

LEE, KAREN JEAN. Hedonic Estimation of Nonindustrial Private Forest Landowner Amenity Values. (Under the direction of Dr. Raymond B. Palmquist and Dr. Jan Laarman).

ABSTRACT

Research into nonindustrial private forest management behavior has often focused on the relationship between harvesting decisions and characteristics of the landowner. In addition to landowner differences, however, private forest management is affected by different levels of amenities present in individual forest stands. This relationship between forest amenity characteristics and private forest harvest and timber supply has not been well established. This paper tests the hypothesis that private forest landowners consider on-site forest characteristics as amenity values in their harvesting decisions. Landowners who value amenities may harvest beyond the optimal financial rotation age, thus incurring opportunity costs. Using a modified hedonic method, a regression of opportunity costs on the forest amenity characteristics provides estimates of the marginal value of these amenities. Because the decision to harvest is influenced by the amenity values present on the site, nonindustrial harvesters are a self-selected sample and econometric techniques were used to minimize bias in the coefficient estimates.

**HEDONIC ESTIMATION OF FOREST AMENITY
VALUES OF NONINDUSTRIAL PRIVATE LANDOWNERS**

by

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DEDICATION

This dissertation is dedicated to the three most important men in my life. In order of their appearance in my life (not their importance to it), they are, my wonderful dad, Robert E. Lee, my best dog Gyllen and my loving husband, Robert C. Abt. Both my Dad and Gyllen died this past year and I miss them very much. I think they would be happy for me. I know that my husband is both happy and proud. I hope I can live up to all their expectations.

PERSONAL BIOGRAPHY

Though I was born in Iowa, I consider myself a Californian. I left there in 1985 to begin my forestry career as a student at Colorado State University. A job with the USDA Forest Service brought me to North Carolina and, eventually, to the graduate school at NCSU. I am currently employed by USDA Forest Service, Southern Research Station.

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I. INTRODUCTION

Forests and forestry have played a significant role in the economic development and psyche of the South. Forests, which originally occupied nearly all of the land area of the South, now occupy only 55 percent (USDA Forest Service 1988). More important, perhaps, is the change in the structure and composition of these forests. Some of these changes have resulted from harvest for conversion to agriculture, and the subsequent reversion to forest (Healy 1985). Other changes have occurred as fiber demand increased and harvested lands were replanted with pines. More recent is the recognition that forests provide amenity and recreational values which may lead to reductions in harvest by nonindustrial private forest landowners.

Most research into private forest management behavior has focused on the relationship between harvesting decisions and characteristics of the landowner (e.g., Binkley 1981). The relationship between forest amenity characteristics and private forest harvest, however, has not been well established. This paper will test the hypothesis that private forest landowners consider on-site forest characteristics as amenity values in their harvesting decisions. If forest stands are valued for their amenity characteristics, then the value of these characteristics should be reflected in the decision to harvest. Given information on the date and value of harvest and nonmarket forest characteristics, a model is developed which is a variant of the traditional hedonic model.

While forests provide both market and amenity outputs, these outputs are not necessarily complementary. The dominant market output is timber, the harvest of which

often conflicts with production of high-quality amenity benefits. Thus, the values held by private landowners for amenities play a role in influencing private forest management by changing the harvest date or amount of timber production from any given stand.

One important implication of the expanding role of amenities in private forest management is the resulting effect on regional timber supplies. As amenities increase in value and harvests occur later or not at all, land is effectively removed from the timber base. Thus, current timber supply models based on timber inventory or land area may overestimate the potential supply available from nonindustrial private forest (NIPF) land. In addition, policies designed to increase stand-level sustainability may be ineffective if current management objectives are not considered (Society of American Foresters 1995). Incentives to promote or reward sustainable management through certification may have little effect on management if landowners already extend their rotation for amenity purposes.

