type of behavior.

This is typical of the free-rider problem in economics. An individual forest landowner has incentive to enjoy the non-timber benefits that are public in nature from adjacent parcels, for instance benefits of wildlife that are free to roam, water quality improvements, etc., but fails to consider the effects on the provision of these public goods from his/her parcel when determining his/her own harvesting behavior. This is especially the case when individual preferences for non-timber amenities are varied between landowners, as they might be for landowners in a watershed. Timber stands in a watershed provide water quality services that are public in nature, so an individual landowner has incentive to enjoy these benefits produced from adjacent stands while failing to account for the effect that their own harvesting may have on the overall nature of the water quality services in the watershed.

Consider the Nash equilibrium for two landowners, for simplicity, where landowners are assumed to have symmetrical preferences for income and non-timber amenities produced by

standing forest stock.⁵ To do this, one follows a similar process to that in the earlier examination of landowner behavior (see Sections 2 and 3). It is assumed that the individual landowners act to maximize their own utility, determined by benefits generated from harvesting timber and those generated from non-timber related activities on their parcels. These assumptions result in the following Bellman equations for the two landowners,

$$V_t^i = U(P_t x_{it}; \Omega) + N(k_{it}, \bar{k}_{jt}) + \beta E[U(P_{t+1} \psi_{it}; \Omega) + N(k_{it+1}, \bar{k}_{jt+1})], \text{ and} \quad (29a)$$

$$V_t^j = U(Z_t x_{jt}; \Omega) + N(k_{jt}, \bar{k}_{it}) + \beta E[U(Z_{t+1} \psi_{jt}; \Omega) + N(k_{jt+1}, \bar{k}_{it+1})], \quad (29b)$$

where the terms in equation (29a,b) are defined as in Section 2 and 3, with a slight change of notation, in that the actions of the adjacent landowner are fixed. The labels, i and j , again refer to both the individual owners and stocks, where the latter can be differentiated by level (in terms of a quantifiable measure, such as volume). Individual landowners are assumed to be price takers, and thus the price of timber is relatively constant throughout, therefore the time subscripts on price will be dropped in the remaining analysis.

To solve for the Nash equilibrium reached by these two landowners, assume that each landowner solves their individual problem under the assumption that the other operates with their “best response” to any action taken by the landowner. That is a landowner assumes that the other landowner’s management decisions are made simultaneously. To characterize the optimal level of harvesting, one must therefore simultaneously solve the following necessary conditions:

$$V_{x_{it}}^{iN} = PU_{c_{it}}(\cdot) - \beta \left\{ \int_0^1 (1 + \Delta) PU_{c_{it+1}}(\cdot) dD(X) + \int_0^1 (1 + \Delta) \frac{\partial N(k_{it+1}, \bar{k}_{jt+1})}{\partial k_{it+1}} dD(K) \right\} = 0, \text{ and} \quad (30a)$$

$$V_{x_{jt}}^{jN} = ZU_{c_{jt}}(\cdot) - \beta \left\{ \int_0^1 (1 + \Delta) ZU_{c_{jt+1}}(\cdot) dD(X) + \int_0^1 (1 + \Delta) \frac{\partial N(k_{jt+1}, \bar{k}_{it+1})}{\partial k_{jt+1}} dD(K) \right\} = 0, \quad (30b)$$

⁵ The symmetric preferences assumption for individual landowners allows for extension of this model, through the addition of adjacent landowners, beyond the case of two landowners examined here.

which have the same mathematical interpretation as the necessary conditions that were found earlier for equation (8'''). Each individual landowner equates the marginal benefit he/she receives from delaying timber harvesting in the current period, $PU_{c_{it}}(\cdot), ZU_{c_{jt}}(\cdot)$ to the marginal

$$\text{cost incurred from delay in harvest, } \beta \left\{ \int_0^1 (1 + \Delta) PU_{c_{it+1}}(\cdot) dD(X) + \int_0^1 (1 + \Delta) \frac{\partial N(k_{it+1}, \bar{k}_{jt+1})}{\partial k_{it+1}} dD(K) \right\} .$$

$$\beta \left\{ \int_0^1 (1 + \Delta) ZU_{c_{jt+1}}(\cdot) dD(X) + \int_0^1 (1 + \Delta) \frac{\partial N(k_{jt+1}, \bar{k}_{it+1})}{\partial k_{jt+1}} dD(K) \right\} .$$

The marginal cost is composed of future deferred revenues in terms of both expected timber and non-timber benefits that are negated by delaying timber harvesting. This term is again indicative of the externality that is present when individuals manage their parcels without taking into consideration the effect on the adjacent parcels. That is each individual landowner will harvest timber when there is no difference between the present benefits they receive and the future benefits that result from leaving standing stock in the ground, where they do not account for the effect of their own actions on the utility and behavior of the other landowner.

There is an externality evident in the last two terms on the right hand side of equations (30a) and (30b). Each individual landowner is looking to maximize own utility from timber and non-timber benefits produced on own forest stock. The landowners in this situation have no incentive to consider the effects of their actions on the non-timber benefits received from adjacent stands or the utility and behavior of the adjacent landowner.

The second order conditions for the landowners are,

$$V_{x_{it}x_{it}}^{iN} = P^2 U_{c_{it}c_{it}}(\cdot) + \beta \left\{ \int_0^1 (1 + \Delta)^2 P^2 U_{c_{it+1}c_{it+1}}(\cdot) dD(X) + \int_0^1 (1 + \Delta)^2 \frac{\partial N^2(\cdot)}{\partial k_{it+1}^2} dD(K) \right\} < 0, \quad (31a)$$

$$V_{x_{jt}x_{jt}}^{jN} : Z^2 U_{c_{jt}c_{jt}}(\cdot) + \beta \left\{ \int_0^1 (1 + \Delta)^2 Z^2 U_{c_{jt+1}c_{jt+1}}(\cdot) dD(X) + \int_0^1 (1 + \Delta)^2 \frac{\partial N^2(\cdot)}{\partial k_{jt+1}^2} dD(K) \right\} < 0. \quad (31b)$$

It is assumed that these conditions hold (see Appendix 1 for proof). A unique and stable Nash equilibrium exists when:

$$\xi^N = V_{x_{it}x_{it}}^{iN} V_{x_{jt}x_{jt}}^{jN} - V_{x_{it}x_{jt}}^{iN} V_{x_{jt}x_{it}}^{jN} > 0, \quad (32)$$

$$\text{where } V_{x_{it}x_{jt}}^{iN} = \int_0^1 (1+\Delta)^2 \frac{\partial N^i(\cdot)}{\partial k_{it+1} \partial k_{jt+1}} dD(K), \text{ and} \quad (33a)$$

$$V_{x_{jt}x_{it}}^{jN} = \int_0^1 (1+\Delta)^2 \frac{\partial N^j(\cdot)}{\partial k_{jt+1} \partial k_{it+1}} dD(K). \quad (33b)$$

Uniqueness and stability of the Nash equilibrium occurs when the determinant of the second order derivative matrix, equation (32) is positive. Equations (31a) and (31b) imply that the first part of equation (32) is positive. Therefore the uniqueness and stability of the Nash game relies on the product of the cross-partial derivatives $V_{x_{it}x_{jt}}^{iN} V_{x_{jt}x_{it}}^{jN}$. The slopes of the individual reaction functions are these cross-partial derivatives.

Similar to the process of deriving the comparative static terms in Section 2 and 3, the qualitative properties of the reaction functions for landowner i and j are obtained by totally differentiating the first order conditions with respect to the condition of adjacent landowner forest stock,

$$i(x_t) = \left. \frac{dx_{it}}{dx_{jt}} \right|_i = -\frac{V_{x_{it}x_{jt}}^{iN}}{V_{x_{it}x_{it}}^{iN}}, \text{ and } j(x_t) = \left. \frac{dx_{jt}}{dx_{it}} \right|_j = -\frac{V_{x_{jt}x_{it}}^{jN}}{V_{x_{jt}x_{jt}}^{jN}}. \quad (34)$$

Following Amacher et al. (2004), under the assumption that the landowner own stock and adjacent stocks are homogeneous in timber productivity, the slope of the reaction functions are determined by the temporal dependence of amenity values between stands, such that,

$$V_{x_{it}x_{jt}}^{iN} \begin{cases} < \\ = \\ > \end{cases} 0 \text{ if } \int_0^1 \frac{\partial N^i(\cdot)}{\partial k_{it+1} k_{jt+1}} dD(K) \begin{cases} < \\ = \\ > \end{cases} 0 \text{ and } V_{x_{jt}x_{it}}^{jN} \begin{cases} < \\ = \\ > \end{cases} 0 \text{ if } \int_0^1 \frac{\partial N^j(\cdot)}{\partial k_{jt+1} k_{it+1}} dD(K) \begin{cases} < \\ = \\ > \end{cases} 0. \quad (35)$$

The signs of equation (35) can be determined utilizing specific probability assumptions as in the single landowner problem in Section 2 (see Appendix 4). When stands are spatial

substitutes in the valuation of amenities, $\int_0^1 \frac{\partial N^n(\cdot)}{\partial k_{n+1} \partial k_{n+1}} dD(K) < 0, n = i, j; i \neq j$, the reaction

functions are decreasing in (x_{it}, x_{jt}) space. The slope of landowner i 's reaction function must be greater than that of landowner j to satisfy the conditions of uniqueness and stability in the

equilibrium. The reaction functions are increasing in (x_{it}, x_{jt}) space when stands are spatial

complements, $\int_0^1 \frac{\partial N^n(\cdot)}{\partial k_{n+1} \partial k_{n+1}} dD(K) > 0, n = i, j; i \neq j$. Here again, the slope of landowner j 's

reaction function must be less than that of landowner i to attain a Nash equilibrium. When the

stands are spatially independent, $\int_0^1 \frac{\partial N^n(\cdot)}{\partial k_{n+1} \partial k_{n+1}} dD(K) = 0, n = i, j; i \neq j$, the product of the cross

partials is not a factor in determining the sign of equation (32), and the first term, $V_{x_i x_i} V_{x_j x_j}$,

indicates that the Nash equilibrium is stable and unique.

When stands are heterogeneous in their productivity, the direction of the cross-partial derivatives is much harder to determine. The assumption is that when stands are spatial independents, the landowners would have no incentive to behave strategically and manage to reach their own equilibrium levels (see previous discussion). Analysis of landowner behavior under this assumption would be best addressed through a simulation of the stand conditions and resulting landowner behavior, which is beyond the scope of this chapter.

5. Costs from not coordinating

The cost from lack of coordination was determined by comparing the first order conditions from the simultaneous decision assumption (Section 4) with those resulting from partial and full cooperation behaviors examined in Section 3. These costs could easily be calculated for the case where there are $n-1$ landowners in proximity to the focal landowner, as opposed to the current cases where the behavior of the focal landowner with regards to a sole adjacent landowner are investigated. This could be accomplished utilizing the assumption that these additional landowners have symmetrical utility preferences for standing timber that is they value both income and non-timber benefits of timber stands.⁶ Beginning with the first order conditions obtained from the evaluation of simultaneous decision making assumption, equations (31a) and (31b), the individual landowner only accounts for his/her own utility from both timber and non-timber benefits in determining their optimal harvesting scheme. In the Nash game, the focal landowner does not account for the effects of management behavior on the adjacent landowner's utility or management decisions. Such behavior is representative of an externality in that standing forests also provide services that are public in nature. The individual therefore has incentive to maximize the timber benefits received from stock, without accounting for the effects of such an action on the preferences of adjacent landowners for non-timber goods. The Nash game outcome is slightly improved when the landowner can cooperate in the timing of harvests with a neighboring landowner to receive a better price for timber. Under this type of cooperation, a single landowner only considers the addition to their own utility from timber benefits resulting from cooperation in determining timing of harvests (equation 19a). The focal

⁶ This is recognized by the author as a limiting assumption of this analysis, and would be interesting to address in further investigations of the effects of spatial interdependencies on the behavior of individual landowners, but such efforts are beyond the scope of this chapter.

landowner has no incentive to account for the effect of their behavior on the adjacent landowners preferences for timber and non-timber benefits produced by the adjacent stock.

When landowners cooperate in non-timber benefits, the situation is again slightly improved. The landowner has incentive to consider the effects of his/her own actions on the non-timber benefits that he/she receives from adjacent stocks (equation 24a). However, the landowner still has no incentive to consider the adjacent landowners valuation of marketable timber benefits, which most likely will be different from his/her own. That is the landowner considers the effects of management behavior on the production of non-timber benefits of each stand, but ignores the effect on timber benefits valued by the adjacent landowner that would be offset by retaining standing stock. Full cooperation, similar to the economic characterization of a social planner, is the only case where the landowner has incentive to consider the effects of their behavior on the utility that adjacent landowners derive from their own stock (equations 29a and 29b). A sole owner considers the effect of a management action on the evolution of timber and non-timber value production fostered by both the managed stand and the adjacent stand.

The direction of the externalities depends on how the parcels are spatially interdependent. For instance, when stands are spatial complements, the marginal amenity valuation increases with increasing rotation age, and this affects the cost differently than when the stands are spatial substitutes. Thus, decreased levels of stock would be harvested on the managed (focal) stand under sole ownership (cooperation in amenity benefits) when stands are spatial complements, compared with cooperation in price or with the Nash outcome. When stands are spatial substitutes, an increased level of stock would be harvested on the managed stand under sole ownership when compared with any of the other outcomes addressed. When stands are spatially independent in their production of amenities, there is no difference between the management

behaviors of a sole owner when compared with that under partial cooperation or Nash assumptions.

In fact, the partial cooperation possibilities investigated were only slightly better at internalizing the spatial interdependence of forest stands than when landowners were assumed to move simultaneously. A landowner in a partial cooperation situation was still required to anticipate the adjacent landowner's behavior, both in terms of level of harvest and cooperation that they would undertake. Under partial cooperation, the landowner might attribute their own preferences to adjacent stands, thus there is no incentive to reach a full compromise in terms of balanced timber and non-timber utilities of each participant.

These differences in the removal of timber stock, accounting for the uncertainties that individual landowners have regarding adjacent landowner behavior and how the non-timber valuation depends on the conditions of timber on their own stand and adjacent stands, when parcels have various spatial relationships provides much insight for policy makers. Determining the extent of cooperation that landowners are willing to undertake, and how this is affected by the landowner's valuation of amenities produced by both own and standing timber, is important for developing policies (see Chapter 3). The spatial interdependencies and the level of coordination between landowners determine the differences in the steady state levels of stock. Policies designed to address landscape level forest sustainability should be based on the spatial interdependencies of parcels. Alleviation of the uncertainties associated with adjacent management behavior and preferences through development of incentives that serve to educate landowners and bring them together are some of the initial suggestions for policy developers that stem from the above analysis.

It should be kept in mind, when developing policies designed to shift forest management outcomes across the landscape, that landowners are highly sensitive to infringements on their property rights (Brunson et al. 1996). Incentives should be developed so that landowners still feel that there is flexibility in their management of forest stocks, yet are driven to manage lands in such a way that is beneficial to both their own goals and those of the adjacent, or proximate, owners. A determination of how landowners own utility is dependent on both own and adjacent parcels is a step towards the development of incentives or programs that serve to best address the needs of all forest landowners.

6. Conclusion

Private individuals represent the majority of forest owners in the United States, particularly in the east. Despite the singular nature afforded to these individuals in terms of property rights, others often benefit from the services fostered by the condition of these lands. For instance, if one were to consider the parcels that comprise a watershed, the management of any one parcel would certainly affect the quality of benefits produced by the other parcels within the watershed. However, boundaries of ecological functions, such as watersheds, often do not correspond with property lines. This presents a challenge when managing ecological functions that are not similarly delineated. Lack of coordination between owners can affect the welfare of owners in the surrounding ecosystem, as was the case in the previous watershed example, creating an externality.

Under the assumption that forest stocks are identical in the steady state, I examined the spatial interdependence of parcels in the production of non-timber benefits under several cases of

landowner commitment level and behavioral decisions, including landowners coordinating all decisions, partially coordinating, or making decisions independently. These results extend upon existing models that consider the substitutability and complementarity of forest stands in the production of amenities with the inclusion of uncertainty the individual landowner has regarding preferences of nearby landowners and how non-timber benefit production on their own stands depend on adjacent stocks. This analysis contributes to existing literature in that it investigates the possible outcomes of partial cooperation agreements among landowners. For the cases of partial cooperation, the results provide an indicator of how steady state levels (or harvesting rules) determined by individual landowners respond to sudden and unexpected changes in proximate stock levels. Previous studies had examined harvesting behavior of individual landowners under the assumption that adjacent behavior was exogenous to the decision-making process but did not consider the effects of shocks to the system, which would be the surrounding landscape, on behavior, as was done here.

The above analysis shows that individual landowner's decisions regarding the management of stock depend on how adjacent stands are spatially dependent in the provision of amenity services, and on the timing of landowner decisions. I find that full coordination among landowners is optimal for proximate landowners, when compared with partial cooperation and Nash outcomes. Coordination of management decisions is also optimal for proximate landowners in that it alleviates the uncertainty regarding adjacent stocks that individual landowners have when faced with planning activities.

The modeling approach developed here could be further extended to analyze empirical data (Chapter 3). The empirical analysis could address the extent of coordination or lack of coordination between landowners, allowing for an assessment of whether there are costs incurred

by individual management resulting from lack of coordination. Also, an examination of the landowner's valuation of amenity benefits could be undertaken by assessing the landowner's use of their own and adjacent forest parcels. The empirical analysis would evaluate the importance of spatial interdependence and uncertainty to individual landowner behavior.

An interesting extension would incorporate landowner behavior models including the evidence on spatial interdependence of parcels with landscape-level models of land use change developed by ecologists. The integration of these two models would allow for prediction of how changes in surrounding land ownerships and land use affect landowners on an ecosystem level, and analyze various future scenarios. Such simulations would assist policy makers in determining areas to target when addressing specific forest sustainability issues.

This chapter confirms that there is indeed a cost resulting from individual management of forestlands associated with lack of coordination between proximate landowners when stands are spatially interdependent. Prior policies have been directed at individuals without specifically accounting for how individual amenity valuations are interdependent across a landscape. However, in an era of increasing forest fragmentation and threats to forest sustainability that do not correspond with existing property lines, it is imperative that policy makers understand how parcels are spatially interdependent regarding the production of amenity type services. With knowledge of the spatial interdependence of parcels regarding the production of benefits, policies addressing forest sustainability issues can be directed at the extent of interaction necessary in order to reach the best outcome for landowners in an affected ecological region. Theoretical analysis, similar to that undertaken in this chapter, would be necessary to analyze policies directed at particular issues, in order to quantify and compare gains from utilizing

different instruments (taxes, subsidies, and technical assistance) to address landscape level management issues.

Chapter 3: Econometric analysis of adjacent landowner behavior

1. Introduction

There have been many studies of nonindustrial private forest (NIPF) landowners over the past 50 years.⁷ These landowners account for a majority of forestlands in the U.S. and are an important source of the nation's timber supply (e.g., see Alig and Plantinga (2004)). NIPF lands represent the frontier for addressing many current and future forest sustainability issues, such as managing fires, invasive species, and watersheds. Research into management of NIPF lands has typically addressed the behavior of an individual landowner, ignoring the potential interaction of landowners and parcels across a landscape.

Most previous theoretical and empirical landowner studies have examined the behavior of NIPF landowners without considering the management responses of these landowners to the actions of neighboring landowners, or that landowners may take into account the effects of their own management on adjacent lands. There is a wealth of literature examining the timber harvesting behavior of private landowners. Within the last twenty years, studies of individual landowners' timber management behavior have proposed that the goal of many owners was not one of pure profit maximization, but rather to maximize utility generated from both the harvesting of timber and from benefits of stands that are not valued in typical market settings, referred to as non-timber benefits, i.e., recreational opportunities or value of timber *in situ*, (Hyberg and Holthausen 1989, Kuuluvainen et al. 1996, Conway et al. 2001). The provision of many non-timber benefits is related to an overall pattern of landscape quality, e.g., water quality,

⁷ For thorough reviews of prior NIPF studies see Amacher et al. (2003), Alig et al. (1990), Kuuluvainen et al. (1996).

recreation, wildlife habitat, thus the assumption that any one landowner's management efforts take place independent of the condition of proximate ownerships/stocks is limiting.⁸

Considering that, it is reasonable to assume that some non-timber benefits that any one landowner receives from their own stand are dependent on both the landowner's own timber stock and on adjacent timber stocks. For instance, a certain wildlife species that is valued by a landowner may utilize stands that are structurally diverse for habitat, thus requiring heterogeneity in the condition of the forest stock (Hunter 1990). This is a case where the landowner's own stand and adjacent stands are complements in their production of the landowner's amenity benefits.

The measure of the reliance of one stand on another in the production of ecological services is referred to as spatial interdependence. Biologists have long touted the relationship between lands in the provision of habitat for many animal species, particularly those requiring a mix of tree species and age classes. The interdependence of land parcels is implied in the ecological concept of biodiversity, which places emphasis on encouraging a variety in all living things. Parcel interdependence is also use related, as some recreational activities are dependent on the interaction or coordinated management of several stands, such as hunting or hiking.

These examples are just some of the ways that the management of any one particular forested plot affects the amenity value of nearby standing forests. Therefore, despite the restrictions on access to private lands in the U.S., the non-timber benefits produced from these lands could indeed be considered public goods. It is reasonable to assume that landowners do not fully account for the public nature of non-timber benefits produced by their individual stand, because there is currently no reason, i.e., a lack of markets for non-timber amenities, for an

⁸ This concept is not new, Hartman (1976), who introduced amenity values into the problem of determining landowner's forest rotation, suggested that amenity production was not solely dependent on the actions taken on one forest plot if there were many plots comprising a unit for making decisions.

individual to undertake such consideration. Individual landowners may have differing amenity valuations for standing timber from adjacent landowners, and management with their sole objectives in mind would thus diverge from what the proximate landowners would prefer. Only a social planner would have incentive to account for the effects of an individual action on the value of benefits generated from a forest landscape by adjacent landowners or proximate landowners on an affected landscape. When addressing large landscape-level problems, individual management of a stand would thus be socially costly when compared with outcomes attained through the coordination of landowner actions across parcels.