At a more aggregate level, the presence and value of on-site amenities has the potential to influence valuation of current productive capital stocks as well as valuation of environmental and amenity stocks. Forests can be considered to be a type of natural capital, where forests provide raw material inputs to production, clean air and water, a source of yet-to-be-discovered medicinal benefits and amenity benefits (Maler 1991). At the present time, however, our most commonly used measure of economic performance, Gross Domestic Product (GDP), does not incorporate nonmarket values of the forest, nor is the depreciation of the stock of forest capital resulting from its use in production subtracted from GDP to arrive at net national product. Thus, these measures of economic

welfare are biased and will not represent a sustainable level of growth and development (Solow 1986, Peskin 1991). Estimates of sustainable income require knowledge of the contribution of forests to national welfare as well as the appreciation, depreciation and degradation of natural forest capital (Daly 1989). In this paper I examine a methodology that may provide information for use in developing these forest capital accounts.

The traditional hedonic method uses evidence of market equilibrium between buyers and sellers of bundled goods to estimate a marginal price for the nonmarket attributes of the good (Rosen 1974). Thus, the sales price of the good is regressed against the characteristics, giving a dollar value to environmental or neighborhood characteristics such as air quality or commute time. Hedonic prices represent equilibrium prices for individual attributes of the bundled good. The Rosen model is based on an equilibrium attained when consumers (buyers) maximize the utility of choosing a bundle of attributes while producers (sellers) maximize utility of profits from producing the commodity bundle.

A forest is a complex bundled good, with varying quantities of both timber and nonmarket goods. In this paper, rather than using sales price of land and quantities of attributes (which are not available for forested tracts), landowners' timber harvest decisions are used to represent market behavior, which is assumed to be influenced by the available on-site amenities. And if we know the age at harvest, we can calculate how much money (opportunity cost) was foregone in order to have the amenities from the mature forests. Thus the opportunity cost reflects a market cost and can be used in a hedonic-type model to estimate the values of on-site forest amenities. This opportunity

cost should represent the landowner's willingness to pay for on-site forest amenities that can be influenced by harvest. These amenities include such attributes as scenery, tree diversity and wildlife habitat.

The total opportunity cost that is foregone by a landowner is not known, however, because the total value of the harvest-influenced resources is not known. What is known, assuming optimal landowner behavior, is that the first order condition with respect to time is equal to zero. At this rotation age, the landowner has maximized the wealth of all harvest-influenced forest characteristics, including both timber and amenities. Thus, the marginal opportunity cost of timber can be ascertained by observing harvest volume, prices and rotation age. Excess of marginal costs over marginal benefit from the first order condition will be equal to the marginal value of the amenities. This value can then be regressed on the amenity quantities to produce marginal hedonic prices for the amenity quantities.

For the hedonic model I use data from forested plots in North Carolina. Collected between 1983 and 1990, information is included on biological resources and attributes of the forest stand including timber volumes and species, vegetation species, occupancy and volume and site characteristics such as slope and distance to roads. The volume harvested and the dates of harvest are also collected. These data allow construction of various amenity indices and development of timber revenues and costs.

The analysis is limited in several ways. First, no public values will be included. Using hedonic methods, I estimate only the value of on-site amenities to private forestland owners. While many of the attributes included, such as wildlife habitat and

scenic beauty are valued by the public, this paper examines only landowner-held values for these attributes. Second, inadequate or asymmetric information and alternative ownership objectives are not tested in this model.

A third limitation of this analysis is that forest characteristics are assumed to accurately represent landowner amenity values. The measures included in the model are those commonly used by practitioners in ecology and wildlife, but the correlation between these measures or indices and landowner preferences has not been explored. Thus, each hypothesis test is actually a joint test of (1) the validity of the index in measuring landowner preferences and (2) the significance of the hedonic price of that amenity. Lastly, limited landowner data are available and thus most landowner differences will be captured in the model only through the error term. Landowner differences are assumed to be independent of the amenity attributes and timber values included in the model. In this paper, I evaluate only farmer-owned and miscellaneous private owned timberland.