Previous research has not fully addressed the issue of individual landowner behavior on the welfare of adjacent or nearby stands. Most research on stand interdependencies in forest management has been theoretical in nature (Bowes and Krutilla (1985, 1989), Swallow and Wear (1993), Swallow et al. (1997), Koskela and Ollikainen (2001), Amacher et al. (2004)). Both Swallow and Wear (1993) and Swallow et al. (1997) employed data from a National Forest in Montana to model the optimal rotation decisions for stands, the only theoretical studies that utilize empirical data in the study of stand interdependencies.

Other recent works have studied the possibilities for nonindustrial landowner cooperation of various forms. Brunson et al. (1996) were the first to gauge landowner attitudes towards the principle components of ecosystem management and the interest level in joining collaborative partnerships, where landowners jointly plan land use activities. Stevens et al. (1999) assessed landowner attitudes toward specific proposed management schemes implemented either independently or in cooperation with adjacent landowners, and found there was not much difference in the probabilities of landowner participation when comparing collaborative and individual management options. Jacobson et al. (2000) and Jacobson (2002) showed that

landowner interest in joint management planning is lower when such plans are regulated or restrict property rights, and higher when landowners are offered incentives, either in the form of financial payment or technical assistance.

Eid et al. (2001) evaluated the net present value of various sustainable forest management regimes and found a relatively small difference between individual and cooperative implementation. However, Eid et al. (2001) did not specifically account for the interdependencies between forested parcels in the production of services. Klosowski et al. (2001) studied the effect of economic incentives on the probability of landowner participation in cooperative management programs using data from Massachusetts. Economic incentives, particularly reduction in property taxes, encouraged participation but did not significantly increase the probability that landowners would enroll in cooperative management programs (Klosowski et al. 2001). Also, an increasing number of empirical studies on ecosystem management and species conservation exist, but these are typically undertaken only from the viewpoint of a single (independent) landowner (Albers 1996, Zhang 2001).

The spatial interdependencies accounted for in an individual landowner's forest management decisions are largely unknown.⁹ Chapter 2 presented a theory of the social costs that result from individual management of forest stands relative to various forms of cooperation. While it is typically assumed that individual landowners manage forests for the purpose of maximizing individual utility, it is possible that the utility of others does play a role in landowner behavior. It is therefore essential before proposing any kind of policies directed at individual landowners to encourage collective action to first understand the extent that coordination between landowners takes place. This information is important to addressing sustainability

⁹ Amacher et al. (2004) were the first to examine the spatial interdependencies of parcels and strategic timing of decisions by private landowners.

issues and analyzing the benefits and costs associated with providing incentives for cooperative management.

The purpose of this chapter is to focus on the landowner's willingness to participate in coordination of resource management activities with neighbors. Most of the previous work cited above has focused on *whether* landowners will cooperate in joint planning efforts, where landowners answer questions based on an assumed hypothetical acreage. In this chapter, this focus is extended by attempting to quantify the interdependencies of parcels in the provision of amenities, by employing the landowner's use of their own and/or adjacent parcels for recreation, as factors in the decision-making process. Evaluations focus on the landowner's actual acreage owned, as Conway et al. (2003) found that parcel size does affect individual landowner's utility from non-timber and timber amenities. This chapter builds upon Chapter 2 and on the work of Koskela and Ollikainen (2001), Amacher et al. (2004), and others through an empirical examination of the spatial interdependence of stands and realization of the complementarity and substitutability, as well as outcomes of various forms of landowner interactions.

2. Methods

Adjacent effects are linked to both historical and planned landowner decisions through a survey targeted at individual non-industrial private forest owners. The purpose of the survey was to determine the spatial relationship between parcels in the production of non-timber benefits, across a landscape, as well as the extent to which landowners view their own decisions as important to adjacent landowners, and how much they anticipate the behavior of others when making harvesting and other land use decisions. In the survey, an individual landowner's use of

own land or adjacent lands for recreational activities was assessed in order to quantify the non-timber benefits of the individual landowner. The hypotheses addressed in this analysis were: (1) landowners make choices with regards to the effect on adjacent landowners, (2) landowners would coordinate management of forest resources, (3) monetary incentives, such as, increased timber prices, would improve landowner willingness to coordinate timber management.

A mail-out, mail-back survey of NIPF landowners was used to assess land use decisions and whether management of adjacent stands was accounted for when determining land management. Development of the survey instrument consisted of several stages, in attempts to generate the best response from the target audience. The survey was initially focus grouped by a pool consisting of graduate students, faculty, extension agents, and others who had prior experience working with landowners. As a result of the focus group, two versions of the survey were developed for pretest in order to evaluate the response rate for different forms of questions designed to address the aforementioned hypotheses.

The focus of this pretest was to determine if the survey would be well received and if framing of the questions could improve response. The first version of the survey pretest consisted of questions that concentrated on retaining information on prior harvesting, prior coordination of harvesting or land management activities, as well as attitudes toward future harvesting and land management coordination. The second version of the survey pretest was designed to focus on obtaining information on future harvesting and land management decisions and assess possibilities for coordination of these activities, as well as, attitudes toward coordinating harvests if better prices would result, if wildlife habitat or recreational opportunities would improve, and attitudes towards entering into joint agreements to forego harvesting a portion of land for the purpose of establishing wildlife habitat or an area for recreation.

The pretest was sent to 200 non-industrial private landowners in Botetourt County, Virginia, with the versions evenly split among the sample. Botetourt County was chosen as it had experienced a change in population similar to that desired for the actual sample. Response rate for the survey pretest was 29%. The reduced response could have resulted from not specifically directing the pretest to forested ownerships (some Virginia counties have delineated forestry as a land use activity for tax purposes) or a result of sending only the initial survey instrument without follow-ups due to budgetary restrictions.

The final survey instrument was a modification of the second version offered in the pretest, and included an assessment of individual landowners prior forest harvesting experience (see Appendix 5). Survey question design was based on Dillman et al. (2001) and Dillman (1978). The main components of the survey were questions regarding various types of cooperative arrangements that landowners could enter into, as well as, an assessment of the landowner's use of their own and adjacent parcels for recreational activities (see Appendix 5). Counties that were under increasing urbanization pressures were specifically targeted, as they represented the frontier for issues such as forest fragmentation and sustainability, and landowners may have had some experience with the land use and landowner change that is driving this empirical research.

Lists of parcels that had been designated in forestland use for taxation were obtained for use in this study from the four central Virginia counties of Albemarle, Goochland, Hanover, and Louisa. These counties were selected because they offered a specific taxation status for forest use and were in areas near the urban centers of Richmond and Charlottesville that are undergoing

increasing fragmentation pressure.¹⁰ Corporate landowners and forested parcels less than 20 acres in size (exception for Louisa) were excluded from our random selection of landowners from the tax roles of the four counties. Overall, 2662 landowners were sent a mail-out-mail-back survey and a follow up postcard; the response rate for the final survey was 45%.

Those surveys that were completed and received were tested for bias. There is a lack of consistency among the survey and forestry literature with regards to testing for nonresponse bias. A fair number of studies compare their study data with known values for the population.¹¹ Others have used telephone follow-up surveys of nonrespondents (Greene and Blatner 1986, Conway et al. 2003, and Zhang 2004). Zhang (2004) and Conway et al. (2003) both employ a follow-up telephone survey of a randomly selected sample of 50 nonrespondents, while Greene and Blatner (1986) used 102 nonrespondents in their telephone follow-up survey. There have also been some studies that utilize a two-stage method for assessing landowner opinions, where in the first stage the researchers gather general socioeconomic data and the second stage involves a mail survey containing questions related to contingent valuation of the resource in question (i.e., Messonnier et al. 2000, Edwards and Anderson 1987, Whitehead et al. 1993). As a result of this inconsistency in the literature with regards to testing for nonresponse bias, two methods were employed, that of telephone follow-up with nonrespondents and that of comparing the sample of respondents and nonrespondents using information from county tax records.

¹⁰ The four counties experienced an average net change in population of 10,519 within the last ten years, with a median change in population of 8,181 (Based on US Census Data for period from 1990-2000 (University of Virginia (2004)).

¹¹ Armstrong and Overton (1977) suggest this method only compounds bias, as other studies may have differences in size of population, sampling method, and response rate. Some examples of use of this method follow. In a regional study of forest owners conducted in Finland, Kurttila et al. (2001) compare the mean forest holding sizes of study respondents and that of the nation. Loomis (1987) compared average education levels, age, and income of study respondents with the averages for the state where the study took place. Bell et al. (1994) compared the means of socioeconomic variables for study participants with the 1987 Census of Agriculture. Jacobson (2002) used information on property size from tax records to compare respondents and nonrespondents.

To test for unit non-response bias, a telephone follow-up survey of 50 randomly selected nonrespondents was performed. In the telephone follow-up, nonrespondents were asked whether they owned at least 5 acres of forest land (a qualifier for participation in the original survey), the extent of their forest land ownership (if applicable, otherwise they were asked if their main reason for not returning the survey was failure to meet the prior qualifier), their age, and education level. The mean parcel size from county tax records of respondents and nonrespondents were also compared using a two-sample t-test and there was not a significant difference at a p-level of less than 0.05 in the mean parcel size between the populations.

3. Econometric model

Individual landowners' decisions to participate in activities on neighboring lands or with neighboring landowners, and the characteristics of individuals and parcels that factor in these decisions were analyzed. The rationale was not to determine specifically the exact extent of interaction between parcels that are spatially interdependent in the provision of amenity services, but to obtain an initial assessment of whether landowners consider the effects of their land use decisions on a spatial scale, which would indicate that landowners account for spatial interdependencies in their own decision-making. It is proposed that landowners facing different types of cooperative arrangements will evaluate them based on the uncertainties that are alleviated through such agreements (e.g., see Chapter 2). It is also proposed that landowners who utilized their own or adjacent parcels for recreation activities were more likely to consider the spatial scale of their decisions. The decision of landowners at any point in time mimics that of a landowner facing the decision at the present time, under the assumption that landowners

decisions regarding their forest land were determined by the current level of forest stock and that the forest stock growth was dynamic, as was done in Chapter 2.

I now develop an empirical approach to study a representative landowner confronted with the decision to coordinate management activities with adjacent owners. Suppose that the individual landowner has the following utility function, without some degree of cooperation, given by,

$$V(c, M, K_i, K_j; \Omega) = E[U(c, M; \Omega) + N(K_i, K_j)], \quad (1)$$

where $V(.)$ is utility, c is the market value of timber on the property, M is the landowners exogenous income, Ω is a vector of landowner preferences, K_i is the forest stock owned by the individual, K_j is the forest stock on adjacent properties where $i \neq j$, $U(.)$ measures benefits from timber harvesting, and $N(.)$ measures non-timber benefits obtained from own and adjacent stocks (see Chapter 2). In equation (1), E is the expectations operator, included because of individual landowner uncertainties regarding adjacent landowner decisions and how non-timber amenities produced on their own land depend on adjacent stocks (see Chapter 2). Here adjacent, or neighboring, properties are defined as those directly bordering the parcel owned by the individual under consideration.

Suppose the landowner is confronted with an offer to enter into a cooperative agreement, which commits K_{ib} acres into an arrangement with neighbors, who commit K_{jb} acres to the agreement.¹² The landowner, by entering into such an arrangement, effectively gives up individual rights to management for a period of time, thus both benefits timber income and non-timber amenities are determined collectively and are subject to a management plan that is

¹² Equations (1) and (2) developed here are similar to an econometric model developed in Sullivan et al. (2005), except for this analysis incorporates landowner uncertainty and the individual landowner is not acting to determine an optimal rotation age for the forest land.

tentatively committed to by the group. This eliminates uncertainty associated with the condition of adjacent forest stock(s), at least for the stocks committed to the joint agreement. The new utility function under this agreement can be written,

$$V(c, M, K_i - K_{ib}, K_{ib}, K_j - K_{jb}, K_{jb}; \Omega) = U(c_{ib}, M; \Omega) + N(K_{ib}, K_{jb}) + E[U(c, M; \Omega) + N(K_i - K_{ib}, K_j - K_{jb})], \quad (2)$$

where the first two terms on the right hand side represent the stream of income and non-timber benefits from the cooperative arrangement, while the third term is just the expectation of rents from forest stock not included in the cooperative management agreement between neighboring landowners. In order for a rational landowner to participate in such a joint management agreement the expected net utility benefits from cooperation must be greater than those received by the landowner if he/she were to maintain individual control of forest management.

With this in mind, it is proposed that, at time t , the probability that a landowner will participate in activities on neighboring lands or with neighboring landowners is:

$$\Pr(a_{ij} = 1) = F(x_t, \beta) \forall j \in J, \quad (3)$$

where $a_i = 1$ is the probability of landowner i participating in an action j (i.e. participating in a form of cooperation) in the set of possible actions J , which is a function of the factors x_t at time t . Previous studies of NIPF behavior considering single-stand management have observed that x_t contains landowner parameters and characteristics,

$$x_t = f(A, S, D, M, t; \Omega), \quad (4)$$

where A is the net assets of the landowner at time t , S is a vector of forest and land characteristics important in the decision to harvest or accept an offer for harvesting at time t , D is a vector of landowner demographic and other variables important to harvesting, M is a vector of expected future and current market factors, and Ω represents a vector of landowner preferences for use of their forests.

Equation (4) is modified to reflect the presumption that an individual landowner also accounts for neighboring land use when considering forest management options:

$$x_t = f(A, S, D, M, t; \Omega, \eta), \quad (4')$$

where η is a vector of neighboring forest characteristics, such as timber stock.

Using x_t an econometric form for the decision to participate or not to participate in a given cooperative activity (equation 3) can be expressed using an error with an extreme value distribution to reflect the discrete choice made by the landowner,

$$\Pr(a_{ij} = 1) = \frac{e^{\beta'X}}{1 + e^{\beta'X}}, \quad (5)$$

where β is a vector of parameters to estimate, and X is a vector of variables explaining the discrete choice and coinciding with variables important to the forest use decision of equation (4'), i.e. $X = \{A, S, D, M, t; \Omega, \eta\}$. Of course, if decisions (4') and (5) are examined at one point in time, then t is no longer an explanatory variable, and all explanatory variables, and the dependent variable would take on their time t values.

For the individual landowner, the utility received from cooperation of different forms depends on the spatial dependence of parcels in the production of non-timber amenities. Transactions costs, in terms of coordinating actions between landowners offsetting individual timber rotations to coincide with group management, should be accounted for by the landowner in their utility assessment. Although utilities associated with cooperation and non-timber related activities on own and adjacent lands (spatial interdependencies) cannot directly be observed, it was possible to observe whether cooperation (or use) increases overall utility when compared with non-cooperation (or non-use) by examining individual choice between the two actions. Two decisions are jointly modeled in this analysis, rather than the examination of one decision as was done in the prior models. Both past and future decisions to cooperate with neighbors in land

management activities, and decisions to use own or adjacent land for recreation activities are jointly examined here.

These decisions are modeled similar to those in equation (2). However, with data on the two decisions, it is possible to determine whether errors in the disturbance terms associated with utility from cooperation in the past (or use of own land for recreation) are correlated with errors in the disturbance terms associated with the utility from cooperation (or use of neighboring lands for recreation). Utility from cooperation (equation 2) can also be delineated as in the following format:

$$V_c = \beta'_c x + \varepsilon_c. \quad (6)$$

While utility when the landowner does not cooperate is given by the following equation:

$$V_{nc} = \beta'_{nc} x + \varepsilon_{nc}. \quad (7)$$

The probability of choosing to cooperate is then given by:

$$\Pr(a_{it} = 1|x) = \Pr(V_c > V_{nc}) = \Pr[(\beta_c - \beta_{nc})'x + \varepsilon_c - \varepsilon_{nc} > 0|x] = \Pr[\beta'x + \varepsilon > 0|x] \quad (8)$$

As a result of examining two decisions:

$$\Pr(a_{ip} = 1|x) = \Pr[\beta'_p x + \varepsilon_p > 0|x], \text{ and} \quad (9)$$

$$\Pr(a_{if} = 1|x) = \Pr[\beta'_f x + \varepsilon_f > 0|x]. \quad (10)$$

The p and f subscripts represent past actions (use of adjacent lands) and future actions (use of own lands) respectively.

When examining the choice to recreate on own or adjacent parcels, it is assumed that when landowners decide to participate in these activities, their utility from participating in actions is greater than the utility from not participating. The same is assumed for the choice of cooperation. It is also assumed that the participation in activities is a function of similar

characteristics as those factoring in the decision to harvest (see equation 4'). There is no reason to believe otherwise, given prior literature discussed above. Utility depends on the amenity value that the landowner associates with the condition of forest stock on own and adjacent parcels.

When modeling the joint decisions (equations 9 and 10), it was assumed that the disturbances followed a bivariate Normal distribution, which allows for correlation in the disturbance terms, ε_p and ε_f . Thus, the probability of an action (cooperation or use) was given by,

$$\Pr(a_{ip} = 1, a_{if} = 1) = \int_{-\infty}^{x_f} \int_{-\infty}^{x_p} \phi_2(z_{ip}, z_{if}, \rho) dz_{ip} dz_{if}, \quad (11)$$

where the z term in equation (11) is defined by the following expression:

$$z_{it} = \beta'_t x_t, \quad t = p, f. \quad (12)$$

and ρ (rho) is the value of the covariance between the disturbance terms. The null hypothesis is that the disturbances are not correlated, i.e. $\rho = 0$. When the null hypothesis cannot be rejected, then it implies that the equations can be efficiently estimated independently.

Interpreting the above terms, $a_i = 1$ is again the probability of landowner i participating in an action j (i.e. participating in a form of cooperation) out of a set of possible actions J , a function of the factors x_t at time t . Where again it was assumed that x_t is a function of characteristics of both the landowner and parcel, as well as neighboring forest characteristics (see equation 4').

4. Descriptive statistics

A summary of descriptive statistics of variables obtained from the survey of four central Virginia counties is presented in Table 1. First, landowners were asked to describe characteristics of their land parcel. The average respondent had 53.4 acres of forested land. This was higher than in prior studies of Virginia landowners (Birch 1996, Sullivan et al. 2005), possibly due to our qualifying question that respondents were those with at least 5 acres of forestland and elimination of non-forest tracts from the sample.¹³ General terrain was classified as either relatively flat or rolling hills by 26% and 68% of respondents respectively. Descriptors of terrain (such as slope) were found significant in prior evaluations of land cover changes (Wear et al. 1998, Turner et al. 1996). Parcels contained an average 0.62 miles of roads, lower than in two prior studies of Virginia landowners (Conway et al. 2003, Sullivan et al. 2005) and were an average of 0.4 miles from the nearest state route. Parcels in this study were also less developed than those in Sullivan et al.'s (2005) study, as determined by the 61% of parcels with existing permanent structures (e.g., house, trailer, barn) present.

Secondly, landowners were asked about their ownership. The majority of landowners, 74%, acquired their parcel by outright purchase, while 26% inherited their parcels. The proportion of landowners purchasing their parcels was higher than that found by Sullivan et al. (2005) and Jacobson (2002), but consistent with that found by Vokoun et al. (2004). The

¹³ This qualifier defined forest use differently than the definition provided in the assessment standards as set by the Virginia Department of Forestry. The latter sets standards requiring a minimum of twenty acres devoted to forest use. To be qualified as productive forest land, the real estate should have existing on it a minimum 40% stocking of commercially valuable timber of sufficient size, that is a minimum number of trees per acre as, that is a minimum number of trees per acre as determined by diameter class (VDOF 2005).

average length of ownership was 19.4 years, in line with Sullivan et al. (2005).¹⁴ An imperfect assessment of fragmentation was obtained when only 12% of respondents had divided their parcel throughout their tenure. The assessment was imperfect, as landowners were asked to answer questions for a specific parcel, delineated by tax records that most likely accounted for prior parcel divisions.

Landowners were also asked questions about the management of their land parcels. Approximately 41% of landowners take into account how their land management decisions affect neighboring parcels defined as those lands directly bordering the surveyed parcel. This high percentage suggested that there was merit to the approach taken here, which examined coordination of forest management decisions. Landowners with previous timber sale experience accounted for 38% of respondents, a smaller portion than that found in previous studies (Hodge and Southard 1992, Birch 1996, Conway et al. 2003, Sullivan et al. 2005, Brunson et al. 1996), with an average 43 acres harvested. A smaller portion of landowners, 17%, had previously worked with neighboring landowners in land management activities (e.g., trail building, improving stream quality, developing wildlife habitat, timber harvesting, farming), consistent with Brunson et al. (1996). Approximately 44% of landowners indicated willingness to harvest at the same time as neighbors if there would be a 20% increase in the price received for timber, under the assumption that their own parcel and neighboring land parcel(s) had trees that were currently ready to harvest.

Landowners' future plans for the surveyed parcel were then assessed. Approximately 36% of respondents indicated they would consider jointly planning future forest management activities with neighboring landowners. The majority of respondents who selected either "yes"

¹⁴ Survey participants were asked to indicate the year they acquired the land parcel. This number is obtained by subtracting the year of acquisition from the current year (2004). If participants indicated multiple years, or a range of years, the mean year was then entered in the data set.

or “I don’t know” (the latter accounted for 21% of respondents) indicated that they would like the joint plan to include provisions that increased overall land value (53%), improved water quality (51%), or reduced property, income, or estate taxes (51%), where the selection of provisions was not designed to be a mutually exclusive decision. It was also found that 48% of landowners expected to harvest trees from their land parcel in the future, a lower percentage than found in prior studies (Birch 1996, Hodge and Southard 1992), as was anticipated due to increases in amenity values for land and increasing fragmentation of forest ownerships in the surveyed area. Lastly, landowners were asked about their future plans for the land parcel. It was found that 69% plan to give land to heirs and 15% plan to eventually sell the parcel. The proportion of landowners with land bequest intentions was smaller than in previous studies (Conway et al. 2003, Sullivan et al. 2005, Vokoun et al. 2004).

Next, landowners were asked about their views of timber as an investment and about their use of their land parcel. A mean score of 2.5 out of 5 was returned by respondents who rated the degree of risk associated with growing trees for income as opposed to typical investments (e.g., stocks, bonds). The degree of risk associated with losing timber to natural occurrences, returned a mean rating of 2.9 for the sample. Several reasons for land ownership were examined using an importance scale, with indicators ranging on a numerical scale from 1 to 5. Landowners considered that owning land to keep in the family as relatively important, with a mean score of 4, similar to that found by Conway et al. (2004). Owning land for environmental reasons (e.g., protection of water quality, wildlife habitat) returned a mean score of 3.9, and the mean score for owning land for the purpose of land investment/real estate was 3.95.¹⁵

¹⁵ The importance of land for investment is similar to that found in Hodge and Southard (1992), while the mean scores for the importance of environmental reasons and land investment were contrary to that found in Vokoun et al. (2004).