I test the general hypothesis that amenity characteristics of standing forests influence landowner harvesting decisions. Within this framework, I test hypotheses related to the sign and significance of specific forest characteristics. I hypothesize that the presence of large diameter trees, higher quality wildlife habitat, higher scenic beauty estimates and increased tree diversity have positive amenity values, thus delaying harvest. A further objective of this analysis is to determine if hedonic estimation of forest amenity values can be used to provide information for natural resource accounting, sustainability measures and green certification.

I.B. THE LITERATURE REVIEW

The literature that addresses optimal rotation, private landowner behavior and hedonic methods is extensive and has been summarized in other places (Newman 1988, Alig et al. 1989, Palmquist 1991). The optimal rotation decision is one of the most intensively studied topics in forest economics. While a significant issue, the importance given this topic, particularly by those unfamiliar with forest economics, is misleading and unfortunate. The normative question of when a landowner should harvest is most correctly followed by a positive analysis of when landowners actually do harvest. And this often leads to a reevaluation of the optimal rotation in general, including an evaluation of profit motives (Binkley 1981), asymmetric information (Larson and Hardie 1989), inefficient markets (Washburn and Binkley 1988) and policy interventions (Boyd and Hyde 1989, Cabbage and Haynes 1988). In evaluating alternatives to profit maximization, nonindustrial landowner evaluations of nonmarket attributes must also be addressed. One method that has significant potential for nonmarket valuation of private land, but has not yet been utilized, is the hedonic method.

I.B.1. Optimal Rotation

The age at which to optimally harvest a stand of trees was correctly solved in 1849 by Martin Faustmann and rediscovered by Gaffney (1957) and Samuelson (1976). For a landowner with an individual stand, it is well established that this solution to the

optimal rotation age provides the maximum monetary income to the profit-maximizing landowner,

$$LV = \max_T \frac{PQ(T)e^{-rT}}{1-e^{-rT}} \quad (1)$$

where LV is the land value at the optimal age (T), P is the price of timber, Q(T) is the volume harvested and r is the discount rate. The Faustmann model assumes constant prices and costs, no risk or uncertainty and no land use change. In short, this is a steady state model that must be modified to account for progress to the steady state. These assumptions have limited and complicated the use of this model for empirical applications.

The optimal rotation age is determined by setting the first derivative equal to zero.

$$PQ_T(T) = r(PQ(T) + \frac{PQ(T)e^{-rT}}{1-e^{-rT}}) \quad (2)$$

This first order condition indicates that forest land wealth will be maximized when the marginal benefits of waiting another year to harvest (the left-hand side of (2)) are equal to the marginal costs of waiting another year (the right-hand side of (2)).

The model provides important insights into how forests should be managed in a world of steady and certain prices, costs, volumes, even-aged management, constant land use, etc. Comparative static solutions to this model (Jackson 1980, Hyde 1980) have revealed that permanent price and volume increases lead to delayed harvests. Increased management intensity, with all other values constant, leads to delayed harvest (Chang 1983). More complex results obtain relative to the discount rate (Nautiyal and Williams

1989) where assumptions regarding the production function for timber are critical to the outcome. Taxation (Chang 1982, 1983), genetic selection (Lofgren 1988, Pye et al. 1997), and risk and uncertainty (Martell 1980, Kao 1982) have also been evaluated using this model or variations. However, there is still little evidence that these models are used by landowners in decision making or that these models reflect landowner decisions.

A significant variant of the Faustmann model was developed by Hartman in 1976. This model includes, as a landowner objective, the maximization of nontimber outputs, in this case, recreation. From the theoretical model, Hartman showed that the presence of nontimber benefits could delay or prevent timber harvesting. Similar to Faustmann, there have been few applications of this model to actual timber management due to lack of data and the severe limitations of the assumptions. The model has, however, provided a basis for many studies that did not assume profit as the only objective for nonindustrial private landowners (e.g., Newman and Wear 1993).

There have been three normative studies which use the Hartman or a similar model. Calish et al. (1978) evaluated optimal rotations in the presence of nontimber values and found that the timing of the stream of nontimber benefits could either lengthen or shorten the rotation. A study by Plantinga and Birdsey (1996) rediscovered the Hartman model and found that landowners who value carbon storage will harvest later than the Faustmann optimal. A third normative study of the Hartman model is Swallow et al. (1990) who found that nonconvexities in the amenity production functions could lead to nonoptimal solutions.