Landowners were asked to assess the number of days they participated in recreational activities on their land in order to establish a quantifiable assessment of the non-timber benefits that they receive from their property. Subsequent separation of activities into consumptive, such as hunting, and non-consumptive, such as walking or horseback riding was performed to utilize these assessments in the previous models. Approximately 40% of respondents indicated participation in hunting in the previous year, while 80% indicated participation in non-consumptive activities.¹⁶ For the majority of landowners surveyed, 77% indicated that their own use of their parcel for recreational activities was not dependent on the condition of neighboring lands. Approximately 70% of respondents allowed others to use their land for recreation (i.e., hunting, hiking, camping, and farming).

Landowners were asked about the parcels directly bordering (neighboring) the surveyed parcel. The responding sample had an average of 4 neighbors (this included any parcels the landowner may own), with 97% of respondents having at least 1 non-industrial private landowner as a neighbor. An average of 63% forestland, 19% cropland, and 11% residential areas, where the latter was defined as a subdivision or a planned development with multiple residences, bordered landowners who responded to this question. Approximately 42% of respondents indicated they would consider jointly planning land management activities other than timber harvesting with neighboring landowners.¹⁷ Those landowners that indicated they would consider or were not sure about jointly planning such activities (18%), would be most comfortable with such cooperation if the plan contained a provision for protection of wildlife

¹⁶ The average number of hunting and non-hunting days is 10.5 and 247, respectively. The number of days spent by landowners in these activities is consistent with previous studies (Conway et al. 2003 and Vokoun et al. 2004).

¹⁷ This question, as a result of survey design, had high item nonresponse. Only 74% of those responding to the survey completed this question.

habitat (74%), a provision for environmental protection (e.g., preserving soil and water quality) (76%), or resulted in a better land price (36%).

Lastly, an assessment of socioeconomic data was obtained for the survey sample. Approximately 48% of respondents had a primary residence on the parcel, a smaller proportion than in Conway et al. (2003) and Sullivan et al. (2005). While 14% of landowners could be classified as absentee according to the literature, where absenteeism is defined as residing more than 50 miles from the surveyed property.¹⁸ The average age and number of heirs (as indicated by number of children) of respondents was 61 years and 2, respectively. Respondents were well-educated, with 22% completing high school (similar to Hodge and Southard 1992), 21% completing some college and 52% completing college. Average household income of respondents was \$78,724, lower than that found by Conway et al. (2003) in a study that encompassed a similar region of Virginia, but similar to Vokoun et al. (2004).¹⁹

5. Logit estimation results

The focus of this chapter will now be directed at estimation of the decision to coordinate in future forest management activities (equation 5), specifically to understand (1) whether the landowner would harvest at the same time as a neighbor with a 20% increase in the price received for timber, (2) whether the landowner would consider jointly planning future forest management activities with neighboring landowners, (3) whether the landowner was willing to enter into a joint agreement with neighboring landowners to **not** harvest timber on a portion of land to create forest cover for wildlife species or (4) to create a forested area for recreation, and

¹⁸ Similar to that found in Schaffer and Meade (1997) and Vokoun et al. (2004), while slightly smaller than in Conway et al. (2003).

¹⁹ This question also had high item nonresponse, with only 84% of respondents indicating an income range.

(5) whether the landowner would enter into an agreement with neighbors to jointly manage land, for activities such as improving water quality, wildlife habitat enhancement, trail building, and farming. NOAA panel recommendations (Randall 1997) were followed for treatment of “don’t know” responses for the willingness to participate questions.

A preliminary test was performed to determine whether some of the right hand side variables (see equation (4')) were correlated. The test was designed to determine whether or not absentee landowners in the sample population were more likely to indicate that they had acquired their parcel through inheritance. It was hypothesized that the means for the absentee variable (those landowners residing more than 50 miles from the surveyed parcel) when comparing the population of respondents that indicated they had purchased their parcel to those that had inherited their parcels were equal. Using a two-sample t-test, this hypothesis could not be rejected at a p-value of 0.05.

Willingness to enter into a joint plan for future forest management

The decision to enter into a joint plan for future forest management with neighbor(s), a variation of equation 3, was the first to be considered. Nine explanatory variables were significant at a p-value less than 10% (Table 2) and included: whether the landowner completed college (+), participation in recreational activities other than hunting or fishing on neighboring parcels (+), previous cooperation with neighbors in land management activities (+), whether the landowner accounted for how their decisions affect neighboring landowners (+), the number of private individuals owning bordering parcels (+), the degree of importance the landowner placed on

owning the parcel for investment/real estate purposes (-), income (+), whether the landowner had acquired the parcel by inheritance (-), and the constant term (-).

Interestingly, the education level of the landowner was significant in the landowner's decision to enter into a joint plan for future forest management with neighbor(s). Stevens et al. (1999) found that the likelihood of participation in one of four land management scenarios was not statistically related to landowner education. However, Jacobson (2002) found that education was significantly related to interest in participating in joint management. Higher levels of education increase a landowner's information capital, which should factor in determining landowner behavior. As expected, the landowner's method of parcel acquisition was significant and negative in determining willingness to enter into this joint agreement. Landowners who inherited their parcels may place higher value on retaining property rights and managing their land independently that stem from the method of acquisition.

Landowner's willingness to enter into the joint agreement is improved by use of neighboring properties for non-consumptive recreation. This is also expected; as such landowners have experience with dealing with neighbors, in retaining permission to use their property, and are familiar with neighboring land characteristics, thus removing some of the uncertainty involved with neighboring land use that could negatively affect the willingness to participate in joint management. Similarly, those landowners who indicated they had cooperated in land management activities, such as trail building, improving stream quality, developing wildlife habitat, farming, or timber harvesting, were also more likely to indicate willingness to enter into a joint agreement for future forest management.

The degree of importance that landowners placed on owning their land for land investment/real estate purposes decreased a landowner's willingness to enter into a joint plan for

future forest management. It was also found that landowners who acquired their parcel through inheritance were less likely to enter into the joint agreement. The two previous results were expected, as landowners with investment objectives and those that acquired parcels through inheritance may be more economically motivated. The former is obvious while the latter reason may be to cover taxes, and thus landowners were less likely to be willing to offset the liquidity of their forest investments by entering into joint agreements.

The marginal effects (Table 2) provided an assessment of the change in probability a landowner would undertake the investigated action for a one percent change in an explanatory variable. The marginal effects were computed for numerical (non-dummy) variables at the overall means of the data set. Analysis of the data indicated that the likelihood of entering into such an agreement increased by approximately 11% with a \$10,000 addition to income. It was expected that landowners with increased wealth outside of timber harvesting activities (declining marginal utility of income from timber) would be less likely to depend on revenue from timber and thus would be willing to enter into such agreements with neighbors, given that these could involve lower harvesting revenues. These results are similar in sign to those of Jacobson et al. (2000), who investigated landowner interest in joint planning.

The number of private individuals bordering the parcel in question improved landowner willingness to manage forests jointly by approximately 2%. That is an additional proximate landowner beyond the sample average of four increases an individual landowner's willingness to participate in a cooperative management agreement of this type. This contrasts to the results of Jacobson et al. (2000), who found that the spatial characteristics were not significant in explaining interest in joint forest planning. This was possibly a result of self-assessment by landowners regarding the number of neighboring landowners, as opposed to employing data

from sources other than the survey as was done in the aforementioned study. Otherwise, it could be that increased fragmentation resulted in landowners with an increased desire for knowledge of future land use activities, and entrance into such an agreement uncertainty associated with adjacent land use is deferred to some extent.

Harvest at the same time as neighbor(s) given a 20% increase in price for timber

The decision to harvest at the same time as neighbor(s) if it resulted in a 20% increase in the price received for timber was the next to be examined. Jacobson (2002) suggested that there is potential for generating revenue from cooperation amongst landowners, by reducing the economies of scale in harvesting. An analysis by Kittredge (2003) confirmed there are potential benefits generated from the economies of scale created by landowner cooperatives.

This decision was posed by placing landowners in a hypothetical situation. Landowners were asked to suppose that both their own and neighboring parcels had trees that were old enough to harvest and then to indicate their willingness to harvest at the same time as their neighbor. There were eight explanatory variables that significantly ($p\text{-value} \leq 0.10$) influenced the decision of landowners to cooperate in harvesting with an increase in price (Table 3). The significant variables and their respective signs were absenteeism (+), whether the landowner completed college (+), whether the landowner previously harvested (+), whether the landowner was employed full time (+), the degree of importance the landowner placed on owning their land for environmental reasons (-), the presence of structures on the property (-), the number of bordering landowners that were private individuals (-) and the percent of agricultural land that bordered the parcel (+).

Although the sign on landowner employment may not be initially expected, as these landowners would have less free-time to commit to establish a long-term cooperative agreement. Following the familiar models of both Martin Faustmann and Hartman (1976), employed landowners may be more willing to offset their harvesting schedule because of their current best alternative of income generation, in the form of employment. Similarly, Jacobson (2002) found that occupation of the landowner was significant in determining interest in joint management. Landowners that feel that ownership of lands is important for environmental reasons were less willing to coordinate timing of harvests with neighbors. The environmental reasons that were provided as examples were the protection of water quality or wildlife habitat. It is expected that landowners with these preferences on a landscape, would desire to avoid harvesting timber at the same time as neighbors in order to protect water quality by minimizing reduction of cover through such a scheme, or protect wildlife habitat by providing an area of forest cover for wildlife species. Increased likelihood that an absentee landowner would enter into such an arrangement was unexpected, but could be explained. Although Conway et al. (2003) found that absenteeism negatively affected harvesting behavior; it could be that these landowners were more willing to undertake a harvesting scheme that could be supervised by adjacent owners.

As expected, participation in this type of arrangement was increased for those landowners who had harvested timber in the past. Landowners who completed college were also more likely to indicate willingness to enter into the aforementioned harvesting arrangement. Both of the previously mentioned variables add to a landowner's information base regarding timber harvesting and were thus anticipated to improve the landowner's attitude towards harvesting timber.

A variable found to favorably affect landowner willingness to enter into such an agreement was the percentage of agricultural land bordering the parcel (Table 3). An increase in the percentage of agricultural land bordering a parcel increased a landowner's willingness to harvest timber at the same time as a neighbor by 25%. This may either be a result of many landowners having small areas of forest, or that landowners may wish to dedicate more of their own land to agriculture or other uses. Increased fragmentation, in terms of the number of private individuals who own adjacent parcels, resulted in a 2% decline in willingness to coordinate timing of harvests. This may be a result of an increased desire for privacy from adjacent properties that is provided by timber, and/or that the landowner may not be familiar with the multiple landowners that surround their property.

Willingness to enter into a joint agreement to forego harvesting to create wildlife cover

A landowner's willingness to enter into a joint agreement such that they would not harvest a portion of their land, in order to create a forest area for wildlife, was the next decision considered. There were many significant characteristics of both landowners and the parcel that influenced this decision by landowners to enter into such a joint agreement (Table 4). These characteristics and their respective signs are as follows; landowner absenteeism (+), income (+), whether the parcel was acquired through inheritance (-), road mileage (-), importance the landowner placed on owning the parcel for environmental reasons (+), degree of risk the landowner associated with growing trees as opposed to other typical investments (-), importance the landowner placed on owning the parcel for family (-), whether the landowner completed college (+), participation in recreational activities other than hunting or fishing on their own

parcel (+) and on neighboring parcels (+), percent of agricultural lands bordering the parcel (-), previous cooperation with neighbors in land management activities (+), and the constant term (-).

As expected, increased access to the parcel determined by the existing miles of roads decreased landowner willingness to enter into a joint management agreement to forego timber harvesting on a portion of their property to create wildlife cover. The fragmentation of the parcel created by an increased network of roads may make it more difficult to create an area large enough to improve wildlife habitat (Hunter 1990). The significance of landowner perceived risk associated with growing timber compared with other types of investment was similar to a land retirement programs studied in Sullivan et al. (2005). Non-consumptive recreation (activities other than hunting and fishing) on neighboring lands was expected to positively influence landowner willingness to enter into a joint agreement, as landowners who participated in such activities would most likely reap direct benefits from such an arrangement and had prior experience dealing with neighboring landowners in order to retain permission to use their property.

Absentee landowners (those residing more than 50 miles from the queried parcel) were more likely to indicate willingness to enter into such an agreement. Conway et al. (2003) found that absentee landowners were less likely to harvest; therefore this may suggest that participation in this agreement would not conflict with their preferences for timber harvesting. Acquisition of parcels by inheritance decreased a landowner's willingness to enter into a joint agreement to forego harvesting a portion their land. Such landowners may be increasingly protective of property rights as a result of their method of land acquisition.

Marginal effects computed at the overall mean of the data set for non-dummy variables significant in this decision were summarized in Table 4. An increase in the percentage of

surrounding parcels employed in agricultural crop or pasture uses decreased landowner willingness to enter into this type of arrangement by 28%. It could be that forested parcels did not border these landowners, or the mixture of crop and forest in the immediate landscape already provided suitable habitat for many wildlife species, such as deer.

An income increase of \$10,000 beyond the sample mean increased the landowner's willingness to enter into the joint agreement by 11%. This finding was consistent with Stevens et al. (1998) who found income to increase the probability of adopting one of four management scenarios offered in their study, and Klosowski et al. (2001), who found that lower income had negative effects on the probability of landowners' participation in coordinated management programs. The remaining significant non-dummy variables all have an effect of 10% or less on landowner willingness to enter into a joint agreement to not harvest a portion of their forest to create a forested area for wildlife.

Willingness to not harvest a portion of forest to create an area for recreation

Landowner willingness to enter into a joint agreement to not harvest a portion of their forest in order to create a forest area for recreation was also considered. Significant variables factoring in this decision (Table 5) were the constant term (-), whether the parcel had been inherited (-), perceived level of risk associated with loss of trees to natural occurrences (-), whether the landowner was employed full time (+) or had previously harvested timber (-), flat terrain (-), whether the landowner had completed college (+), the percent of agricultural lands that bordered the parcel (-), the number of bordering parcels owned by private landowners (-), previous

cooperation with neighbors in land management activities (+), and whether the landowner accounted for how their management affects neighboring parcels (+).

The number of private individuals that bordered the parcel was expected to negatively effect landowner willingness to enter this arrangement. An increased number of adjacent owners would serve to increase the transaction costs associated with the creation of contiguous areas for recreation and would also increase the probability of free riding (see Chapter 2). As expected, landowners who perceived greater risk associated with loss of timber to natural occurrences were also less likely to enter into an agreement that would essentially increase the probability of such events affecting timber stock.²⁰ Willingness to enter into this arrangement was positively affected by full-time employment status of the landowner, this is an example of an income effect, in that such landowners have an increased capacity for outside earnings, other than timber harvesting, which allows the flexibility of altering the timing of timber harvests.

The completion of a college education by the landowner effectively increased landowner participation in this joint management agreement. Landowners who have cooperated with neighbors in the past in activities such as trail building, stream quality improvement, creation of wildlife habitat, farming, or timber harvesting, were also more willing to participate in this agreement. The two aforementioned variables represented an increase in the individual landowner's information capital and thus were expected to increase willingness to cooperate.

Landowners who had previously harvested timber were less likely to enter an agreement to not harvest a portion of their land to create an area for recreation. This result is similar in sign to that found in the previous model of landowner willingness to enter into a joint agreement to forego harvesting on a portion of land to create an area for wildlife (Kline et al. 2001). The

²⁰ Sullivan et al. (2005) find that perceived risk of timber loss is not significant in determining the probability of price acceptance to enroll land in a program where rights to timber management would transfer to another party.

acquisition of the parcel through inheritance also decreased the probability that landowners would be willing to set aside land from harvesting to establish a recreational forest. An increase in the percentage of agricultural crop or pasture land that bordered a landowner beyond the sample mean decreased the probability of entering into this arrangement by 13% (Table 5). Remaining non-dummy variables affected landowner willingness to enter into such an agreement by 6% or less when evaluated at the mean of the data set.

Willingness to enter into a joint agreement to manage land use activities, excluding harvest

The decision by landowners to enter into an agreement with neighbors to jointly manage land, for activities such as improving water quality, wildlife habitat enhancement, trail building, and farming (Table 6) was examined. Previous coordination with neighbors in land management activities (+), whether the landowner accounted for how their management of land affected neighboring parcels (+), whether the landowner participated in non- consumptive recreation on neighboring parcels (+) or allowed others to use their own land for recreation (+), whether the landowner had completed college (+), the level of importance the landowner associated with owning land for environmental reasons (+), and whether the parcel had been inherited (-) were all significant to the landowner's decision to enter into a joint land management agreement. A landowner who feels that environmental aspects, such as protection of water quality and wildlife habitat, were an important reason for owning land was more likely to enter into an agreement with neighbors for land management activities, as expected. The presence of structures on a parcel increased landowner participation in this joint arrangement; similar to results found in Vokoun et al. (2004).

When landowners' participated in non-consumptive recreational activities on neighboring properties it increased their willingness to enter into a joint land management plan with neighbors. Similarly, an increase in the willingness of landowners to enter into such an agreement with their neighbors was found for those landowners who had previously coordinated with neighbors in land management activities. These variables indicated that landowners who have had prior contact with neighbors, either through coordination activities or in retaining permission to use their land, were willing to enter into this cooperative agreement. This was similar to the findings of Brunson et al. (1996), where probability of cooperative management was positively related to observation of a joint management program at work. College education increased landowner participation in this arrangement. Jacobson (2002) also found that the education level of landowners was significantly related to their interest in joint management.

Landowners who acquired their parcel through inheritance were less likely to participate in such an agreement. Acquisition of the parcel through inheritance may result in a greater desire for preservation of property rights, and thus may negatively affect landowner willingness to enter into agreements that may comprise these rights. Willingness to participate in this agreement was improved for those landowners who allow others to use their parcel for recreation, obviously landowners who value amenities in their utility function are more likely to delay timber harvesting or even to not harvest timber for income at all.

The marginal effects provided the probability that a landowner would be willing enter into an agreement with neighbors to jointly manage land, for activities such as improving water quality, wildlife habitat enhancement, trail building, and farming (Table 6). Landowners who place increased (or decreased) importance on owning lands for environmental reasons beyond

the mean of the sample data set were approximately 5% less likely to indicate willingness to participate in such an agreement.

Likelihood ratio tests

The effect of removing groups of explanatory variables on the performance of the model to estimate landowner willingness to enter into a joint management agreement with neighbors was also of interest. Therefore, the null hypothesis that the coefficients of different groups of variables were zero was tested. This was accomplished by using likelihood ratio test to compare a restricted model, with coefficients of an individual group of variables set to zero, with the unrestricted models. Variable groups with restrictions on their coefficients and modeled included (1) those representing use of own and adjacent parcels, (2) the demographic variables of income and number of children, (3) access, and (4) those associated with bequest intentions (Table 7).

In general, the null hypothesis was rejected at a p-level less than 0.05 when the coefficients of variables indicating that the landowners used either their own or neighboring parcels for recreation were set to zero and compared to the unrestricted models. This result is of particular interest, as it suggests the non-timber benefits from both own and adjacent parcels have an effect on landowner willingness to enter into cooperative agreements. This assessment of landowner time spent in recreational activities on their own or adjacent lands provided a means of quantifying the landowner's non-timber benefits and the spatial relationship of the parcels in the provision of these benefits.

Next, the null hypothesis that a model restricted by setting the coefficients of access variables equal to zero was valid also was rejected at a p-level less than 0.05 for the various models of landowner willingness to cooperate. This was also the case when the bequest variables were excluded. This is consistent with previous studies such as Conway et al. (2003) and Vokoun et al. (2004) who found that bequest intentions of landowners do indeed function in determining landowner timber harvesting behavior. The null hypothesis could also not be rejected for most of the models where the demographic variables were removed. The exception to this last case was rejection of the null hypothesis that the demographic variables income and children have no effect on landowner willingness to enter into a joint agreement with neighbors to not harvest a portion of their land to create a forested area for recreation at a p-level of 0.05 or less.

6. Bivariate probit estimation results

The possibility that the disturbances in the decisions to coordinate past and future land management and to use own and adjacent lands for recreation activities were correlated was considered. These decisions were thus modeled as a bivariate probit problem.

Initially, landowner decisions to coordinate land management activities i.e., trail building, improving stream quality, developing wildlife habitat, farming, timber harvesting with neighboring landowner(s) in the past were examined. I also examined landowner willingness to participate in joint agreements involving either future planning decisions or timing of harvests. These latter decisions are similar to those studied with the above logit models.

Landowner decisions to use own and adjacent lands for either consumptive or non-consumptive recreation activities were also studied. Correlation in the disturbances in the error terms associated with utility received from own and adjacent lands would suggest that there is merit to the approach of examining coordination of forest management decisions for parcels that are spatially interdependent in an individual's amenity valuation.

Decision to cooperate in the past and to coordinate timing of harvests with a price incentive

Consider first the decisions by landowners (1) to coordinate land management activities, in the past and (2) to harvest at the same time as neighboring landowners if it resulted in a 20% increase in the price received for harvest (Table 8). Due to potential correlation in the error terms, a bivariate probit model was used to determine significant variables factoring in the landowner decisions.

There were five (seven) variables significant at a p-level less than 0.1 in the first (second) equation. In the decision to coordinate land management activities in the past, the significant variables and their respective signs were the miles of roads (+), the importance level the landowner associated with the objective to own land for environmental reasons (+), the level of risk the landowner perceived with loss of timber to natural occurrences (-), whether the landowner had harvested timber in the past (+), and whether the landowner had completed college (+). The significant variables and their respective signs in the landowner's decision to coordinate timing of timber harvests were: the importance level the landowner associated with the objective to own land for environmental reasons (-), number of children (+), whether the landowner was employed full-time (+), whether the landowner had harvested timber in the past

(+), whether the landowner had completed college (+), the number of private individual owners that bordered the property (-), and whether the landowner intended to bequeath land to heirs in the future (-).

There were some differences in the level of significance and the coefficients when comparing the three variables that were significant in both equations. As might be anticipated, the importance level the landowner attributes to owning land for environmental reasons was positive (negative) in the decision to coordinate in the past (timing of harvests). Although the coefficients for prior timber sale experience were similar in sign between the two equations, this variable had greater significance (lower p-value) in the second decision investigated. The coefficients and significance levels for landowner education were similar for the two equations.

The coefficient of correlation in the disturbances was not significant in this model. This result indicated that coordination of harvests that resulted in an increase in timber prices was not correlated with prior decision to cooperate with neighbors in land management activities. Therefore, individual probit (or logit) estimates of the above decisions could be obtained without concern for inefficiencies that result from ignoring the correlation in disturbance terms. The Lagrange multiplier (LM) test (Greene 1998) was used to test the hypothesis that the disturbances are homoscedastic (variance is constant), and the null hypothesis was rejected at a p-value of 0.5.

Decision to cooperate in past and enter into a joint agreement for future forest management

The decision to (1) coordinate land management activities in the past and (2) jointly plan future forest management activities with neighbor(s) were the next set of estimations addressed with the

bivariate probit method. The significant variables (Table 9) in the first decision and their respective signs were: miles of roads (+), the importance level the landowner associated with the objective of owning land for environmental reasons (+), the level of risk the landowner associated with losing timber to natural occurrences (-), and whether the landowner had completed college (+). Only one variable from the first equation, whether the landowner had completed college, was also significant in landowner willingness to jointly plan forest management with neighbors.

The other significant variables that factor into this second decision were: the number of children (-), whether the landowner was employed full-time (+), generally flat terrain (-), and the importance level the landowner associated with the objective of owning land for investment purposes (-). All variables in the first model are significant at p-values less than 0.6, while only two variables in the second equation are significant at this level (education and importance of owning land for investment purposes). The coefficient of correlation, rho, of 0.428 was significant in the bivariate probit estimation. Therefore, the null hypothesis that the disturbances were equal to zero ($\rho=0$) was rejected at a p-level of less than 0.05. Using the LM test, the null hypothesis that the models are homoscedastic in disturbances was also rejected.

Prior cooperation and joint agreement to not harvest a portion of land for wildlife

Landowner decisions (1) to cooperate in land management activities in the past and (2) to enter into a joint agreement with neighbors to not harvest a portion of land to create an area for wildlife, were the next to be assessed with the bivariate probit method. Variables that were significant at a p-level less than 0.5 (Table 10) in both equations were: the constant term,

whether the landowner had completed college, the importance associated with owning land for environmental reasons, and the road mileage on parcel. The first three of these common factors between the two equations had similar signs and magnitudes, while the existing road mileage variable was positive (negative) in the first (second) equation. Perceived risk associated with loss of timber to natural occurrences (-) was the only other significant variable at a p-level of 0.10 in the first equation.

The five additional significant variables in the second equation were landowner absenteeism (+), income (+), perceived risk associated with growing timber opposed to typical investments (-), percent of forest land that bordered the parcel (+), and whether the landowner had inherited the parcel (-). The coefficient of correlation in the disturbance terms of 0.272 was also positive and significant at a p-level of less than 0.01; therefore the null hypothesis that there was no correlation in the disturbance terms was rejected. This suggested that a bivariate probit approach would improve the efficiency of estimates of these two decisions. Similarly, by the LM test, the null hypothesis that disturbances are homoscedastic can also be rejected.

Prior cooperation and joint agreement to not harvest a portion of land for recreation

Next, the decisions to (1) cooperate in land management activities in the past and (2) to enter into a joint agreement with neighbors to not harvest a portion of land to create a forested area for recreation were estimated via this method (Table 11). Only one variable was significant with a p-value less than 0.1 in the first equation that was not also significant in the second equation - this variable was the existing road mileage on the parcel (+). The common significant variables between the two equations also had similar signs throughout and included: the constant term (-),

importance associated with owning land for environmental reasons (+), perceived risk associated with loss of timber to natural occurrences (-), and whether the landowner completed college (+). Whether the landowner had harvested timber (-) and inherited the parcel (-) were also significant variables in the second equation. The coefficient of correlation in the disturbances of 0.245 is significant at a p-level less than 0.01, suggesting that the bivariate probit method should be utilized to model these decisions faced by the landowner. The hypothesis of homoscedasticity could be rejected at a p-level less than 0.05, using the LM test.

Prior cooperation and joint land management activities, excluding timber harvesting

The final land management decisions estimated with a bivariate probit analysis were (1) past coordination of such actions and (2) the decision to enter into an agreement with neighbors to jointly manage land, for activities such as improved water quality, wildlife habitat enhancement, trail building, and farming. Significant variables (Table 12), at a p-level less than 0.01, common between the two equations were the importance associated with owning land for environmental reasons (+) and whether the landowner completed college (+). In the first equation, the constant term (-) and existing road mileage on the parcel (+) were also significant at a p-level of 0.1. Whether the landowner was employed full-time (+), flat terrain (-), and the presence of structures (+) were significant factors in the second equation. The coefficient of correlation in disturbances of 0.462 was significant at a p-level less than 0.01, indicated that the bivariate probit was the appropriate method for estimation of these two landowner decisions. Similarly, the hypothesis of homoscedasticity, tested with the LM method, was not rejected at a p-level less than 0.05.

Decision to use own and adjacent lands for hunting related activities

Landowner decisions to (1) hunt or fish on neighboring properties and (2) hunt on their own property were investigated with a bivariate probit formulation (Table 13). These types of activities were classified as consumptive recreation throughout this chapter. There were only three and four variables that were significant, with p-value less than 0.1 in the first and second decisions. Whether the landowner was employed full-time and had harvested timber in the past were both significant and positive in the two equations, with greater significance (lower p-value) attributed to the variable indicating whether the landowner had harvested timber in the decision to hunt on own land.

Additional significant variables in equation (2) were whether the landowner completed college (-) and generally flat terrain (+), while in equation (1) the constant term (+) was also significant. The correlation coefficient of 0.831 was significant. This indicated the bivariate probit estimation of the equations proposed to describe landowner decision to hunt or fish on neighboring properties and to hunt on their own land was appropriate. Also, the null hypothesis of homoscedasticity in disturbances was rejected at all p-levels.

Decision to use own and adjacent lands for non-hunting recreation

Lastly, landowner decisions to participate in recreational activities other than hunting or fishing (1) on neighboring parcels and (2) on their own land, which were referred to as non-consumptive activities, were examined (Table 14). Variables significant at the p-value of less than 0.10 and respective signs in the first equation were the constant term (-), the importance level associated

with the objective of owning land for environmental reasons (+), whether the landowner was employed full-time (+), flat terrain (-), and whether the landowner had completed college (+). In the second equation, significant variables included: the percent of forest land that bordered the parcel (+), presence of structures (+), and whether the landowner inherited the parcel (-) or completed college (+). The correlation coefficient of 0.389 was significant at a p-level less than 0.01. This indicated that the bivariate probit method was appropriate to model landowner decisions to participate in non-consumptive activities on neighboring and own land. Moreover, the hypothesis of homoscedastic disturbances was rejected at all p-levels.

7. Conclusion

Research focusing on adjacent landowner effects on NIPF landowner behavior is rather sparse, and prior research has focused primarily on the concepts of ecosystem management, i.e., the behavior of a single landowner managing multiple stands across a landscape. There has also been a separate set of theoretical literature on the spatial interdependence of forested parcels in the production of benefits, particularly non-timber benefits, for an individual landowner or a social planner. In this literature, it has been established that there are externalities present in individual management of forested parcels, because landowners do not account for spatial interdependence and temporal (time) dependence of parcels in the production of landscape level non-timber benefits.

It was expected that landowners manage land with their own individual interests in mind, however it was found in this analysis that many do account for the effects of their management on neighboring parcels. However, without proper incentives it was expected that individual

landowners would manage lands focusing first on their own interests and second on the effects of management on adjacent landowners, or alternatively as was the case in Chapter 2, attribute their own preferences for timber and non-timber benefits to proximate landowners. This behavior typifies the free-riding problem often associated with the production of public goods.

These sets of literature have been connected in this chapter and provide a contribution to the empirical research on NIPF behavior. The specific consideration of how private landowners account for adjacent lands when making forest management and use decisions constituted the contribution of this chapter. The survey of landowners that concentrated on use of their own and neighboring parcels and their willingness to participate in cooperative agreements with neighbors for land management activities accomplished this connection. An assessment of individual landowner use of parcels, either on their own land or neighbors' lands, provided a means of quantifying how non-timber benefits drive decision-making. This further set this chapter apart from prior empirical studies.

The types of cooperative arrangements proposed to landowners in this analysis were separated into two categories: one involved landowner willingness to enter into a joint agreement with neighboring landowners to manage some aspect of their land, and another involved coordination of harvest timing with a price incentive. In general, several variables were found to affect landowner participation in all of these proposed cooperative arrangements these included landowner demographic characteristics, bequest preferences, use of their own lands and neighbors' lands, and spatial characteristics.

College completion by a landowner was the only consistent significant variable that factored in landowner decisions to enter into any of the proposed cooperative arrangements; otherwise characteristics that factor in landowners' decisions to enter into cooperative

agreements with neighbors were not uniform. A negative predictor of landowner participation in a joint agreement to manage land resources was whether the landowner had inherited the parcel, but this variable was not a significant determinant of whether landowners would decide to coordinate timing of harvests. Landowner participation in past land management cooperation activities with neighbors was not a significant factor in the decision to coordinate timing of harvests, while it was a positive predictor of landowner participation in one of the cooperative arrangements involving land management activities.

The percent of the landowner's parcel bordered by land employed in agricultural crop or pasture use positively (negatively) influenced landowner willingness to harvest at the same time (forego harvesting a portion of timber). This result was expected, given the opportunity costs associated with crop rents, and the fact that there would be less forest landowners to cooperate in such an arrangement. In comparing the decision (1) to enter into an agreement with neighbors to forego harvesting a portion of land to create an area for wildlife and (2) to coordinate timber harvests, it was found that whether the landowner had harvested in the past and the level of importance associated with owning land for environmental reasons affected the first decision negatively and positively, respectively, while these variables had the opposite effect on the second decision. Acquisition of the parcel through inheritance was a prominent negative factor in determining landowner willingness to enter into cooperative agreements governing both specific forest and land management activities not specifically associated with timber harvesting, possibly a result of the potential of such agreements to limit property rights.

The potential correlation between the disturbance terms in the determination of previous and future types of cooperation yielded some mentionable results. For instance, the hypothesis that disturbances were not correlated ($\rho=0$) was not rejected when the equations that examined

landowner decisions to participate in (1) prior land management cooperation and (2) coordination in the timing of harvest with the provision of a price incentive. This is the only case of the above bivariate models where this null hypothesis that the disturbances were uncorrelated was not rejected.

Landowner college completion was significant in the second equations for all of the estimated bivariate models. This suggested that highly educated landowners were more likely to enter into cooperative agreements and more likely to participate in recreational activities on their own parcels. When landowner decisions to coordinate in past and future management activities were estimated, road mileage on the parcel and the level of importance associated with owning land for environmental reasons had a consistent positive influence on landowner decisions to coordinate land management activities in the past across all models. Variables that indicated whether landowners were employed full-time and parcel with flat terrain had a negative and positive influence on the behavior toward participation in joint forest management and land management activities in the above models. When the second equation was formulated to assess landowner willingness to enter into an agreement with neighbors to not harvest a portion of land to create an area for either wildlife or recreation the importance the landowner associated with ownership for environmental reasons was a positive factor in this decision, as expected.

When landowner decisions to use adjacent lands and own parcels for recreation activities were examined, activities were divided into types delineated by use, i.e., hunting and fishing and non-hunting activities were typed as consumptive and non-consumptive activities, respectively. In estimations of the decision to use adjacent lands for activities, whether the landowner was employed full-time had a consistent positive influence on the selection of either type of activity by the individual. Landowners who had harvested timber in the past were more likely to

participate in consumptive recreation activities on both adjacent parcels and their own parcels. This may be a result of the habitat needs of hunted species, such as deer and birds that thrive in young forests.

The bivariate probit results imply that there were indeed spatial interdependencies among parcels in the production of non-timber benefits and that prior experience with cooperation influenced a landowner's willingness to cooperate in land management type activities, but not in the synchronization of harvests. This latter result was expected, as prior experience would serve to increase a landowner's information set, and therefore decrease the uncertainty involved with entering into cooperative type arrangements that would govern land management over time.

These results imply that landowners indeed value amenities produced on their own and adjacent parcels. Such valuations of amenity benefits by landowners may result in anticipatory behavior (similar to a simultaneous mover) or may lead to cooperation between landowners as studied in Chapter 2. Respondents in this empirical analysis who had inherited their parcels were less likely to participate in any form of cooperative agreement. The theory developed in Chapter 2 suggests that such landowners may have amenity values that do not depend on the condition of adjacent stocks, but are more site-specific in nature. The empirical results also implied that education, either formal or through prior experiences, served to increase willingness to cooperate in management. The latter type of experience would alleviate some of the uncertainty associated with cooperation and would thus provide an inherit incentive to the landowner to cooperate.

In the future, this approach could be employed to calculate the probability that landowners with specific preferences and parcel characteristics would enter into cooperative forest management agreements. The estimated equations could also be used to further evaluate the spatial interdependencies of benefits an individual landowner received from standing forest

stock, and the how the landowner accounted for these interdependencies when land management activities were determined. The estimation of spatial interdependencies and landowners' willingness to coordinate management of forest resources with neighbors could also be incorporated into a spatially explicit model to assess how changes in landscape and landowner characteristics influenced future supplies of timber and amenity benefits across a landscape.

Chapter 4: Conclusion

1. Introduction

Many of the current threats to forest sustainability are best addressed not at the individual parcel or forest stand level, but at a landscape level that considers the interaction of parcels in promoting sustainable conditions. Forest stands often come together to produce conditions that are beneficial to areas larger than a single stand; consider, for instance, wildlife or watershed services. Typically, the study of forest management has been addressed at the single forest stand level, without consideration of the interaction of adjacent stands in the provision of services and the effect that adjacent landowners have on an individual's management behavior. This however does not account for the public nature of many of the services provided by standing timber to other individuals across a landscape. Land management activities undertaken by an individual landowner without consideration for the effects on the amenities of adjacent landowners will lead to social costs, if the surrounding owners' amenity valuations depend on the interaction of parcels across the landscape. A more thorough understanding of the spatial interdependencies in the production of non-timber benefits and how individual decision makers account for the effect of their management decisions on the welfare of surrounding landowners is necessary in order to best address many of the current landscape level forest sustainability threats.

In the prior chapters, I have examined the effects of adjacent landowners on the management behavior of non-industrial private forest landowners, with a particular focus on the interdependencies of stands in the production of amenity services. These chapters employed theoretical and empirical analyses to address the uncertainties that individual landowners face

with regards to adjacent landowner preferences for standing timber, and how the non-timber amenity benefits from their own forest stock were dependent on the condition of adjacent stock(s). This determination of how adjacent stands affect the land management and use decisions of individual landowners contributes to the literature, in that it provides an assessment of landowner behavior across the landscape and the importance of the lack of coordination between landowners.

As many of the services that forests promote are not traded in typical market settings and do not accrue solely to the individual forest landowner, there is a need to understand whether landowners account for spatial interdependencies in the formulation of their management plans. Individual landowners, who manage stands with only their own preferences in mind, may not account for the interdependencies of parcels in the production of services, or they may try to anticipate the actions of adjacent landowners. This behavior is not optimal from the perspective of either the individual or proximate landowners that may also value amenity production from an individual stand, as there is an externality resulting from non-optimal use of the resource.

Prior literature examined either the effects of stand interdependencies on landowner behavior or landowner attitudes toward participation in cooperative management agreements. The former set of literature incorporated the spatial relationship between parcels in the production of amenity benefits into a typical single-stand framework (e.g., see Bowes and Krutilla 1985, Swallow and Wear 1993). The latter investigated the probability of landowner participation in cooperative management agreements (e.g., see Stevens et al. 1999, Jacobson et al. 2000). However, these two schools of literature were developed separately. The previous chapters here have integrated these ideas through development of a theoretical model of

landowner timber stocking decisions, and an empirical evaluation of individual landowner forest management and use behavior.

2. Theory results

Chapter 2 detailed a theoretical model of adjacent landowner effects on individual landowner behavior. Previous theoretical models of stand interdependencies had only recently addressed the timing of decisions by landowners and employed the economic characterizations of complements and substitutes in production of amenity values (see Koskela and Ollikainen 2001 and Amacher et al. 2004). However, these models were deterministic in nature. The theoretical model developed in Chapter 2 extended these analyses in an examination of the dynamic decisions of landowners, formally accounting for the uncertainties that landowners face in managing forest resources. The model was developed under the assumption that owners were uncertain regarding adjacent landowner preferences, and how the non-timber benefits valued on their own parcels depend on adjacent stand conditions. The various spatial interdependencies and temporal dependence relations between an individual stand and adjacent stands in the production of amenities were also considered.

Several levels of cooperation between landowners, as well as the assumption that individual landowners make decisions simultaneously, were examined. The steady state outcomes of these decisions were compared to evaluate the social cost of individual stand management. The theoretical model was also unique in that it assumed that landowners receive timber and non-timber benefits that were dependent on the condition of *in situ* stock of the landowner's own stand and adjacent stands, and through modeling of uncertainty a landowner

has with adjacent landowner behavior. Prior studies had focused on the effects of the benefits over time determined by stand age (e.g., see Bowes and Krutilla 1985, Swallow and Wear 1993, Koskela and Ollikainen 2001). Development of the model in this manner allowed for an assessment of the interdependencies among parcels that were not identical in species composition or rotation age.

The cooperative and timing assumptions investigated in the analysis included one of simultaneous decision-making behavior, the option to cooperate in timing of harvests that would result in an improved price for timber, the option to cooperate in amenity production, and full cooperation where a sole owner in-effect manages both stands. These results extend on prior literature investigating management behavior of a single landowner who considers the spatial interdependencies of parcels when determining their harvesting behavior (Swallow and Wear 1993), as well as those that examine the timing of landowner decisions when stands are interdependent in the valuation of amenity services (Amacher et al. 2004).

It was determined in this assessment that the optimal stock level decision of any one landowner depends on the spatial interdependencies of own stock and stock on adjacent stands in terms of amenity valuation, as well as the type of cooperation or timing strategies undertaken by the landowner. It was suggested in the analysis of partial cooperative behaviors that unexpected changes in the valuation of amenities on adjacent stocks, as a result of unanticipated changes in adjacent management behavior, affect the steady state levels of forest stock when landowners do not fully cooperate in joint maximization of total revenues and amenity rents from timber resources. Here, it was also found that the spatial interdependencies and direction of temporal dependence in the valuation of amenities determined the direction of change in a choice variable,

either level of stock or cooperation, with a change in the parameter that delineated the condition of adjacent stock.

Changes in the conditions of adjacent stocks had different effects on the steady state levels of stock and cooperation, when different forms of cooperation were investigated. Under the assumption that the landowners cooperated in terms of synchronizing timing of harvests to receive a better price for timber, a positive shift in both the steady state levels of stock and cooperation resulted from shifts in the parameters when stands were spatial complements. Similarly, when stands were spatial substitutes and price was affected by cooperation, shifts in the condition of forest stock on adjacent parcels resulted in a negative shift in both the steady state levels of stock and consumption.

The effects of a shift in the parameters on the steady state levels of stock and consumption were less similar under the assumption that the landowner cooperated with neighbors to determine the non-timber benefit production of the stands. Here, there was a positive shift in the steady state level of stock with a shift in the parameters; however this result was only true for the latter when stands were spatial complements. While, when the amenity values produced by own and adjacent stocks were substitutes from the standpoint of the landowner, marginal amenity valuation for the own stock and adjacent stock decreased with increased conditions of the adjacent stock, and the shift in the steady state level of stock occurring with an unexpected shift in the amenity benefits fostered by the condition of adjacent stocks was *a priori* ambiguous. Such a result was expected, as when stands were spatial substitutes the landowner's marginal valuation for their own stock decreased with increasing conditions of both own and adjacent stock, which would lead to a decreased incentive for the landowner to cooperate in the production of similar non-timber amenities over time.

Under the assumptions of cooperation in amenity production, the direction of the shifts in the steady state levels of cooperation with a shift in a parameter describing the level of adjacent stock for stands that were spatial complements was determined by the sign of the cross-partial derivative of non-timber valuation with respect to cooperation and adjacent stock levels. The directions of the response of the landowner's steady state level of cooperation were *a priori* ambiguous when stands were spatial substitutes in the valuation of amenities. Without further information on the relative weights of the spatial interdependencies, it was not possible to determine how changes in the parameters affected the steady state levels of cooperation. The outcomes that resulted from the assumption of full cooperation were not evaluated for the change in steady state level of stock that would result from a change in the amenity benefits fostered by the condition of adjacent stock, as it was assumed that the levels of cooperation were equivalent between the stands.

Full cooperation behavior, or sole ownership, represented the social optimum in the theoretical models.²¹ This was the only case where the uncertainties that the landowner faced regarding adjacent landowner preferences, and how non-timber amenities on their own stand were dependent on adjacent stand conditions were completely alleviated. An indication of the social cost of lack of coordination between landowners depends on the spatial interdependencies between parcels in the production of amenities and the level of coordination among landowners in terms of joint maximization of utility from timber revenues and amenity rents from employing the land in forested uses.

When the amenity valuation of own stock by any landowner was not related to the condition of adjacent stock, the stands were spatially independent. When this was the case there

²¹ This really is a modified social optimum, because non-participant landowner utility is not part of the sole owner's objective function.

was no cost associated with lack of coordination or resulting from individual management of a stand under the objective of maximizing own utility. However, when stands were spatially interdependent in the production of amenities, costs were identified that resulted from independent management behaviors that were quantitatively determined by comparison of the outcomes determined from the different behavior assumptions.

When landowners do not consider the effects of their own management decisions on adjacent landowner preferences and behavior, there is an externality evident in the level of stock removed in that it is not optimal from the standpoint of proximate landowners that may be affected by such actions. As some of the services of standing forests do not accrue solely to the individual landowner, that is, they do not correspond with typical property boundaries, there is the potential for free-riding behavior of landowners in the provision of these public goods. If the adjacent parcels also provide these amenity services, then the individual landowner with increased preferences for timber revenues has an incentive to harvest timber to receive net revenues from their standing timber without concern for the effects of their own management on the condition of adjacent parcels and adjacent landowner behavior. This is indicative of the cost resulting from individual management in terms of the effects of lack of coordination on the overall welfare of surrounding landowners.