I.B.2. Nonindustrial Private Forest Management

The optimal rotation literature has tended to focus on landowners who are likely to maximize profits, namely forest industry landowners. While the Hartman model seems more appropriate for both nonindustrial and public landowners, it is a normative model with enormous data and assumption requirements. Thus, the benefits of applying the Hartman model are limited, while the costs are high. Although it is now commonly recognized that NIPF's may have alternative objectives, two factors have combined to limit research in this area (1) data limitations and (2) misunderstanding of the value of studying private landowner amenity values.

Data limitations are a long-standing issue in addressing forestry concerns, particularly with respect to NIPF landowners. Industrial landowners are presumed to maximize profits, and it has been shown that their behavior does not reject the profit motive (Wear and Newman 1991). Also, industrial owners are assumed to be more alike than different. NIPF owners, in contrast, are assumed to have objectives ranging from pure profit (i.e., tree farmers) to pure enjoyment (i.e., wilderness inholders with no intent to develop) to pure neglect (i.e., nonresident, nonmanaging landowners). And because of the long timber period over which forests grow and change and are managed as well as the frequency of ownership changes, it is felt that little can be understood about landowner objectives by observing the land itself. Thus, the primary source of information on NIPF objectives has been through landowner surveys. Two large surveys, Fecso et al. (1982) and Birch et al. (1996) provided information on reasons for owning,

managing, harvesting and investing in forestland. Most surveys are much smaller and address very specific questions.

The second issue that has reduced research interest in NIPF amenities is that timber supply has been the primary policy objective of NIPF research. In addition, the primary focus of nonmarket valuation has been public lands and public goods (Pearse and Holmes 1993). Recent public interest in ecosystem or landscape level management has raised the issue of private landowner management for outputs other than timber. Sustainability issues such as green certification, resource accounting and sustainable forest management have also heightened interest in private landowner's management for amenity values.

As early as the 1950's, researchers noted that landowners may have alternative objectives (Yoho and James 1958), although a more common characterization of NIPF landowners was that they did not know how to correctly manage their land for profit (USDA Forest Service 1951). Clawson (1977) found that NIPF landowners were not substantially different from profit maximizing industrial landowners, implying that alternative objectives were not an issue. Even among those who viewed NIPF management as sub-par, the 'fault' was attributed to lack of information, not alternative objectives (Le Master 1978).

'Bad' NIPF management continued to be blamed on asymmetric information, capital constraints and landowner education. A conspicuous example of this belief can be found in the South's Fourth Forest (USDA Forest Service 1988), where less-than-optimal behavior leads to the presence of widespread timber investment opportunities on NIPF

lands. For example, of the 110 million acres of NIPF land in the South, 52 million are identified as having opportunities to improve profitability. On the other hand, there is at least some evidence that NIPF's can be characterized as profit maximizers (Newman and Wear 1993).

The empirical economic analysis of NIPF behavior began in earnest following Binkley (1981). Binkley proposed that NIPF's maximize utility instead of profit, and that this model could be used to explain much NIPF behavior that had previously been seen as irrational, uninformed or resulting from market failure. This model did not necessarily change analysts' perceptions of NIPF's, but it did provide an economic explanation and structure for further empirical analyses. Further studies by Boyd (1984), Royer (1987) and Dennis (1989), among others, did not reject the utility maximization hypothesis. Landowner age and income were influential in harvesting decisions, consistent with this model where increasing income would lead to increased valuation of nonmarket attributes, thus leading to delay in harvest.

Many other analyses of NIPF harvesting have been conducted without reference to an economic model (Bliss and Martin 1989, Greene and Blatner 1986). Landowner attributes such as income, age, education, tenure and technical assistance have been identified as significant influences, while tract information such as size, timber type and location are also identified as influential in affecting NIPF forest management.

I.B.3. Hedonic Methods

As recognition of nontimber values of forests increased, alternative methodologies such as travel cost, hedonic travel cost and contingent valuation began to be applied to forestry questions (Pearse and Holmes 1993). Hedonic travel cost, like other hedonic methods, uses an agent's revealed preferences, revealed in this case from travel expenses to forest recreation sites with differing site qualities. Contingent valuation is based on agent's stated preferences, i.e., from surveys or questionnaires. The methods of nonmarket valuation have primarily been used to discern values associated with public lands, or values held by the public for privately held resources (such as scenery or visual quality). With the recognition of the role of private lands in landscape level management, private landowner's nonmarket values will become more important in developing sustainable forest management plans for large-scale areas.

Hedonic travel cost methods assume forest user's choices are based on (1) the costs of the trip or destination and (2) the amenity attributes of the trip or destination. This method determines use values only and has been applied to hunting (Brown and Mendelsohn 1984), fishing (Smith et al. 1991), wilderness use (Haefele et al. 1991) and others. These studies use a two-step procedure, first, to determine the values of the attributes and second, to estimate a demand curve for these values. The demand curve is important if inferences need to be made regarding a change in either the travel costs or the site qualities.

The hedonic method, also a revealed preference method, was first given a theoretical foundation by Sherwin Rosen in 1974. This method assumes a market

equilibrium for a bundled good wherein both buyers and sellers maximize their utility or profit functions, leading to an equilibrium hedonic price for each attribute of the bundled good. Literature on the hedonic method, as well as limitations and advantages of the method are summarized in Palmquist (1991).

Consumers or buyers are assumed to maximize utility, subject to a budget constraint. A bid function is used to represent a buyer's choices for characteristics of the bundled good. An optimizing consumer will equate the marginal bid for a characteristic with the marginal market price of the characteristic. Producers of the bundled good are assumed to maximize profit, subject to technology and input prices. The optimizing producer equates the marginal market price of a characteristic with the marginal cost of producing that characteristic. When opportunities for arbitrage have been exhausted, a market equilibrium is reached. This model has also been extended to incorporate differentiated factors of production, such as labor and land (Palmquist 1989).

Issues and topics raised by Palmquist (1991) include (1) costless repackaging and linear hedonic price schedules, (2) achieving market equilibrium, (3) adequate variation in the characteristics, and (4) data errors. The relationship between these issues and forestland valuation is discussed below.

In evaluating either a traditional hedonic model using timberland sales prices or the first order condition model using opportunity cost, forests clearly cannot be costless repackaged. In order to change attributes of the forest a landowner must usually wait for nature to make the changes. Some changes can be encouraged, through thinning or clearing, but most changes will take some time. Some will also require active

intervention by the landowner. The implication is that the hedonic price function should not be constrained to be linear.

Questions have been raised regarding the assumption that markets reach equilibrium. Factors such as transactions costs or moving costs can be considerable and could preclude equilibrium. Of particular importance in forestry is the cost of attaining information about timber sales and the cost of making an actual sale. Because timber sales on a particular stand occur infrequently, many landowners will have had little or no prior experience in the timber market. Timber buyers, on the other hand, will have access to market information. The resulting asymmetry could impede equilibrium.

Adequate variation in the characteristics is necessary to ensure continuous bid and offer functions. This variation is clearly available in forest stands, although, at any one time, the complete range of forest characteristics is unlikely to be available for purchase. Data errors (Epple 1987) could be significant in evaluating hedonic prices of timberland. The assumed presence of asymmetric information, lack of site-specific revenue data and incomplete landowner characterization could result in data error. These issues are not confined to the use of the hedonic model, however, but will affect any modeling of individual landowner behavior given the available data sources.

II. NONINDUSTRIAL PRIVATE FOREST MANAGEMENT

As discussed in the literature review, the Faustmann model (equation 1) is the theoretically correct and accepted model for determining the optimal age of harvesting of an even-aged stand under conditions of perfect information, no risk, and steady state and assuming the landowner's objective is to maximize an infinite stream of profits from the forestland. This model, however, is unlikely to accurately describe the behavior of NIPF landowners because it does not include the nonmarket and amenity values of owning forestland.