When landowners' make decisions simultaneously (Nash game), there is no incentive for the landowner to consider the effects of their actions on the adjacent landowners utility and preferences for timber and non-timber benefits fostered by the adjacent standing stock. This is typical of the free-riding behavior associated with provision of public services. This is especially the case when individual preferences for non-timber amenities are varied among landowners. As each individual landowner determines their optimal harvesting rule by equating their own

marginal benefit received from harvesting timber in the present to their own marginal cost incurred from harvesting, in terms of any additional timber and non-timber rents that will result from leaving the stock in the ground. The externality is evident here, as the individual landowner does not have the ability to benefit from adjacent owner's decisions. The landowner considers that own management decisions and those of adjacent owners are made simultaneously.

When individual landowners act to coordinate timing of harvests with adjacent owners to receive a better price for timber, their optimal harvesting rule considers the effect of the increased price on their own utility over time. That is, the individual has no real incentive to consider adjacent preferences. The individual in this case does have incentive to determine how the increased price for their own timber resulting from coordination will affect their own utility levels over time. This type of behavior also results in an externality. Even though the individual landowner has the ability to benefit from the adjacent landowners' behavior, they have no incentive to consider the effects of coordinating timing of harvests on the adjacent landowners' amenity valuations.

Individual harvesting rules equate the marginal benefit from harvesting in the present to the marginal cost from harvesting, in terms of additional amenity rents resulting from cooperation and total revenue that would accrue to standing timber when cooperation is a factor in the landowner's non-timber amenity valuation over time. There is still an externality present in that the landowner has no incentive to consider the adjacent landowners preferences for utility from timber income. That is, the individual landowner considers their own additional benefits from cooperation in non-timber benefit production and attributes similar preferences to the

adjacent landowner, even though the adjacent landowner may have different preferences for timber and amenity benefits of their own stock.

The only type of behavior that could be considered close to socially optimal was full cooperation. Under full cooperation, landowners manage parcels as a sole owner with incentive to consider the effects of actions taken on any one parcel on the evolution of timber and non-timber benefit production on both that stand and on adjacent stands. Under sole ownership, the optimal harvesting rules adjust according to the stock conditions on both the stand being considered for management and the adjacent stand. For instance, if marginal amenities decrease with increasing conditions on the adjacent stand (the stands are spatial substitutes in the production of amenities), the landowner would harvest the focal stand at the optimal level considering the relation among stands in the valuation of amenities. A sole owner would not have to anticipate the harvesting or cooperation behavior of an adjacent owner, as the effects of actions on adjacent stands on own stand benefits are internal to their own objective function.

The direction of the externalities in terms of their effects on the optimal level of stock depends on the spatial interdependencies between the parcels in terms of amenity valuation. When stands are spatial complements and the marginal amenity values for both own and adjacent stocks increase with increasing conditions of the stocks, the optimal levels of stock removals under the Nash and partial cooperation assumptions are smaller than those when a sole owner manages the stands. This is because the sole owner accounts for the effects of management on one stand on the valuation of timber and non-timber benefits from that stand and the adjacent stand over time. When marginal amenity values decrease with increasing conditions of stocks and the stands are spatial substitutes, the optimal levels of stock removals under Nash and partial cooperation assumptions are higher than under sole ownership. Again, this result stems from the

alleviation of uncertainty regarding the adjacent preferences, and how non-timber benefits on one stand depend on the condition of adjacent stock in the sole owner problem. These differences reflect the level of certainty that an individual landowner has with regards to adjacent landowner's preferences and management behavior. The above results also implicitly reflect the difficulty that may confront policy makers in terms of developing incentives to reconcile differences in individual preferences across the landscape.

Future work on landowner behavior models

Simulations of the various management behaviors for landowners with stands that are related spatially, where the stand interdependencies are determined by the level of amenities provided, would prove useful in that they might lend further support to the above conclusions. They would also be suggestive of the magnitude of social costs under a variety of parameter assumptions. These simulations would provide a more rigorous analysis of the difference between the types of coordination on the steady state level of timber stock determined by individual forest managers. Such an analysis would be especially useful to address outcomes when forest stocks conditions were heterogeneous between the focal landowner and adjacent owner(s) and the existence of a steady state under such assumptions. The development of the above theory in a computer-based framework would also prove useful, in that modifications of the assumptions would be relatively simple to address. For instance, it would not be difficult to determine behavior of landowners with an additional adjacent owner or to modify the assumption of linear growth to one of quadratic growth or to incorporate nonsymmetrical utility relations of landowners. The effects of various instruments, e.g., taxes, subsidies, etc., directed at improving forest sustainability could

be examined in the computer-based framework. Policy makers could thus determine the optimal instrument for addressing the extent of cooperation necessary to address a specific threat to forest sustainability based on stand interdependencies in production of services.

The spatial interdependencies between parcels and how these spatial relations respond to increases in conditions of the landowner's own stock and adjacent stocks affect the social costs resulting from individual management. Developers of policies based on the spatial relation between parcels in the production of timber and amenity benefits would benefit from use of the methods developed in this assessment of the effects of different behaviors on the uncertainties that landowners face when managing timber stock. Prior policies that had been directed at individual behavior without specifically considering how individual amenity valuations were interdependent across the landscape would not be as effective in addressing landscape level threats.

When threats to forest sustainability are not restricted by property boundaries, it is imperative that policies are developed based on the spatial interdependencies of parcels in the production of goods and services related to the condition of standing forest stock. Policies addressing landscape-level forest sustainability threats will focus on improving the individual landowner's ability to account for adjacent landowner preferences when determining management of forest stock. Policy makers will have to alter some of the theoretical assumptions in Chapter 2 to address specific issues confronting forest sustainability and determine the costs resulting from individual stand management under specific scenarios and compare these with the benefits resulting from cooperation between landowners. However, the models in Chapter 2 are relatively easy to adjust to correspond with decisions landowners face regarding a particular threat to sustainability, i.e., reducing risk of fire occurrence.

Prior to developing policies directed at improving management of timber stock by individual landowners based on spatial interdependencies, an assessment of the extent of cooperation between landowners in management activities would improve the effectiveness of policy implementation. This assessment should also address the spatial interdependencies between parcels in an individual landowner's amenity valuation. The severity of cooperation (or lack of) between landowners in determining management of existing forest stock would provide an indicator of the level of adjustment that is required through policy implementation to address landscape-level forest sustainability threats.

3. Empirical results

Cooperative behavior of non-industrial private forest landowners was addressed in previous literature (e.g., see Brunson et al. 1996, Stevens et al. 1999, and Jacobson 2002). These surveys focused on the concepts of ecosystem management, but did not formally account for the landowner's amenity valuations of own stock and adjacent stocks in the determination of the probability of landowner participation in a joint management agreement. In Chapter 3, the survey-based method developed extends previous studies of landowner cooperative management behavior. Landowners' use of own parcel and adjacent parcel(s) for recreation activities were assessed in this analysis in order to quantify the interdependencies between stands in an individual's amenity valuation. Evaluation of cooperative type behavior in this analysis was also based on landowners' actual acreage owned, rather than on an assumed hypothetical acreage as in previous survey-based studies (see Stevens et al. 1999, Klosowski et al. 2001).

An empirical investigation of how landowners use their own and adjacent parcels for recreation activities provided an initial assessment of the spatial interdependencies between parcels in the production of amenity benefits. The extent that these spatial interdependencies factored in a landowner's participation in cooperative management activities with neighbors was indicative of the role that amenity valuations play in behavior determination. This empirical evaluation was also indicative of the lack (or extent) of coordination between individual landowners, and characteristics that were influential in the determination of cooperative behaviors.

Spatial interdependencies in amenity valuation and their influence in a landowner's decision to participate in a cooperative arrangement with adjacent landowners were investigated through a survey targeted at NIPF landowners in four central Virginia counties. The purpose of the survey was to determine the complementarity or substitutability of parcels in the production of non-timber benefits across a landscape, as well as the extent to which landowners' view their own decisions as important to adjacent owners, and whether landowners were willing to enter into agreements to jointly manage some aspect of land use with adjacent owners. The counties were targeted for assessment of landowner behavior because they offered a specific taxation status for forest use and were undergoing increasing threats from forest fragmentation. This resulted in a 45% response rate with an initial survey and follow-up postcard reminder.

The types of cooperative arrangements offered to landowners in the empirical study were divided into two categories: those that involved entrance into a joint agreement to manage some aspect of land, and another that involved synchronized timing of timber harvest with neighbors that resulted in an improved price for timber. These types of cooperative arrangements were offered to determine whether different characteristics factored in landowner behavior towards

participation in the various joint management activities. Here, it was hypothesized that amenity benefits, quantified by an individual's use of own parcel and adjacent parcels, for recreation activities were important factors in landowner decisions to participate in cooperative management agreements. This hypothesis was not rejected at a p-level of 0.05 when a likelihood ratio test was employed to evaluate the importance of amenity benefits in participation decisions using the survey-based data gathered from forest landowners in four Virginia counties.

Over 40% of respondents to the survey indicated that they accounted for how their management actions would affect neighboring landowners. This statistic provided merit to the approach taken here, which examined the type of cooperation that forest managers would undertake and characteristics of the landowners and their land parcels that influenced this decision. Also, at least 35% of respondents indicated that they would participate in an agreement to jointly manage some aspect of land, the only exception to this was the approximate 16% of respondents who would participate in a joint agreement to forego timber harvesting on a portion of land in order to create a forested area for recreation. However, a majority of landowners who indicated favor or uncertainty towards participation in joint forest (or land) management agreements indicated their comfort level with taking such an action would increase if the agreements were to include certain provisions or incentives. This statistic supports the theoretical assumption that incentives for cooperation were not inherent to the individual landowner.

The empirical approach developed in Chapter 3 studied the behavior of a representative landowner confronted with the decision to coordinate management activities with adjacent landowners. It was proposed that the probability of participation in land management activities with neighboring lands was a function of landowner parameters and characteristics similar to

those that determine probability of harvesting behavior in previous studies of NIPF landowners (e.g., see Conway et al. 2003) as well as characteristics describing the condition of adjacent stock. These probabilities were evaluated using discrete-choice models which employed the assumption that the probability of an action was determined by the difference the utilities from the alternative choices to cooperate (or not). The direct individual utilities could not be observed, but it was possible to observe the landowner's willingness to participate in a joint management agreement, where willingness to participate was indicative of higher utility from cooperation.

Several empirical assumptions were employed. The first econometric form utilized was one that assumed that the errors had an extreme value distribution, a logit model. All of the decisions to enter into a cooperative agreement with neighboring landowners to manage some aspect of the forest stands were estimated, individually, as logit problems. Similarly, two decisions were jointly modeled in a bivariate probit analysis to determine whether there was correlation in the disturbance terms. Here, the decisions examined jointly were either that of prior coordination in land use activities and participation in one of the cooperative agreements offered or use of own land and adjacent lands for recreation activities. In this joint analysis, it was assumed that the disturbance terms followed a bivariate Normal distribution. The null hypothesis in these models was that there was no correlation between the disturbance terms in estimating the decisions to previously cooperate with adjacent owners in land management activities (use adjacent parcel for recreation) and participate in one of the offered cooperative management agreements (use own parcel for recreation).

In the logit framework, a consistent predictor of participation in any of the cooperative arrangements offered was the completion of college by landowners. A negative predictor of

landowner participation in a joint agreement to manage land resources was whether the landowner had inherited the parcel, but this variable was not a significant determinant of whether landowners would decide to coordinate timing of harvests. This method of parcel acquisition might increase the possibility that the landowner's amenity valuation was site-specific, thus these landowners would consider parcels to be independent in the production of amenities valued (see Chapter 2), however amenity valuations of adjacent landowners were likely to differ. The opportunity cost of crop rents were most likely accounted for by landowners whose parcels were bordered by agricultural crop or pasture lands, as this variable positively influenced the decision to synchronize timing of harvests, and negatively influenced the decision to enter into a joint agreement to not harvest a portion of land to create a forest area for either wildlife or recreation. Lack of coordination in forest management activities was found to be stronger for landowners with particular characteristics as evidenced by the prior results. Such information would be useful to policy developers when addressing landscape level forest sustainability threats.

Further investigation with a bivariate probit approach implied that prior coordination of land management activities, such as trail building, stream quality improvement, wildlife habitat development, timber harvesting, or farming, were correlated with decision to enter a cooperative agreement that governed land management activities, but not with the decision to synchronize timing of harvests with an adjacent owner. These results implied that landowners with greater information through prior experiences were more likely to participate in cooperative arrangements without specific income incentives. Theory suggested that such information would serve to alleviate some of the uncertainty associated with adjacent landowner preferences. Similarly, the decisions to participate in recreational activities on own land and adjacent lands

were correlated. This last result was indicative of the spatial interdependencies between own and adjacent parcels in the production of an individual's non-timber benefit valuation.

In the bivariate probit framework, a consistent predictor of participation in the cooperative agreements offered (recreation on their own parcel) was, as in the logit framework, the completion of a college education by landowners. The decisions to participate in recreation activities, either consumptive or non-consumptive, on own parcel and adjacent parcel(s) were consistently positively influenced by whether the landowner was employed full-time. It could be that such landowner found it more convenient to recreate on own and adjacent lands, as recreation on public lands might require a greater time commitment that may not be suitable for employed individuals. Another indicator of spatial interdependencies in a landowner's amenity valuations was observed in the behavior of landowner's who had harvested timber in the past. These landowners were more likely to indicate participation in hunting and fishing recreation own and neighboring parcels, and it may be that variation in stock conditions between the stands produce optimal habitat for a particular game species.

Future work in empirical analysis

In the future, the empirical approach developed here could be employed to calculate the probability that landowners with specific preferences and parcel characteristics would enter into cooperative forest management agreements. Despite a nearly 35% predicted participation rate in most of the cooperation agreements offered in the survey, there is further need to explore landowners reactions to incentives designed to encourage joint management of both total revenues and amenity rents accruing to the use of land for forest management. This was evident

in the high percentage of landowners that were certain or unsure about participation in a management agreement that would like such an agreement to include provisions that would meet certain requirements of the individual owner, i.e., improved wildlife habitat and/or improved water quality. Such a result is reaffirmed in the economic analysis that suggested that individual landowners did not possess inherent incentives to jointly manage the total revenues and amenity rents from forest stock.

The estimated equations could also be used to further evaluate the spatial interdependencies of benefits an individual landowner received from standing forest stock, and the how the landowner accounted for these interdependencies when land management activities were determined. The estimation of spatial interdependencies and landowners' willingness to coordinate management of forest resources with neighbors could also be incorporated into a spatially explicit model to assess how changes in landscape and landowner characteristics influenced future supplies of timber and amenity benefits across a landscape. This type of integrated model would further improve the ability of policy developers to address threats to forest sustainability.

The empirical results and theoretical approach to determining landowner forest management behavior suggest that existing methods of policy design based on single-stand analyses may be inefficient in addressing landscape level forest sustainability issues. There is empirical evidence for the approach to analyzing the effects of spatial interdependencies on landowner uncertainties and timing of decisions. Furthermore, the theoretical analysis suggests that incentives, beyond those that are inherent to the individual landowner, would improve coordination between landowners. The spatial interdependencies between stands in terms of amenity value production had very different effects on the optimal stocking level decisions of

landowners when stands were managed independently or jointly with neighbors under the objective of maximization of total utility attained from use of the land for forestry, and these differences should be accounted for when developing policies to address the social welfare effects resulting from individual management.

There are many possible extensions for examining landowner risk reduction behavior when confronted with threats to forest sustainability that do not adhere to typical property boundaries. For instance, it would be interesting to examine, both theoretically and empirically, management behavior of landowners who face threats to forest sustainability from the spread of invasive species. Such an examination could be improved by assessing the value of information in determining landowner participation in joint agreements that would effectively reduce the susceptibility of standing timber to the spread of invasive species. As it may be the case that increased information with regards to how invasive species would change the condition of timber stock would effectively increase a landowner's inherent incentives to coordinate management of forest stocks with adjacent landowners. The effects of increased education were already observed in the empirical evaluation of landowners' willingness to participate in cooperative management agreements with adjacent owners to manage some aspect of forestland use.

Research on adjacent landowner effects on NIPF behavior could also be applied to fire risk management. The outcomes of individual and joint actions to reduce fuel loading could be analyzed to determine the need for policies that would encourage landowners to cooperate with adjacent owners to mitigate fire risk. It may be the case that the costs of such policies to encourage joint management of forests to reduce the risk from the spread of fire events would be less costly than current fire suppression methods. The adjacent landowner research would not just apply to the previously mentioned topics, however, as it could be applied to a variety of

current landscape level forest sustainability threats, such as water quality and fragmentation.

Development of incentives based on the spatial interdependencies of parcels in the production of services and encourage sustainable uses of the resource should allow for flexibility in a landowners decision making and that encourage preservation of the land in forestry uses.

Otherwise, the landowner might perceive such policies in a negative light. Without such flexibility, the policies might be perceived as limiting property rights, which should not be the case.

Table 1: Descriptive statistics of selected variables for survey on the effect of adjacent parcel management on land management and use decisions of Virginia NIPF landowners.

Variable	Mean	Standard Deviation
Age (years)	60.81	14
Household income (\$)	78723.52	43834.11
Married (0,1)*	0.783	
Number of children	2.07	1.445
Completed high school (0,1)	0.218	
Completed some college (0,1)	0.205	
Completed college (0,1)	0.523	
Roads (miles)	0.614	0.988
Employed full time (0,1)	0.472	
Retired (0,1)	0.438	
Forested acres	53.63	66.42
Pine acres	13.319	38.798
Hardwood acres	20.809	47.062
Mixed pine and hardwood acres	19.140	35.763
Bought land (0,1)	0.743	
Inherited land (0,1)	0.256	
Years owned property	19.446	14.545
Sold timber in past (0,1)	0.377	
Hunted in past year (0,1)	0.398	
Spent time in non-consumptive recreational activities (0,1)	0.803	
Reside on property (0,1)	0.481	
Environmental reasons (1-5)**	3.919	1.248
To keep for family (1-5)	4.007	1.339
Land investment (1-5)	3.502	1.436
Give land to heirs (0,1)	0.686	
Consider affect of own management on neighboring lands	0.413	
Hypothetical harvest (0,1)	0.308	
Coordinate in hypothetical harvest with 20% increase in price (0,1)	0.438	
Jointly plan future forest management	0.362	
Forego harvesting for wildlife (0,1)	0.395	
Forego harvesting for recreation (0,1)	0.157	
Future harvest plans	0.477	
Own land use for recreation depends on neighboring land condition (0,1)	0.381	
Jointly plan future land management	0.424	

*(0 = no; 1 = yes), **1 = not important; 5 = very important

Table 2: Logit estimation results of landowner willingness to enter into a joint agreement with neighbors for future forest management.

Variable	Coefficient	Standard Error
Constant	-2.226**	0.923
Absentee	0.263	0.312
Household income	4.67E-6** (1.14E-6)	2.26E-6
Land bequest intentions	-0.313	0.238
Inherited parcel	-0.457*	0.253
Roads (miles)	-2.80E-2	0.102
Importance placed on owning land for environmental reasons	1.12E-2	8.30E-2
Years owned	-2.71E-3	8.71E-3
Risk associated with growing trees for investment purposes	-8.56E-2	9.30E-2
Risk associated with losing timber to natural occurrences	-4.33E-2	0.101
Forested acres	1.16E-3	1.87E-3
Children	-6.74E-2	7.17E-2
Employed full-time	0.327	0.216
Importance placed on owning land to keep for family	-4.92E-3	8.55E-2
Sold timber in the past	0.221	0.231
Flat terrain	-0.248	0.234
Structures on property	-3.53E-2	0.210
Importance placed on owning land for investment purposes	-0.147** (-3.59E-2)	7.24E-2
Completed college	0.896***	0.210
Hunted in last year on own parcel	0.132	0.233
Recreated (no hunting) in last year on own parcel	0.485	0.396
Forest lands border parcel (percent)	0.691	0.450
Agricultural lands border parcel (percent)	0.873	0.563
Number of private individuals owning bordering parcel	8.57E-2** (2.09E-2)	4.12E-02
Others allowed access to own parcel	0.181	0.230
Hunts/fishes on adjacent parcels	-7.28E-2	0.288
Other recreation on adjacent parcels	0.666***	0.243
Prior cooperation with neighbors in land management activities	0.659***	0.263
Account for how own management affects neighbors	0.423**	0.203
*** significant with p-value 0.01, ** significant with p-value 0.05, * significant with p-value 0.10.		
Marginal effects of non-dummy variables computed at the overall mean of the data set indicated in parentheses.		

Table 3: Logit estimation results of predicting landowner willingness to harvest at the same time as neighbor(s) with a 20% increase in the price received for timber.

Variable	Coefficient	Standard Error
Constant	-0.297	0.853
Absentee	0.529*	0.297
Household income	6.55E-7	2.18E-6
Land bequest intentions	-0.333	0.228
Inherited parcel	0.173	0.238
Roads (miles)	-8.56E-2	9.72E-2
Importance placed on owning land for environmental reasons	-0.347*** (8.65E-2)	8.07E-2
Years owned	2.13E-3	8.47E-3
Risk associated with growing trees for investment purposes	-9.08E-2	9.10E-2
Risk associated with losing timber to natural occurrences	-5.56E-2	9.81E-2
Forested acres	2.46E-3	1.90E-3
Children	6.49E-2	6.84E-2
Employed full-time	0.484**	0.213
Importance placed on owning land to keep for family	7.45E-3	8.25E-2
Sold timber in the past	0.814***	0.223
Flat terrain	-0.102	-0.225
Structures on property	-0.433**	0.204
Importance placed on owning land for investment purposes	6.21E-2	6.87E-2
Completed college	0.555***	0.206
Hunted in last year on own parcel	6.88E-2	0.225
Recreated (no hunting) in last year on own parcel	0.374	0.351
Forest lands border parcel (percent)	0.507	0.427
Agricultural lands border parcel (percent)	1.01* (0.253)	0.532
Number of private individuals owning bordering parcel	-7.00E-2* (-1.75E-2)	4.11E-2
Others allowed access to own parcel	0.341	0.225
Hunts/fishes on adjacent parcels	0.156	0.276
Other recreation on adjacent parcels	0.307	0.236
Prior cooperation with neighbors in land management activities	-8.30E-3	0.202
Account for how own management affects neighbors	-0.209	0.259
*** significant with p-value 0.01, ** significant with p-value 0.05, * significant with p-value 0.10.		
Marginal effects of non-dummy variables computed at the overall mean of the data set indicated in parentheses.		

Table 4: Logit estimation results of landowner willingness to enter into a joint agreement with neighbors to not harvest a portion of land to create a forested area for wildlife.

Variable	Coefficient	Standard Error
Constant	-1.702*	0.950
Absentee	0.851***	0.324
Household income	4.44E-6** (1.10E-6)	2.30E-6
Land bequest intentions	0.287	0.243
Inherited parcel	-0.589**	0.260
Roads (miles)	-0.336** (-8.33E-2)	0.149
Importance placed on owning land for environmental reasons	0.403*** (9.98E-2)	8.79E-2
Years owned	-8.49E-3	9.07E-3
Risk associated with growing trees for investment purposes	-0.154* (-3.82E-2)	9.41E-2
Risk associated with losing timber to natural occurrences	4.57E-4	0.101
Forested acres	2.17E-3	1.92E-3
Children	-0.104	7.36E-2
Employed full-time	0.349	0.220
Importance placed on owning land to keep for family	-0.241*** (-5.97E-2)	8.86E-2
Sold timber in the past	-0.357	0.234
Flat terrain	-2.02E-2	0.240
Structures on property	0.318	0.219
Importance placed on owning land for investment purposes	-8.30E-2	7.47E-2
Completed college	0.672***	0.213
Hunted in last year on own parcel	0.122	0.237
Recreated (no hunting) in last year on own parcel	0.682*	0.416
Forest lands border parcel (percent)	-6.09E-2	0.451
Agricultural lands border parcel (percent)	-1.135** (-0.281)	0.576
Number of private individuals owning bordering parcel	-1.06E-2	4.22E-2
Others allowed access to own parcel	0.238	0.232
Hunts/fishes on adjacent parcels	5.55E-2	0.292
Other recreation on adjacent parcels	0.457*	0.254
Prior cooperation with neighbors in land management activities	0.625**	0.274
Account for how own management affects neighbors	0.116	0.211
*** significant with p-value 0.01, ** significant with p-value 0.05, * significant with p-value 0.10. Marginal effects of non-dummy variables computed at the overall mean of the data set indicated in parentheses.		

Table 5: Logit estimation results of landowner willingness to enter into a joint agreement with neighbors to not harvest a portion of land for the purpose of creating a forested area for recreation.

Variable	Coefficient	Standard Error
Constant	-2.506**	1.225
Absentee	0.561	0.368
Household income	1.57E-6	2.85E-6
Land bequest intentions	-0.264	0.294
Inherited parcel	-0.756**	0.375
Roads (miles)	9.63E-2	0.184
Importance placed on owning land for environmental reasons	0.144	0.115
Years owned	1.88E-3	1.21E-2
Risk associated with growing trees for investment purposes	-1.89E-2	0.117
Risk associated with losing timber to natural occurrences	-0.236* (-2.60E-2)	0.128
Forested acres	-9.84E-4	3.12E-3
Children	6.16E-2	9.39E-2
Employed full-time	0.541*	0.283
Importance placed on owning land to keep for family	0.145	0.113
Sold timber in the past	-0.777***	0.318
Flat terrain	-0.637**	0.329
Structures on property	1.37E-2	0.266
Importance placed on owning land for investment purposes	2.66E-2	9.21E-2
Completed college	0.792***	0.288
Hunted in last year on own parcel	0.136	0.300
Recreated (no hunting) in last year on own parcel	0.400	0.598
Forest lands border parcel (percent)	-0.241	0.542
Agricultural lands border parcel (percent)	-1.176* (-0.130)	0.724
Number of private individuals owning bordering parcel	-0.114** (-1.26E-2)	5.76E-2
Others allowed access to own parcel	4.86E-2	0.293
Hunts/fishes on adjacent parcels	-0.238	0.364
Other recreation on adjacent parcels	0.292	0.302
Prior cooperation with neighbors in land management activities	0.605**	0.307
Account for how own management affects neighbors	0.571**	0.259
*** significant with p-value 0.01, ** significant with p-value 0.05, * significant with p-value 0.10. Marginal effects of non-dummy variables computed at the overall mean of the data set indicated in parentheses.		

Table 6: Logit estimation of landowners' decision to jointly plan land management activities, such as, trail building, stream quality improvement, wildlife habitat development, and farming, with neighboring landowner(s).

Variable	Coefficient	Standard Error
Constant	-1.716	1.087
Absentee	0.261	0.382
Household income	8.93E-7	2.75E-6
Land bequest intentions	-0.393	0.295
Inherited parcel	-0.656**	0.303
Roads (miles)	-5.77E-2	0.113
Importance placed on owning land for environmental reasons	0.186* (4.66E-2)	0.101
Years owned	-1.21E-2	1.05E-2
Risk associated with growing trees for investment purposes	1.70E-2	0.109
Risk associated with losing timber to natural occurrences	-0.163	0.118
Forested acres	5.00E-4	2.14E-3
Children	-9.11E-2	8.16E-2
Employed full-time	0.240	0.256
Importance placed on owning land to keep for family	5.67E-2	0.105
Sold timber in the past	6.00E-2	0.278
Flat terrain	-0.198	0.273
Structures on property	0.606**	0.249
Importance placed on owning land for investment purposes	-6.74E-2	8.62E-2
Completed college	0.857***	0.246
Hunted in last year on own parcel	-0.113	0.283
Recreated (no hunting) in last year on own parcel	-5.68E-2	0.448
Forest lands border parcel (percent)	-0.112	0.544
Agricultural lands border parcel (percent)	-0.269	0.683
Number of private individuals owning bordering parcel	-1.70E-2	4.98E-2
Others allowed access to own parcel	0.618**	0.280
Hunts/fishes on adjacent parcels	4.75E-2	0.332
Other recreation on adjacent parcels	0.989***	0.270
Prior cooperation with neighbors in land management activities	0.976***	0.314
Account for how own management affects neighbors	0.781***	0.237
*** significant with p-value 0.01, ** significant with p-value 0.05, * significant with p-value 0.10. Marginal effects of non-dummy variables computed at the overall mean of the data set indicated in parentheses.		

Table 7: Results of likelihood ratio test when groups of variables are removed from the initial logit estimations of landowner decisions regarding entering into cooperative arrangements with neighbors.

Decision	Groups of variables removed			
	Access	Bequest	Demographic	Use
Enter into joint agreement with neighbors for future forest management	12.940***	11.715***	11.921***	97.620***
Harvest at same time as neighbors with a 20% increase in price for timber	16.600***	15.777***	8.978**	101.829***
Enter into joint agreement to not harvest a portion of land to create a forest area for wildlife	19.908***	18.580***	9.107**	97.220***
Enter into joint agreement to not harvest a portion of land to create a forest area for recreation	13.130***	14.247***	3.832	58.729***
Enter into joint agreement for future land management, excluding timber harvesting	11.932***	11.551***	9.031**	101.829***

*** significant at p-value < 0.01, ** significant at p-value 0.01, * significant at p-value 0.05

Table 8: Landowner decisions to cooperate in land management activities in the past and to coordinate timing of harvest under the condition of an offered price incentive.

Variable	Prior land management cooperation		Coordinate timing of harvest given a increase in price of timber	
	Coefficient	Standard Error	Coefficient	Standard Error
Constant	-0.6545	0.477	0.423	0.425
Absentee	0.301	0.186	0.253	0.171
Household income	-2.38E-6	1.87E-6	-4.75E-7	1.54E-6
Roads	0.145*	8.69E-2	-3.71E-2	5.67E-2
Importance placed on owning land for environmental reasons	0.126**	5.62E-2	-0.198***	4.80E-2
Years owned	-2.44E-3	6.13E-3	-1.30E-3	5.16E-3
Perceived risk associated with timber growth	-2.76E-2	7.20E-2	-4.02E-2	5.78E-2
Perceived risk associated with timber loss	-0.144*	7.25E-2	2.43E-2	6.00E-2
Forested acres	-2.09E-3	1.63E-3	1.63E-3	1.32E-3
Children	-5.58E-2	4.55E-2	8.28E-2**	4.14E-2
Full-time employment	0.204	0.152	0.328***	0.129
Prior timber sale experience	0.264*	0.148	0.602***	0.132
Flat terrain	-0.189	0.164	-5.03E-2	0.137
Importance placed on owning land for investment purposes	-6.64E-2	4.92E-2	1.78E-2	4.27E-2
Completed college	0.407***	0.159	0.329***	0.122
Forest use bordering parcel (%)	-0.144	0.226	4.45E-2	0.179
Private landowners bordering	1.35E-3	2.78E-2	-5.21E-2**	2.39E-2
Inherited land			-3.95E-2	0.139
Land bequest intentions			-0.213*	0.126
Structures present			-0.194	0.124
Rho			0.113	8.23E-2

*** significant at p-value 0.01, ** significant at p-value 0.05, * significant at p-value 0.10

Table 9: Landowner cooperation in past land management activities and future forest management with neighbors estimated with bivariate probit model.

Variable	Prior land management cooperation		Joint forest management	
	Coefficient	Standard Error	Coefficient	Standard Error
Constant	-0.634	0.489	-0.611	0.433
Absentee	0.299	0.188	4.84E-2	0.187
Household income	-2.48E-6	1.87E-6	2.45E-6	1.57E-6
Roads	0.156*	8.38E-2	4.23E-4	7.29E-2
Importance placed on owning land for environmental reasons	0.120**	5.74E-2	4.85E-2	4.85E-2
Years owned	-2.79E-3	6.29E-3	-4.53E-3	5.16E-3
Perceived risk associated with timber growth	-4.57E-2	7.07E-2	-4.77E-2	5.90E-2
Perceived risk associated with timber loss	-0.133*	7.03E-2	7.99E-4	6.12E-2
Forested acres	-2.18E-3	1.68E-2	-2.06E-4	1.13E-3
Children	-5.21E-2	4.41E-2	-6.98E-2*	4.29E-2
Full-time employment	0.205	0.153	0.212*	0.127
Prior timber sale experience	0.225	0.148	0.144	0.135
Flat terrain	-0.200	0.162	-0.241*	0.135
Importance placed on owning land for investment purposes	-6.20E-2	4.88E-2	-9.12E-2***	4.15E-2
Completed college	0.426***	0.159	0.720***	0.125
Forest use bordering parcel (%)	-0.144	0.221	0.197	0.184
Private landowners bordering	2.65E-3	2.76E-2	2.97E-2	2.42E-2
Inherited land			-0.223	0.144
Land bequest intentions			-6.92E-2	0.127
Structures present			-2.17E-2	0.121
Rho			0.428***	7.43E-2

*** significant at p-value 0.01, ** significant at p-value 0.05, * significant at p-value 0.10

Table 10: Landowner cooperation in past land management activities and willingness to enter into an agreement with neighbors to not harvest on a portion of land to create an area for wildlife.

Variable	Prior land management cooperation		Joint agreement to not harvest a portion of land for wildlife	
	Coefficient	Standard Error	Coefficient	Standard Error
Constant	-0.890*	0.478	-1.223***	0.429
Absentee	0.207	0.178	0.353**	0.179
Household income	8.81E-7	1.54E-6	2.04E-6*	1.27E-6
Roads	0.166**	7.97E-2	-0.170**	8.00E-2
Importance placed on owning land for environmental reasons	0.142***	5.38E-2	0.275***	4.80E-2
Years owned	7.96E-4	5.78E-3	-3.37E-3	4.95E-3
Perceived risk associated with timber growth	-4.79E-2	6.46E-2	-9.58E-2*	5.35E-2
Perceived risk associated with timber loss	-0.118*	6.85E-2	1.94E-2	5.79E-2
Forested acres	-2.07E-3	1.64E-3	-2.49E-5	1.01E-3
Children	-5.17E-2	4.35E-2	-9.23E-2**	4.13E-2
Full-time employment	0.190	0.142	0.180	0.127
Prior timber sale experience	0.187	0.141	-0.117	0.127
Flat terrain	-0.223	0.156	-0.132	0.135
Importance placed on owning land for investment purposes	-6.18E-2	4.65E-2	-6.67E-2	4.28E-2
Completed college	0.387***	0.147	0.490***	0.118
Forest use bordering parcel (%)	-0.138	0.215	0.401**	0.183
Private landowners bordering	3.40E-3	2.67E-2	5.33E-4	2.16E-2
Inherited land			-0.358***	0.137
Land bequest intentions			7.41E-3	0.127
Structures present			0.161	0.119
Rho			0.272***	8.35E-2

*** significant at p-value 0.01, ** significant at p-value 0.05, * significant at p-value 0.10

Table 11: Landowner decisions to cooperate in past land management and to forego harvest on a portion of land to create an area for recreation.

Variable	Prior land management cooperation		Joint agreement to not harvest a portion of land for recreation	
	Coefficient	Standard Error	Coefficient	Standard Error
Constant	-0.862*	0.471	-1.131***	0.501
Absentee	0.198	0.180	0.291	0.207
Household income	-8.12E-7	1.57E-6	8.65E-7	1.61E-6
Roads	0.163**	7.91E-2	-4.19E-2	0.123
Importance placed on owning land for environmental reasons	0.146***	5.45E-2	0.166***	6.39E-2
Years owned	4.29E-4	5.65E-3	2.70E-3	6.96E-2
Perceived risk associated with timber growth	-4.88E-2	6.51E-2	-1.45E-3	6.43E-2
Perceived risk associated with timber loss	-0.123*	6.84E-2	-0.129*	7.22E-2
Forested acres	-2.10E-3	1.58E-2	-9.29E-4	2.22E-3
Children	-5.65E-2	4.31E-2	3.19E-2	5.17E-2
Full-time employment	0.187	0.142	0.301*	0.164
Prior timber sale experience	0.187	0.141	-0.301*	0.179
Flat terrain	-0.217	0.157	-0.298*	0.177
Importance placed on owning land for investment purposes	-6.52E-2	4.73E-2	-1.82E-2	5.19E-2
Completed college	0.380***	0.146	0.472***	0.159
Forest use bordering parcel (%)	-0.136	0.215	7.86E-2	0.227
Private landowners bordering	-3.29E-3	2.69E-2	-3.12E-2	2.88E-2
Inherited land			-0.399*	0.212
Land bequest intentions			-0.144	0.148
Structures present			-0.631	0.143
Rho			0.245***	8.87E-2

*** significant at p-value 0.01, ** significant at p-value 0.05, * significant at p-value 0.10

Table 12: Landowner decisions to coordinate with neighbors in past land management and future land management, excluding harvesting, activities estimated with bivariate probit.

Variable	Prior land management cooperation		Joint land management excluding timber harvesting	
	Coefficient	Standard Error	Coefficient	Standard Error
Constant	-0.935*	0.550	-0.607	0.450
Absentee	0.202	0.200	0.102	0.205
Household income	-2.20E-6	1.69E-6	1.12E-6	1.45E-6
Roads	0.138*	8.44E-2	-1.20E-2	7.14E-2
Importance placed on owning land for environmental reasons	0.189***	7.03E-2	0.171***	5.29E-2
Years owned	-3.18E-3	6.52E-3	-8.22E-3	5.55E-3
Perceived risk associated with timber growth	-3.58E-2	7.06E-2	1.67E-2	6.09E-2
Perceived risk associated with timber loss	9.90E-2	7.57E-2	-8.41E-2	6.51E-2
Forested acres	-1.61E-3	1.70E-3	5.85E-5	1.08E-3
Children	-4.50E-2	4.66E-2	-3.78E-2	4.23E-2
Full-time employment	0.220	0.154	0.264*	0.141
Prior timber sale experience	0.216	0.162	0.198	0.149
Flat terrain	-0.160	0.167	-0.312**	0.145
Importance placed on owning land for investment purposes	-6.74E-2	5.16E-2	-5.24E-2	4.57E-2
Completed college	0.440***	0.154	0.610***	0.130
Forest use bordering parcel (%)	-0.138	0.241	-0.128	0.203
Private landowners bordering	-1.79E-3	2.96E-2	-1.43E-2	2.61E-2
Inherited land			-0.195	0.155
Land bequest intentions			-9.79E-2	0.132
Structures present			0.321**	0.134
Rho			0.462***	7.79E-2

*** significant at p-value 0.01, ** significant at p-value 0.05, * significant at p-value 0.10

Table 13: Landowner use of own and adjacent parcels for consumptive recreation (hunting) to assess spatial interdependencies using a bivariate probit model.

Variable	Hunt or fish on neighboring parcels		Hunt on own parcel	
	Coefficient	Standard Error	Coefficient	Standard Error
Constant	-1.266***	0.455	-0.653	0.443
Absentee	4.15E-2	0.190	-0.143	0.183
Household income	-1.81E-6	1.75E-6	-2.19E-6	1.60E-6
Roads	5.85E-2	7.06E-2	0.109	7.43E-2
Importance placed on owning land for environmental reasons	6.62E-2	5.33E-2	2.69E-2	4.88E-2
Years owned	-1.85E-3	5.56E-3	-1.75E-3	5.27E-3
Perceived risk associated with timber growth	-1.99E-2	6.07E-2	2.61E-2	5.51E-2
Perceived risk associated with timber loss	2.50E-2	6.44E-2	2.19E-2	5.78E-2
Forested acres	-1.75E-3	1.35E-3	6.52E-4	1.08E-3
Children	-1.41E-3	4.97E-2	6.64E-2	4.20E-2
Full-time employment	0.439***	0.151	0.496***	0.134
Prior timber sale experience	0.269*	0.144	0.458***	0.135
Flat terrain	-8.24E-2	0.159	0.229*	0.136
Importance placed on owning land for investment purposes	3.01E-2	4.52E-2	1.17E-2	4.27E-2
Completed college	-0.104	0.134	-0.257**	0.126
Forest use bordering parcel (%)	0.287	0.215	5.47E-2	0.187
Private landowners bordering	-2.40E-2	3.26E-2	-2.48E-2	2.58E-2
Inherited land			-0.143	0.130
Land bequest intentions			1.21E-2	0.106
Structures present			-0.121	0.107
Rho			0.831***	4.22E-2

*** significant at p-value 0.01, ** significant at p-value 0.05, * significant at p-value 0.10

Table 14: Estimation of landowner use of own parcel and adjacent parcels for activities other than hunting using a bivariate probit model.

Variable	Non-consumptive recreation on neighboring parcels		Non-consumptive recreation on own parcel	
	Coefficient	Standard Error	Coefficient	Standard Error
Constant	-1.418***	0.444	0.847	0.577
Absentee	-0.144	0.199	-8.15E-2	0.246
Household income	-2.06E-6	1.61E-6	-2.54E-7	2.08E-6
Roads	6.00E-2	8.04E-2	0.111	0.110
Importance placed on owning land for environmental reasons	0.113**	5.08E-2	0.106	6.64E-2
Years owned	1.45E-3	5.42E-3	-8.03E-3	6.28E-3
Perceived risk associated with timber growth	4.03E-2	5.65E-2	-4.74E-2	8.19E-2
Perceived risk associated with timber loss	4.67E-3	6.06E-2	-6.46E-2	8.27E-2
Forested acres	-1.05E-3	1.08E-3	-5.35E-4	1.62E-2
Children	3.00E-2	3.96E-2	-4.43E-2	6.00E-2
Full-time employment	0.468***	0.133	3.80E-2	0.175
Prior timber sale experience	2.65E-2	0.141	9.87E-3	0.185
Flat terrain	-0.348**	0.143	-0.122	0.179
Importance placed on owning land for investment purposes	2.89E-3	4.67E-2	-1.22E-3	5.58E-2
Completed college	0.333***	0.133	0.529***	0.183
Forest use bordering parcel (%)	0.153	0.203	0.516**	0.268
Private landowners bordering	-5.44E-3	2.48E-2	-6.42E-3	3.37E-2
Inherited land			-0.583***	0.166
Land bequest intentions			-0.211	0.205
Structures present			0.355**	0.175
Rho			0.389	0.121

*** significant at p-value 0.01, ** significant at p-value 0.05, * significant at p-value 0.10

Literature Cited

- Albers, H. 1996. Modeling Ecological Constraints on Tropical Forest Management: Spatial Interdependence, Irreversibility, and Uncertainty. *Journal of Environmental Economics and Management* 30:73-94.
- Alig, R.J. and A.J. Plantinga. 2004. Future forestland area: Impacts from population growth and other factors that affect land values. *Journal of Forestry* 102(8):19-24.
- Alig, R.J., K.J. Lee, and R.J. Moulton. 1990. Likelihood of timber management on nonindustrial private forests: evidence from research studies. USDA Forest Service, General Technical Report SE-60. Southeastern Forest Experiment Station. 17p.
- Amacher, G., C. Conway, and J. Sullivan. 2003. Econometric analysis of forest landowners: Is there anything left to study? *Journal of Forest Economics* 9(2):137-164.
- Amacher, G., E. Koskela, and M. Ollikainen. 2004. Forest rotation and stand interdependency: ownership structure and timing of decisions. *Natural Resource Modeling* 17(1):1-45.
- Ando, A., J. Camm, S. Polasky, and A. Solow. 1998. Species distribution, land values and efficient conservation. *Science* 279:2126-2128.
- Armstrong, J.S. and T.S. Overton. 1977. Estimating nonresponse bias in mail surveys. *Journal of Marketing Research* 14(3): 396-402.
- Bell, C. D., R.K. Roberts, B.C. English, and W.M. Park. 1994. A logit analysis of participation in Tennessee's Forest Stewardship Program. *Journal of Agricultural and Applied Economics* 26(2):463-472.
- Birch, T.W. 1996. Private forest-land owners of the Southern United States, 1994. Resource Bulletin NE 138. Radnor, PA: USDA, Forest Service, Northeastern Research Station. 183 p.
- Bowes, M. and J. Krutilla. 1989. *Multiple-Use Management: The Economics of Public Forests*. Resources for the Future: Washington, D.C. 353 p.
- _____. 1985. Multiple-use management of public forestlands in: *Handbook of Natural Resource and Energy Economics* vol. II, Kneese, A. and J. Sweeney (eds.). North Holland, Amsterdam. 655-663.
- Brunson, M.W., D.T. Yarrow, S.D. Roberts, D.C. Guynn, Jr., and M.R. Kuhns. 1996. Nonindustrial private forest owners and ecosystem management: Can they work together? *Journal of Forestry* 94(6):14-21.