Stand-level management for a utility maximizing landowner, where the standing forest has value, can be characterized by the Hartman model (1976). This model, an extension of the Faustmann model, also maximizes the wealth of a forest, although in this model the land wealth is the sum of future discounted benefits from the forest including both market and nonmarket benefits. The Hartman and Faustmann models derive the value of land based on an infinite series of identical rotations. The models are steady-state models where timber yields, prices, costs and interest rates are assumed constant and known with certainty. The Hartman model, shown in equation 3, assumes that timber is the only income-producing forest output and all nonmarket outputs are represented by the function $A(x)$. HLV is the Hartman land value.

$$HLV = \max_T \frac{PQ(T)e^{-rT}}{1-e^{-rT}} + \frac{\int_0^T A(x)e^{-rx}dx}{1-e^{-rT}} \quad (3)$$

Thus, a landowner maximizes the sum of an infinite series of timber rotations plus the infinite series of benefits from the nonmarket benefit function $A(x)$. Nonmarket benefits are produced throughout the rotation although in varying amounts as a stand develops, so the benefit function is integrated from stand origin to harvest age (T).

Hartman's normative analysis showed that longer rotations may be optimal in the presence of nontimber attributes. (This was also shown by Calish et al. in 1978 and again by Plantinga and Birdsey in 1996). If these attributes increase with rotation length, then the Hartman rotation will always be longer than the optimal timber-only rotation. Hartman also notes that it may be optimal to never harvest some stands with high nontimber values. His analysis originally applied only to public land management, but clearly the model is appropriate for private lands as well.

Forestland markets will have incorporated other values, such as zoning regulations, school districts and tax systems that do not influence the amenity values of forests. Market land values will also reflect amenity values that are not affected by forest management decisions. These values may include proximity to resorts, lakeshore or beach access. In these cases, the Hartman land value (equation 3) would not be equal to the sales price of timberland unless the equation is modified to include these attributes.

These location and other values are unlikely to be influenced by the harvest decision nor would the harvest decision influence these values, although some interaction is possible. For example, a lakeshore tract may be more valuable with standing timber than the sum of the value of the lakeshore without timber plus the timber value. However, I assume there are no interactions of this type, and thus the timber harvest decisions are not influenced by these other values.

Public values of private land attributes, such as clean air and water services, scenery and wildlife habitat could be an important component of the nonmarket value of private forestland. In particular, these values are of considerable importance in measuring economic sustainability and in natural resource accounting. But unless these values are incorporated into the equilibrium market value of forest land by the buyers and sellers of such land, these values will not be observable in private land markets. In this case it would be necessary to use other methods, such as stated preference models, to elicit these values. If one believed in a rational political process and an unbiased institutional implementation of policy, then the management of National Forest System lands could be used to discern these values.

While the Hartman model may be more suitable in characterizing NIPF land management than the profit-maximizing wealth model of Faustmann, there are significant impediments to using this type of model, including capital constraints ("Volvo harvests"), inadequate information, and risk and uncertainty. The term "Volvo harvest" was coined by Johansson and Lofgren (1985) to describe NIPF landowners who harvest when they need an infusion of cash to pay for a large purchase such as a car or college or a boat.

Thus the forest is being used as a savings account, and management behavior may not be related to on-the-ground forest characteristics. The second issue is that landowners do not realize how much money they could be making from their timber. Because participation in the timber market is infrequent, there is clearly an effort required to sell timber that may not be present in selling other goods and information may not be symmetric between timber buyers and sellers. Finally, the Hartman model assumes perfect knowledge of future prices and costs, and assumes certainty in timber yield information. Management behavior is likely different when actual expectations and damage risks are incorporated.

Empirical tests of the Hartman model have been limited because data on landowner values and forest land attributes are generally unavailable. Even after making the above assumptions required by the Hartman model, the hedonic model is of little use because accurate and detailed forest land sales data are unavailable. It is possible to get sales data, and in some cases detailed information on timber volumes is available from the consulting forester. These records, however, do not include information on amenity or nonmarket characteristics of the land. Also, unless the timber is harvested immediately before or after the sale, it is not possible to determine buyers' values for amenities as distinct from the values for timber.