- Conway, M.C., G.S. Amacher and J. Sullivan. 2003. Decisions nonindustrial forest landowners make: an empirical examination. *Journal of Forest Economics* 9(3):181-203.
- Csuti, B. S. Polasky, P. Williams. R. Pressey, J. Camm, M. Kershaw, R. Kiester, B. Hamilton, M. Huso, and K. Sahr. 1997. A comparison of reserve selection algorithms using data on terrestrial vertebrates in Oregon. *Biological Conservation* 80:83-97.
- Dillman, D.A. 2001. *Mail and telephone surveys: The tailored design method*. 2nd ed. John Wiley & Sons: New York. 464 p.
- Dillman, D.A. 1978. *Mail and telephone surveys: The total design method*. John Wiley & Sons: New York. 325 p.
- Edwards, S.F. and G.D. Anderson. 1987. Overlooked biases in contingent valuation surveys: Some considerations. *Land Economics* 63(2):168-78.
- Eid, T., H. Hoen, and P. Økseter. 2001. Economic consequences of sustainable forest management regimes at non-industrial forest owner level in Norway. *Forest Policy and Economics* 2(3-4):213-228.
- Greene, J.L. and K.A. Blatner. 1986. Identifying woodland owner characteristics associated with timber management. *Forest Science* 32(1):135-146.
- Greene, W.H. 2000. *Econometric Analysis*. Fourth edition. Prentice Hall: New Jersey. 1004 p.
- Greene, W.H. 1998. *Limdep Version 7 User's Manual*. Econometric Software Inc: New York. 925 p.
- Hartman, R. 1976. The harvesting decision when a standing forest has value. *Economic Inquiry* 14:52-58.
- Hodge, S.S. and L. Southard. 1992. A profile of Virginia NIPF landowners: Results of a 1991 survey. *Virginia Forests* 47(4):7-11.
- Hunter, M.L., Jr. 1990. *Wildlife, Forests, and Forestry: Principles of Managing Forests for Biological Diversity*. Prentice Hall: New Jersey. 370 p.
- Hyberg, B.T. and D.M. Holthausen. 1989. The behavior of nonindustrial private forest landowners. *Canadian Journal of Forest Research* 19:1014-1023.
- Jacobson, M. 2002. Ecosystem management in the United States: Interest of forest landowners in joint management across ownerships. *Small Scale Forest Economics, Management, and Policy*. 1(1):71-92.
- Jacobson, M., R. Abt, and D. Carter. 2000. Attitudes toward joint forest planning among private landowners. *Journal of Sustainable Forestry* 11(3):95-112.

- Kittredge, D. 2003. Private forestland owners in Sweden: Large-scale cooperation in action. *Journal of Forestry* 101(2):41-46.
- Kline, J.D., R.J. Alig, and R.L. Johnson. 2000. Fostering the production of nontimber services among forest owners with heterogeneous objectives. *Forest Science* 46(2):302-311.
- Klosowski, R., T. Stevens, D. Kittredge, and D. Dennis. 2001. Economic incentives for coordinated management of forest land: A case study of Southern New England. *Forest Policy and Economics* 2:29-38.
- Koskela, E., and Ollikainen, M. 2001. Optimal private and public harvesting under spatial and temporal interdependence. *Forest Science* 47(4):596-607.
- Kurttila, M., K. Hämäläinen, M. Kajanus, and M. Pesonen. 2001. Non-industrial private forest owners' attitudes towards the operational environment of forestry: A multinomial logit model analysis. *Forest Policy and Economics* 2(1):13-28.
- Kuuluvainen, J., H. Karppinen, and V. Ovaskainen. 1996. Landowner objectives and nonindustrial private timber supply. *Forest Science* 42(3):300-309.
- Lee, L-F. 1983. Generalized econometric models with selectivity. *Econometrica* 51(2):507-512.
- Léonard, D. and N. Van Long. 1992. *Optimal control theory and static optimization in economics*. Cambridge University Press: New York. 353 p.
- Loomis, J.B. 1987. Expanding contingent value sample estimates to aggregate benefit estimates: Current practices and proposed solutions. *Land Economics* 63(4):396-407.
- Mas-Colell, A., M.D. Winston, and J.R. Green. 1995. *Microeconomic Theory*. Oxford University Press: New York.
- Messonnier, M., J. Bergström, C. Cornwell, R.J. Teasley, and H.K. Cordell. 2000. Survey response-related biases in contingent valuation: Concepts, remedies, and empirical application to valuing aquatic plant management. *American Journal of Agricultural Economics* 82(2):438-50.
- Newman, D.H. 2002. Forestry's golden rule and the development of the optimal forest rotation literature. *Journal of Forest Economics* 8(1):5-27.
- Parkhurst, G.M., J.F. Shogren, C. Bastian, P. Kivi, J. Donner, and R.B.W. Smith. 2002. Agglomeration bonus: an incentive mechanism to reunite fragmented habitat for biodiversity conservation. *Ecological Economics* 41:305-328.
- Pattanayak, S.K., B.C. Murray, and R.C. Abt. 2002. How joint is joint forest production? An econometric analysis of timber supply conditional on endogenous amenity values. *Forest Science* 48(3):479-491.

- Polasky, S., J. Camm, and B. Garber-Yonts. 2001. Selecting biological reserves effectively: an application to terrestrial vertebrate conservation in Oregon. *Land Economics* 77(1):68-78.
- Randall, A. 1997. The NOAA panel report: A new beginning of the end of an era? *American Journal of Agricultural Economics* 79(5):1489-1494.
- Sample, V.A. and R.A. Sedjo. 1996. Sustainability in Forest Management: An evolving concept. *International Advances in Economic Research* 2(2):165-173.
- Schaffer, R.M. and G.S. Meade. 1997. Absentee forest landowners in Virginia. *Virginia Journal of Science* 48(3):219-223.
- Smith, R.B.W., and J.F. Shogren. 2002. Voluntary incentive design for endangered species protection. *Journal of Environmental Economics and Management* 43:169-187.
- Snyder, D.L., and R.N. Bhattacharyya. 1990. A more general dynamic economic model of the optimal rotation of multiple-use forests. *Journal of Environmental Economics and Management* 18:168-175.
- Stevens, T.H., D. Dennis, D. Kittredge, and M. Rickenbach. 1999. Attitudes and preferences toward co-operative management agreements for management of private forestlands in the North-eastern United States. *Journal of Environmental Management* 55:81-90.
- Swallow, S., P. Talukdar, and D. Wear. 1997. Spatial and temporal specialization in forest ecosystem management under sole ownership. *American Journal of Agricultural Economics* 79(2): 311-326.
- Swallow, S. and D. Wear. 1993. Spatial interactions in multiple-use forestry and substitution and wealth effects for the single stand. *Journal of Environmental Economics and Management* 25:103-120.
- Sullivan, J., G.S. Amacher, and S. Chapman. 2005. Forest banking and forest landowners forgoing management rights for guaranteed financial returns. *Forest Policy and Economics* 7(3):381-392.
- Turner, M., D. Wear, and R. Flamm. 1996. Land ownership and land-cover change in the Southern Appalachian Highlands and the Olympic Peninsula. *Ecological Applications* 6(4):1150-1172.
- University of Virginia Geospatial and Statistical Data Center. *County and City Data Book*. <http://fisher.lib.virginia.edu/index.html>, accessed May 2004.
- Uusivuori, J. and J. Kuuluvainen. 2001. Benefits of forest-owner collaboration and imperfect capital markets. *Forest Science* 47(3):428-436.

- VDOF (Virginia Department of Forestry). 2005. *Land use tax: assessment standards*.
<http://www.dof.virginia.gov/mgt/land-use-tax-stand.shtml>, accessed March 2005.
- Vincent, J.R. and C.S. Binkley. 1993. Efficient multiple-use forestry may require land-use specialization. *Land Economics* 69(4):370-376.
- Vokoun, M., G.S. Amacher, and D. Wear. 2004. Scale of harvesting and price acceptance of nonindustrial private forest landowners. Working Paper. Virginia Polytechnic Institute and State University.
- Wear, D., M. Turner, and R. Naiman. 1998. Land cover along an urban-rural gradient: Implications for water quality. *Ecological Applications* 8(3): 619-630.
- Whitehead, J., P. Grootuis, and G. Blomquist. 1993. Testing for nonresponse and sample selection bias in contingent valuation: Analysis of a combination mail/phone survey. *Economics Letters* 41: 215-220.
- Zhang, D. 2001. Endangered species and timber harvesting: The case of red-cockaded woodpecker. *Economic Inquiry* 42(1):150-165.
- Zeitouni, N. and A. Dinar. 1997. Mitigating negative water quality and quality externalities by joint management of adjacent aquifers. *Environment and Resource Economics* 9(1):1-20.

Appendix 2: Proof of a stable equilibrium when there is cooperation in price.

The assumptions in this problem are similar to those presented in Appendix 1, with the additional

assumption that $\frac{\partial \tilde{P}}{\partial \gamma_i} > 0$ and $\frac{\partial^2 \tilde{P}}{\partial \gamma_i^2} = 0$. Also, adjacent stocks (management behavior) are

exogenous from the standpoint of the individual (focal) landowner. The landowner chooses the level of harvesting and cooperation. The stability of a solution depends on the following second order conditions:

$$V_{x_{it}x_{it}} = P^2 U_{c_{it}c_{it}}(\cdot) + \beta \left[(1 + \Delta)^2 \tilde{P}^2 U_{c_{it+1}c_{it+1}}(\cdot) \right] + \beta \left[\int_0^1 (1 + \Delta)^2 \frac{\partial^2 N(k_{it+1}, k_{jt+1}^s)}{\partial k_{it+1}^2} dD(K) \right] < 0, \quad (\text{A2.1})$$

$$V_{\gamma_i \gamma_i} = \beta \left[\psi^2 \tilde{P}^2 U_{c_{it+1}c_{it+1}}(\cdot) + \psi \tilde{P} U_{\gamma_i \gamma_i} U_{c_{it+1}}(\cdot) \right] < 0, \quad (\text{A2.2})$$

and the determinant of the Jacobian matrix,

$$\det(J^P) = V_{x_{it}x_{it}} V_{\gamma_i \gamma_i} - V_{\gamma_i x_{it}} V_{x_{it} \gamma_i} > 0. \quad (\text{A2.3})$$

The assumptions of concave utility and the price derivatives assure that equation (A2.2) holds, and conditions for meeting equation (A2.1) are similar to those developed in Appendix 1.

The first part of equation (A2.3) is positive as indicated by the second order conditions (equations (A2.1) and (A2.2)). The product of the cross-derivatives thus determines the stability of the steady state,

$$V_{\gamma_i x_{it}} = V_{x_{it} \gamma_i} = \beta \left[(-1 - \Delta) \tilde{P}_{\gamma_i} \{ U_{c_{it+1}}(\cdot) + \psi \tilde{P} U_{c_{it+1}c_{it+1}}(\cdot) \} \right]. \quad (\text{A2.4})$$

For equation (A2.4) to hold it must be the case that the following expression is true,

$$V_{x_{it}x_{it}} V_{\gamma_i \gamma_i} > V_{\gamma_i x_{it}} V_{x_{it} \gamma_i}. \quad (\text{A2.3}')$$

From equations (A2.1) and (A2.2), the term on the right hand side of the above equation is positive and quite complex, and follows,

$$\begin{aligned} & \beta \psi^2 P^2 \tilde{P}_{\gamma_i}^2 (U_{c_{it}c_{it}}(\cdot))^2 + \beta^2 (1 + \Delta)^2 \psi^2 \tilde{P}_{\gamma_i}^2 \tilde{P}_{\gamma_i}^2 U_{c_{it}c_{it}}(\cdot) U_{c_{it+1}c_{it+1}}(\cdot) + \\ & \beta^2 \psi^2 \tilde{P}_{\gamma_i}^2 U_{c_{it+1}c_{it+1}}(\cdot) \int_0^1 (1 + \Delta)^2 \frac{\partial^2 N(\cdot)}{\partial k_{it+1}^2} dD(K) \end{aligned} \quad (A2.5)$$

The term on the left hand side of equation (A2.3') is expressed as:

$$\beta^2 (1 + \Delta)^2 \tilde{P}_{\gamma_i}^2 \left[(U_{c_{it}c_{it}}(\cdot))^2 + 2\psi \tilde{P} U_{c_{it}c_{it}}(\cdot) U_{c_{it+1}c_{it+1}}(\cdot) + \psi^2 \tilde{P}^2 (U_{c_{it+1}c_{it+1}}(\cdot))^2 \right]. \quad (A2.6)$$

The second term in equation (A2.5) is equivalent to the third term in brackets in equation (A2.6).

These expressions can be further simplified by dividing by β and $\tilde{P}_{\gamma_i}^2$, that results in the

following:

$$\psi^2 P^2 (U_{c_{it}c_{it}}(\cdot))^2 + \beta \psi^2 U_{c_{it+1}c_{it+1}}(\cdot) \int_0^1 (1 + \Delta)^2 \frac{\partial^2 N(\cdot)}{\partial k_{it+1}^2} dD(K), \text{ and} \quad (A2.5')$$

$$\beta (1 + \Delta)^2 \left[(U_{c_{it}c_{it}}(\cdot))^2 + 2\psi \tilde{P} U_{c_{it}c_{it}}(\cdot) U_{c_{it+1}c_{it+1}}(\cdot) \right]. \quad (A2.6')$$

The condition in equation (A2.3') will hold, as the term on the right hand side (equation A2.5') is far more complex than that the one on the left hand side of equation (A2.6').

Appendix 3: Proof of a steady state when there is cooperation in the production of non-timber benefits.

The assumptions in this problem are similar to those presented in Appendix 1, with the additional

assumption that $\frac{\partial N^{i,j}}{\partial \gamma_i} > 0$ and $\frac{\partial^2 N^{i,j}}{\partial \gamma_i^2} > 0$. The stability of a solution when studying the

behavior of an individual landowner depends on the following second order conditions:

$$V_{x_{it}x_{it}} = P^2 U_{c_{it}c_{it}}(\cdot) + \beta \left[\int_0^1 (1+\Delta)^2 P^2 U_{c_{it+1}c_{it+1}}(\cdot) dD(X) \right] + \beta(1+\Delta)^2 \left[\frac{\partial^2 N^i(\cdot)}{\partial k_{it+1}^2} + \frac{\partial^2 N^j(\cdot)}{\partial k_{it+1}^2} \right] < 0, \quad (\text{A3.1})$$

$$V_{\gamma_i \gamma_i} = \beta \left[\frac{\partial^2 N^i(\cdot)}{\partial \gamma_i^2} \right] < 0, \text{ and} \quad (\text{A3.2})$$

$$V_{x_{it}\gamma_i} = V_{\gamma_i x_{it}} = \beta \left[-(1+\Delta) \frac{\partial N^i(\cdot)}{\partial k_{it+1} \partial \gamma_i} \right] >, <, = 0. \quad (\text{A3.3})$$

The existence of a stable state is determined by equations (A3.1) and (A3.2) along with the following equation:

$$|J^A| = V_{x_{it}x_{it}} V_{\gamma_i \gamma_i} - V_{\gamma_i x_{it}} V_{x_{it} \gamma_i} > 0. \quad (\text{A3.4})$$

Therefore, as was the case in Appendix 2, for equation (A3.4) to be true the following must hold:

$$V_{x_{it}x_{it}} V_{\gamma_i \gamma_i} > V_{\gamma_i x_{it}} V_{x_{it} \gamma_i} \quad (\text{A3.4}')$$

From equations (A3.1) and (A3.2), the expression on the right hand side is positive, and is expressed in the following:

$$\beta P^2 U_{c_{it}c_{it}}(\cdot) \left[\frac{\partial^2 N^i(\cdot)}{\partial \gamma_i^2} \right] + (\beta^2 P^2 (1+\Delta)^2 \frac{\partial^2 N^i(\cdot)}{\partial \gamma_i^2}) \left[\int_0^1 U_{c_{it+1}c_{it+1}}(\cdot) dD(X) \right] + \beta^2 (1+\Delta)^2 \left[\frac{\partial^2 N^i(\cdot)}{\partial k_{it+1}^2} + \frac{\partial^2 N^j(\cdot)}{\partial k_{it+1}^2} \right] \left[\frac{\partial^2 N^i(\cdot)}{\partial \gamma_i^2} \right] \quad (\text{A3.5})$$

The expression on the left hand side of equation (A3.4') is also positive or neutral, depending on the sign of the $\frac{\partial N^i(\cdot)}{\partial k_{it+1} \partial \gamma_i}$ term. This expression is given by the following:

$$\beta^2 (1 + \Delta)^2 \left[\frac{\partial N^i(\cdot)}{\partial k_{it+1} \partial \gamma_i} \right]^2. \quad (\text{A3.6})$$

When stands are spatial complements, the landowner's marginal amenity valuation increases with own stand condition, resulting in a positive value for equation (A3.6). A similar positive value results when stands are spatial substitutes and the landowner's marginal amenity valuation decreases with own stand condition, as the product of two negative terms is a positive. When the stands are spatially independent, the landowner's marginal amenity valuation for both stands remains constant with increases in own stand condition, and thus the sign of equation (A3.6) is neutral. When the sign of equation (A3.6) is neutral, it is not difficult to prove that equation (A3.4') holds (as a positive expression is greater than zero). When (A3.6) is positive, compliance with equation (A3.4') is a little more difficult to prove.

Simplifying equations (A3.5) and (A3.6) by dividing by $\beta^2 (1 + \Delta)^2$, results in the following,

$$\left[\frac{\partial^2 N^i(\cdot)}{\partial \gamma_i^2} \right] \left[P^2 \left\{ \frac{U_{c_{it}c_{it}}(\cdot)}{\beta(1 + \Delta)^2} + \int_0^1 U_{c_{it+1}c_{it+1}}(\cdot) dD(X) \right\} + \left\{ \int_0^1 U_{c_{it+1}c_{it+1}}(\cdot) dD(X) \right\} \right], \text{ and} \quad (\text{A3.5}')$$

$$\left[\frac{\partial N^i(\cdot)}{\partial k_{it+1} \partial \gamma_i} \right]^2. \quad (\text{A3.6}')$$

For equation (A3.4') not to hold it would require that equation (A3.6') be equal or greater than equation (A3.5'). The complexity of equation (A3.5') implies that this requirement is not met.

Appendix 4: Proof of a stable Nash equilibrium.

In the simplified case of two landowners and homogenous conditions of timber stock on the parcels, it is possible to determine the signs of the cross-partial derivatives (see the discussion in the text). This examination concentrates on the cross-derivative $V_{x_{it}x_{jt}}$.

Recall the assumptions that the probability that adjacent stock is present is defined

by $\Pr(\tilde{k}_{jt+1} > 0) \equiv \eta$, while the probability that adjacent stock is not present

by $\Pr(\tilde{k}_{jt+1} = 0) \equiv 1 - \eta$. Also, the assumption that non-timber benefits are bound from above

$N(0,0) < \infty$. The following cross derivative results from these assumptions:

$$V_{x_{it}x_{jt}}^{iN} = \beta(1 + \Delta)^2 \eta \frac{\partial N^i(k_{it+1}, k_{jt+1}^s)}{\partial k_{it+1} \partial k_{jt+1}}. \quad (\text{A4.1})$$

Here it is apparent that under decreasing temporal dependence the sign of equation (A4.1) is negative, because $\beta(1 + \Delta)^2 > 0$. While, under increasing temporal dependence, the sign of the term on the right hand side is positive, and so the cross partial must be positive. When amenity valuation is temporally independent, the term on the right hand side is zero, and thus the landowner's management remains constant with changes in adjacent stocks.

Appendix 5: Survey Instrument

INSTRUCTIONS

- ▶ This questionnaire should be completed by the person who makes most of the decisions for the land parcel.
- ▶ Please answer the following questions only for your land parcel specified in the cover letter. If you own multiple parcels of this size in the county, please answer for only one parcel and consistently answer for this parcel throughout the survey.
- ▶ Please check the box in front of your answer where applicable. When a numerical answer is required, please write “0” if your answer is none.

CHARACTERISTICS OF YOUR LAND PARCEL

- 1 For the purpose of this study, **forestland** consists of land with at least 10 trees per acre **or** land where trees have been cut but not converted to agricultural, residential, or other non-forest use. An acre is roughly the size of a football playing field (100 yards by 55 yards). Also, **neighboring parcels** are those land parcels either directly bordering your parcel.

Does your parcel include at least 5 acres of forestland?

- YES → *Go to Question 2*
- NO

IF NO, PLEASE DO NOT ANSWER ANY MORE QUESTIONS AND RETURN THE SURVEY USING THE POSTAGE-PAID ENVELOPE PROVIDED.

- 2 Approximately how many acres of forestland are on this parcel?

_____ ACRES

- 3 How would you describe the overall structure of the trees on your forestland? (Please check all that apply)

- MORE THAN 70% ARE LARGE TREES (BIGGER THAN 12 INCHES IN DIAMETER AT 4 FEET HIGH)
- MORE THAN 70% ARE MEDIUM TREES (BETWEEN 5 AND 12 INCHES IN DIAMETER AT 4 FEET HIGH)
- MORE THAN 70% ARE SMALL TREES (SMALLER THAN 5 INCHES IN DIAMETER AT 4 FEET HIGH)
- A MIX OF LARGE AND MEDIUM TREES
- A MIX OF LARGE AND SMALL TREES
- A MIX OF MEDIUM AND SMALL TREES

Please check this box if you don't know:

- 4 Approximately how many **acres** of the forestland on this property are currently in the following types of forest?

_____ PINE (NEEDLE BEARING)

_____ HARDWOOD (LEAF BEARING)

_____ MIXED PINE AND HARDWOOD

Please check this box if you don't know: → *Skip to Question 7*

- 5 How would you describe the average size of your **pine** trees?

- THEY ARE SMALLER THAN 5 INCHES IN DIAMETER AT 4 FEET HIGH
- THEY ARE MORE THAN 5 INCHES BUT LESS THAN 9 INCHES IN DIAMETER AT 4 FEET HIGH
- THEY ARE MORE THAN 9 INCHES IN DIAMETER AT 4 FEET HIGH

- 6 How would you describe the average size of your **hardwood** trees?

- THEY ARE NO SMALLER THAN 5 INCHES IN DIAMETER AT 4 FEET HIGH
- THEY ARE MORE THAN 5 INCHES BUT LESS THAN 11 INCHES IN DIAMETER AT 4 FEET HIGH
- THEY ARE MORE THAN 11 INCHES IN DIAMETER AT 4 FEET HIGH

7 How would you classify the general terrain of your land parcel? (Please check all that apply)

- RELATIVELY FLAT
- ROLLING HILLS
- STEEP

8 How many miles of dirt or paved roads would you estimate are on this land parcel?

_____ MILES

9 Are there any permanent structures (Examples: house, trailer, barn) on this land parcel?

- YES
- NO

10 What is the approximate distance from your land to the closest state route?

_____ MILES

QUESTIONS ABOUT OWNERSHIP

11 How did you acquire your land parcel?

- I INHERITED IT
- I BOUGHT IT
- OTHER (Please specify): _____

12 What year did you acquire the land parcel?

_____ YEAR

13 Has this parcel been divided since you acquired it?

- YES
- NO → *Skip to Question 14*

If you answered YES to QUESTION 13, please answer the following questions.

▶ How many parcels resulted from the division(s)?

_____ PARCELS

▶ Why did you divide your land parcel? (Please check all that apply)

- TO SPLIT THE LAND PARCEL AMONG MY HEIRS
- TO SELL THE LAND PARCEL(S)
- OTHER (Please specify): _____

14 Are there any existing easements for access to this parcel that extend through neighboring parcels?

- YES
- NO
- I DON'T KNOW

MANAGEMENT OF YOUR LAND PARCEL

15 Do you take into account how your land management decisions affect neighboring lands, those lands bordering or adjacent to the parcel specified in the cover letter?

- YES (Please specify how): _____
- NO

16 Have you ever had any of the trees on your land parcel harvested for the sale of timber?

- YES
- NO → *Skip to Question 17*

If you answered YES to QUESTION 16, please answer the following question.

► How much of your forestland was harvested?

_____ ACRES

17 Have you ever worked together with neighboring landowners in land management activities (Examples: trail building, improving stream quality, developing wildlife habitat, timber harvesting, farming)?

- YES (Please specify activity): _____
- NO

18 Suppose your land parcel has trees that are currently ready to harvest. Would you be interested in harvesting at least 5 acres of trees for a timber sale?

- YES → *Skip to Question 19*
- NO
- I DON'T KNOW

If you answered either NO or I DON'T KNOW to QUESTION 18, please answer the following question.

► What prevents you from being interested in harvesting trees from the land parcel?

- I AM NOT INFORMED ABOUT TIMBER PRICES OR MARKETS
- I AM NOT INFORMED ABOUT MANAGEMENT PLANS FOR NEIGHBORING PARCELS
- ENVIRONMENTAL REASONS (Example: preservation of soil and water quality)
- DESIRE TO PROTECT WILDLIFE HABITAT
- DESIRE TO PRESERVE SCENIC BEAUTY
- OTHER (Please specify): _____

19 Suppose that your land parcel and neighboring parcel(s) have trees that are currently ready to harvest. Would you consider harvesting at the same time as your neighbor(s) if there were a 20% increase in the price you received for your timber as a result of harvesting together?

- YES
- NO
- I DON'T KNOW

20 How important is price in determining whether to harvest trees from your land parcel? (1 is not important, 5 is very important)

- | | | | | |
|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| 1 | 2 | 3 | 4 | 5 |
| <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

21 How important is management of neighboring parcels in determining how you manage your land? (1 is not important, 5 is very important)

- | | | | | |
|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| 1 | 2 | 3 | 4 | 5 |
| <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

FUTURE PLANS FOR YOUR LAND PARCEL

22 Would you consider jointly planning **future** forest management activities with neighboring landowner(s)?

- YES
- NO → *Skip to Question 23*
- I DON'T KNOW

If you answered either YES or I DON'T KNOW to QUESTION 22, please answer the following question.

► What provisions would you like to have in a joint forest management plan? (Please check all that apply)

- HARVEST OF TIMBER STANDS IN ALTERNATE YEARS
- REDUCTION IN COSTS OF TIMBER MANAGEMENT
- INCREASE IN OVERALL LAND VALUE
- IMPROVEMENT OF WILDLIFE HABITAT, INCLUDING NON-GAME SPECIES
- IMPROVEMENT OF RECREATION OPPORTUNITIES
- IMPROVEMENT OF WATER QUALITY ACROSS PARCELS
- REDUCTION OF PROPERTY, INCOME, OR ESTATE TAXES
- INCREASE FARM REVENUE
- OTHER (Please specify): _____

23 Would you be willing to enter into a joint agreement with neighboring landowner(s) to **not** harvest timber on a portion of your land in order to create forest cover for wildlife species?

- YES
- NO
- I DON'T KNOW

24 Would you be willing to enter into a joint agreement with neighboring landowner(s) to **not** harvest timber on a portion of your land to create a forested area for recreation?

- YES
- NO
- I DON'T KNOW

25 Do you expect to harvest trees from this land parcel in the future?

- YES
- NO

26 What do you plan to do with this land parcel in the future?

- GIVE THE LAND PARCEL TO MY HEIRS
- GIVE ONLY PART OF THE LAND PARCEL TO MY HEIRS AND SELL THE REST
- SELL THE LAND PARCEL
- OTHER (Please specify): _____

YOUR VIEWS OF TIMBER AS AN INVESTMENT

27 How would you rate the degree of risk associated with growing trees for income as opposed to typical investments like stocks and bonds? (1 is least risk, 5 is most risk)

- | | | | | |
|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| 1 | 2 | 3 | 4 | 5 |
| <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

28 How would you rate the degree of risk associated with losing your timber to fire, insects, disease, wind/ice damage, or other natural occurrences? (1 is least risk, 5 is most risk)

- | | | | | |
|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| 1 | 2 | 3 | 4 | 5 |
| <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

USE OF YOUR LAND PARCEL

29 How important are the following reasons for owning your forestland? (1 is not important, 5 is very important)

	1	2	3	4	5
ENVIRONMENTAL REASONS (Examples: protection of water quality, wildlife habitat)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
TO KEEP FOR FAMILY	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
SCENIC BEAUTY	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
INCOME FROM TIMBER PRODUCTION	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
LAND INVESTMENT/ REAL ESTATE	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
HUNTING/FISHING	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
OTHER RECREATION (Examples: hiking, camping, observing wildlife)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
PART OF RESIDENCE OR FARM	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

30 On approximately how many **days** of 2003 did you participate in each of the following activities?

_____ ATV/FOUR-WHEELING	_____ HUNTING
_____ BIKING	_____ OBSERVING WILDLIFE
_____ BIRD WATCHING	_____ PASTURING HORSES OR CATTLE
_____ CAMPING	_____ PHOTOGRAPHY
_____ COLLECTING FIREWOOD	_____ PICNICKING
_____ FISHING	_____ RUNNING
_____ FLOWER, PLANT, OR BERRY PICKING	_____ WALKING/HIKING
_____ HORSEBACK RIDING	_____ OTHER (Please specify): _____

31 Is your use of your land parcel for the above activities dependent on the condition of neighboring land(s)?

- YES
- NO → *Skip to Question 32*
- SOMEWHAT

If you answered either YES or SOMEWHAT to QUESTION 31, please answer the following question.

- ▶ If a neighboring forest landowner were to harvest timber from their land, how would this affect your use of your parcel for recreational activities?
 - INCREASE NUMBER OF DAYS SPENT
 - DECREASE NUMBER OF DAYS SPENT
 - NO EFFECT ON NUMBER OF DAYS SPENT

32 Do you allow others to hunt on or use your land for other activities (Examples: hiking, camping, observing wildlife, farming)?

- YES
- NO

NEIGHBORING LAND PARCELS

33 Are there any existing easements for access to neighboring parcels that extend through your land parcel?

- YES
- NO
- I DON'T KNOW

34 How many different landowners, including you, have parcels directly bordering the parcel specified in the cover letter?

_____ LANDOWNERS

Please check this box if you don't know: → *Skip to Question 36*

35 Of the bordering landowners from QUESTION 35, how many are in the following categories?

- _____ GOVERNMENT
- _____ FOREST INDUSTRY (Example: MeadWestvaco)
- _____ PRIVATE INDIVIDUAL
- _____ OTHER (Please specify): _____

36 Approximately what **percent** of the land parcel is bordered by:

- _____ FORESTLAND
- _____ CROPLAND OR PASTURE
- _____ RESIDENTIAL AREA (Examples: Subdivisions or a planned development with multiple residences) → *Skip to # 37*
- _____ OTHER (Please specify): _____ → *Skip to # 37*

If you indicated FORESTLAND or CROPLAND OR PASTURE in QUESTION 37, please answer the following questions.

▶ Is neighboring land use a factor you consider when making land use decisions?

- YES
- NO
- I DON'T KNOW

▶ How important are the following reasons to **you** for having neighboring parcels in their current land use?
(1 is not important, 5 is very important)

	1	2	3	4	5
ENVIRONMENTAL REASONS (Examples: protection of water quality, wildlife habitat)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
SCENIC BEAUTY	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
PREVENTS DEVELOPMENT FOR OTHER USE (Examples: subdivision, industrial)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
HUNTING/FISHING	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
OTHER RECREATION (Examples: hiking, camping, observing wildlife)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
TAX PURPOSES	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

▶ Do you hunt or fish on neighboring parcel(s)?

- YES
- NO

- ▶ Do you participate in other activities (Examples: hiking, camping, observing wildlife, farming) on neighboring parcel(s)?
 - YES
 - NO

If you answered YES to either of the PREVIOUS QUESTIONS, please answer the following questions.

- ▶ Is your use of neighboring land parcel(s) for hunting, fishing, **or** other recreational activities dependent on the condition of the parcel?
 - YES
 - NO
- ▶ If a neighboring forest landowner were to harvest timber from their land, how would this affect your use of that parcel for hunting, fishing, **or** other recreational activities?
 - INCREASE NUMBER OF DAYS SPENT
 - DECREASE NUMBER OF DAYS SPENT
 - NO EFFECT ON NUMBER OF DAYS SPENT
- ▶ Would you consider jointly planning land management activities other than timber harvesting with neighboring landowners (Examples: trail building, stream quality improvement, developing wildlife habitat, farming)?
 - YES
 - NO → *Skip to Question 37*
 - I DON'T KNOW

If you answered either YES or I DON'T KNOW to the PREVIOUS QUESTION, please answer the following question.

- ▶ What would make you most comfortable with jointly planning land management activities with neighbor(s)? (Please check all that apply).
 - A BETTER LAND PRICE
 - A PROVISION FOR PROTECTION OF WILDLIFE HABITAT
 - A PROVISION FOR ENVIRONMENTAL PROTECTION (Example: preservation of soil and water quality)
 - A BINDING CONTRACT
 - A PROFESSIONAL ASSESSMENT OF LAND PARCELS
 - OVERSIGHT BY AN INDEPENDENT PARTY
 - OTHER (Please specify): _____

QUESTIONS ABOUT YOU

The following questions help us obtain background information for statistical purposes. As is true for the rest of the survey, all information is kept strictly confidential.

37 Is your primary residence located on this land parcel?

- YES → *Skip to Question 38*
- NO

If you answered NO to QUESTION 37, please answer the following question.

- ▶ Approximately how far away is your primary residence from this land parcel?
_____ MILES

38 How many children do you have?

_____ CHILDREN

39 What is your age?

_____ YEARS

40 What is your gender?

- MALE
- FEMALE

41 What is your current marital status?

- SINGLE
- MARRIED
- DIVORCED/SEPARATED
- WIDOWED

42 What is your current employment status?

- EMPLOYED FULL TIME
- EMPLOYED PART TIME
- UNEMPLOYED
- RETIRED

43 What is the highest level of education that you have completed?

- LESS THAN HIGH SCHOOL
- HIGH SCHOOL
- SOME COLLEGE
- COLLEGE (Please specify highest degree obtained) _____

44 Did you earn income from any of the following activities in 2003? (Please check all that apply)

- SELLING FIREWOOD
- SELLING TIMBER
- SELLING AGRICULTURAL CROPS
- SELLING LIVESTOCK
- NONE OF THE ABOVE

45 What was your approximate household income (before taxes) in 2003?

- LESS THAN \$10,000
- \$10,000 TO \$29,999
- \$30,000 TO \$49,999
- \$50,000 TO \$74,999
- \$75,000 TO \$99,999
- \$100,000 TO \$124,999
- \$125,000 OR GREATER

Thank you VERY MUCH for taking the time to respond to this survey. Please return the completed survey in the envelope provided. Remember, if you would like a copy of our results, please provide an address where the results should be sent on the back of the return envelope. If you have additional comments, please write them in the space below.

Curriculum Vita

Melinda M. Vokoun

1850 Vienna Woods Dr. Apt 204
Raleigh, NC 27606
Phone: (919) 233-4809
Email: mejones@vt.edu

EDUCATION

Ph.D., Forest Resource Economics, May 2005
Virginia Polytechnic Institute and State University, Blacksburg, VA

Dissertation Title: “Investigating the cooperative behavior of nonindustrial private forest landowners when stands are spatially interdependent”
Advisor: Dr. Gregory S. Amacher

M.S., Forest Resource Economics, May 2002
Virginia Polytechnic Institute and State University, Blacksburg, VA

Thesis Title: “Non-industrial landowners, the incentives to forego harvesting, and the importance of scale activities”
Advisor: Dr. Gregory S. Amacher

B.S., Forestry, Magna Cum Laude, May 2000
Michigan Technological University, Houghton, MI

RESEARCH EXPERIENCE

Research Associate. Department of Forestry and Environmental Resources, North Carolina State University. Raleigh, NC. (2005). Examining performance of two separately developed land use models; research and development of forest supply side of decadal assessment models; building a simulation model to link timber supply to detailed inventory and related market models.

Research Assistant. Department of Forestry, Virginia Polytechnic Institute and State University. Blacksburg, VA. (2004). Dissertation research on the effects of adjacent landowner activities on the decisions of non-industrial private forest landowners; analysis of policy instruments; applications to fire and invasive species.

Research Assistant. Department of Forestry, Virginia Polytechnic Institute and State University. Blacksburg, VA. (2003). Developed procedures for integrating forest landowner behavior models into landscape models for the prediction of forest fragmentation patterns; developed econometric approaches to predict probabilities of scale of harvesting decisions at various price

levels using referendum data from non-industrial private forest landowners; expected products include two refereed journal articles in progress and a report submitted to the USDA Forest Service Southern Research Station.

Research Assistant. International Forestry Center in the Department of Forestry, Virginia Polytechnic Institute and State University. Blacksburg, VA. (Summer 2003). Assisted in analyzing data for smallholder behavior and deforestation in Brazil; data entry for illegal logging project in Indonesia.

Research Assistant. Department of Forestry, Virginia Polytechnic Institute and State University. Blacksburg, VA. (2000-2002). Conducted and managed a project examining behavior of forest and agricultural landowners in Virginia and Mississippi; duties included identifying survey recipients; assembling and mailing surveys; data entry; and assisting in supervising another Master's degree student's thesis; products include a report submitted to the USDA Forest Service Southern Research Station, a paper submitted to *Forest Science* and another paper under revision for publication in the *Journal of Forestry*.

TEACHING EXPERIENCE

Guest Lecturer. Department of Agricultural and Applied Economics, Virginia Polytechnic Institute and State University. Blacksburg, VA. (October 25, 2004). *Rural and Regional Development Policy*. Presented guest lecture on research regarding affects of adjacent landowner activities on decisions of non-industrial private forest landowners relating to rural and regional policy development.

Teaching Assistant. Departments of Economics and Forestry, Virginia Polytechnic Institute and State University. Blacksburg, VA. (Fall 2004). *Forest Resource Management*. Assisted with reviewing and grading of laboratory exercises.

Teaching Assistant. Departments of Economics and Forestry, Virginia Polytechnic Institute and State University. Blacksburg, VA. (Fall 2001-2003). *Natural Resource and Environmental Economics*. Taught review sessions of course material; held office hours; assisted with reviewing and grading of exams and quizzes.

Teaching Assistant. Department of Forestry, Virginia Polytechnic Institute and State University. Blacksburg, VA. (Fall 2002). *Forest Resource Economics*. Assisted with reviewing and grading of exams and quizzes.

Teaching Assistant. Department of Forestry, Virginia Polytechnic Institute and State University. Blacksburg, VA. (Spring 2002). *Forestry Spring Field Camp, Forest Management and Economics Portion*. Assisted students with formulation of field forest management plans.

Teaching Assistant. Department of Forestry, Virginia Polytechnic Institute and State University. Blacksburg, VA. (Spring 2001). *Consulting Forestry Business*. Assisted with reviewing and grading course papers, projects, and exams.

Instructor. Copper Country Intermediate School District. Hancock, MI. (Winter 1999). Developed a lesson plan for an interactive science workshop focusing on fungi and delivered it to elementary-aged school children and their parents as part of Family Science Night in the local schools.

OTHER EMPLOYMENT

Graduate Honor System Member. Virginia Polytechnic Institute and State University. Blacksburg, VA. (2000-2003). Served on Investigative Boards of Graduate Honor System; acted as a committee member to determine if there was enough evidence to merit a Judicial Panel; served on Judicial Panels of Graduate Honor System; acted as a committee member to determine guilt or innocence of accused parties; and determine appropriate punishment when warranted.

Instructor Assistant. North Carolina Forestry Association. Various locations, NC. (2000-2002). Assisted with instruction of forestry related topics to, and supervised educational activities of, elementary-aged school children (5th and 6th grade).

Graduate Student Mentor. Virginia Polytechnic Institute and State University. Blacksburg, VA. (2002-2004). Served as a mentor for a Master's student in the Department of Forestry, College of Natural Resources.

Vegetative Sampler. Michigan Department of Natural Resources. Roscommon, MI. (Summer 1999). Performed extensive vegetative samples of the eastern half of the Upper Peninsula of Michigan; recorded ground vegetative species and tree species, percent cover of ground species and tree crown, topographical and soil characteristics of selected plots.

Field Assistant and Inventory. Isle Royale National Park and Michigan Technological University. (Summer and Fall 1997). Assisted in field measurements of balsam fir plots; cataloged and inventoried moose bone specimens.

GRADUATE LEVEL COURSEWORK IN ECONOMICS

Seminar in Mathematics for Economists	Applied Microeconomic Theory I
Mathematical Programming for Economists	Elementary Econometrics
International Development and Trade	Principles of Finance
Applied Microeconomic Theory II	Forest and Recreation Economics
Advanced Forest Management and Economics	Mathematical Economics
Advanced Microeconomic Theory I	Advanced Microeconomic Theory II
Advanced Econometrics I	Advanced Macroeconomic Theory I
Advanced Econometrics II	Advanced Topics in Forest Economics
Dynamic Optimization and Natural Resource Economics	
Advanced Macroeconomic Theory II	

PUBLICATIONS

Vokoun, M., G.S. Amacher, and D.N. Wear. "Scale of harvesting and price acceptance behavior of nonindustrial private forest landowners." *Journal of Forest Economics* (submitted).

Conway, M.C., G.S. Amacher, D.N. Wear, J. Sullivan, M. Vokoun, and D.L. Grebner. "New evidence concerning non-industrial forest landowner behavior in two regions of the southern U.S." *Journal of Forestry* (revision and resubmission encouraged February 2004).

Amacher, G.S. and M. Vokoun. "Estimates of market entry behavior of forest landowners in Virginia." Final report for submission to USDA Forest Service Southern Research Station.

Amacher, G.S., M.C. Conway, J. Sullivan, M. Vokoun, and D.L. Grebner. 2003. "Comparisons of reservation prices for harvesting and land use change in Mississippi and Virginia." Final report submitted to USDA Forest Service Southern Research Station, Southern Forest Resource Assessment Consortium (SOFAC).

Vokoun, M. and G.S. Amacher. 2002. "Non-industrial landowners, the incentives to forego harvesting and the importance of scale of activities." in: G.S. Amacher and J. Sullivan, eds. *Proceedings of the 2002 Southern Forest Economics Workshop*, Virginia Beach, Virginia.

DISSERTATION AND OTHER WORK IN PROGRESS

Vokoun, M., G.S. Amacher, J. Sullivan, and D. Wear. "The influence of adjacent landowners on the forest management decisions of non-industrial landowners."

Vokoun, M., D. N. Wear, and G.S. Amacher. "Predicting future timber supplied by NIPF landowners through the incorporation of landowner behavior models into landscape models."

PRESENTATIONS

Vokoun, M. 2005. "Investigating the cooperative behavior of nonindustrial private forest landowners when stands are spatially interdependent." Department of Forestry, Virginia Polytechnic Institute and State University. March 7, 2005. Blacksburg, Virginia.

Vokoun, M. 2004. "New models of predicting non-industrial private forest landowner behavior." Department of Forestry, West Virginia University. July 1, 2004. Morgantown, West Virginia.

Vokoun, M. 2004. "New models of predicting non-industrial private forest landowner behavior." U.S. Forest Service Southern Research Station. June 28, 2004. Research Triangle Park, North Carolina.

Vokoun, M. 2004. "New models for predicting non-industrial private forest landowner behavior." Department of Forestry, Virginia Polytechnic Institute and State University. June 11, 2004. Blacksburg, Virginia.

Vokoun, M. and G.S. Amacher. 2002. "Non-industrial landowners, the incentives to forego harvesting and the importance of scale of activities." Southern Forest Economics Workshop March 17-19, 2002. Virginia Beach, Virginia.

HONORS

Robert S. Burruss Academic Fellowship, Department of Forestry, Virginia Polytechnic Institute and State University (2000-2002)
Board of Control Academic Scholarship, Michigan Technological University (1996-2000)
Robert Byrd Memorial Scholarship, State of Michigan (1996-2000)

AFFILIATIONS

Xi Sigma Pi (2001-present)
Society of American Foresters (1999-2002)

SKILLS

LIMDEP; Lindo; GAMS; MATLAB; dynamic optimization; non-linear and linear programming; doctoral courses in microeconomic theory; macroeconomic theory; forest resource economics and policy; forest management; econometrics; finance; natural resource policy; international development and trade; SAS

REFERENCES

Dr. Gregory S. Amacher, Associate Professor, Department of Forestry, Virginia Polytechnic Institute and State University, (540) 231-5943, gamacher@vt.edu

Dr. Jay Sullivan, Associate Professor, Department of Forestry, Virginia Polytechnic Institute and State University, (540) 231-4356, jsulliv@vt.edu

Dr. Steve Prisley, Associate Professor, Department of Forestry, Virginia Polytechnic Institute and State University, (540) 231-7674, prisley@vt.edu