Detailed information is, however, available on harvest volumes, ages, amenity characteristics and standing timber volumes from the USDA Forest Service Forest Inventory. Thus, I use landowner decisions to harvest or not harvest timber as market

behavior and the opportunity cost of not harvesting at the Faustmann-optimal-rotation as the market value of amenity characteristics in the stand.

For a given stand, a delay in harvest beyond the Faustmann optimal rotation results in an opportunity cost to the landowner. The perfectly informed landowner will then decide to harvest when the marginal opportunity cost of the delay in harvest is equal to whatever he or she derives from the delay in harvest, the marginal benefits. The first order condition with respect to T results in

$$\frac{\partial HLV}{\partial T} = 0 \tag{4}$$

$$r(PQ + HLV(T)) = A(T) + PQ_T$$

where the left-hand side of (4) represents the marginal cost and the right-hand side the marginal benefits of waiting another year to harvest the standing timber. The amenity benefits at the current age are represented by A(T), the marginal benefit of the current timber stand is represented by price (P) times the marginal timber growth (Q_T). The marginal cost includes the stand rent (rPQ) and the land rent (rHLV(T)). In the Hartman solution, the benefits are recreational, or more broadly, amenity, derived from the standing forest. This model provides testable hypotheses which can be addressed with available data by assuming that landowners maximize the wealth of utility.

Because the estimation of an infinite series of amenity benefits was not possible at this time, a second behavioral model was developed. In this model, the landowner is assumed to maximize the sum of the infinite stream of timber revenues plus the amenity benefits that occur in the current rotation.

$$MLV = \max_T \frac{PQ(T)e^{-rT}}{1-e^{-rT}} + \int_0^T A(x)e^{-rx}dx \quad (5)$$

The model implies that landowners value revenues from beyond their lifetimes but only value amenities from the current rotation. The assumption is that amenity values are individually held values and future benefits and costs may not have been fully capitalized into the value of the land, while timber revenues are commonly held values and have been capitalized. The first order condition with respect to time results in:

$$\frac{\partial MLV}{\partial T} = 0$$

$$PQ_T + A(T) = r(PQ(T) + \frac{PQ(T)e^{-rT}}{1-e^{-rT}}) \quad (6)$$

This sets the marginal timber and amenity benefits of harvest delay equal to the marginal timber cost of harvest delay. The missing factor, relative to the first order condition in equation 3, is the cost to amenity values of a delay in harvest. The infinite rotation cost for a Faustmann solution is small in most real world applications, and with the longer rotations of the Hartman solution, this amenity rent cost is likely to be quite small.

The model includes both market and amenity measures. Market measures are represented by timber outputs, which include softwood and hardwood sawtimber and pulpwood, and softwood chip-and-saw. The amenity measures include scenic quality, nongame wildlife habitat, tree diversity, presence of large trees and deer habitat. Under the assumption that amenities generally increase with the age of the stand, their presence

will delay the harvest of the timber. Premerchantable stands do provide significant wildlife habitat but in this model I make the assumption that the quality of all amenity characteristics improves as the stand ages. Thus, information on harvest age and forest characteristics prior to harvest can provide information on the tradeoffs landowners make between timber income and nonmarket attributes of the stand.

The estimated equation is:

$$r(PQ(T) + \frac{PQ(T)e^{-rT}}{1 - e^{-rT}}) - PQ_T = f(\text{forest characteristics}) = A(T) \quad (7)$$

In further discussion of this model, the left-hand side, which is a calculated value, will be referred to as the marginal opportunity cost of timber (MOCT).

This model assumes a landowner makes a decision each year using a deterministic model and there is no dynamic optimization involved. I am also assuming that an landowner variation in preferences and discount rates will be incorporated into the error term of the estimated model. All variation in modeling the choice of harvest dates derives from differences in the land. If one believes that landowners make a free choice in owning land of a particular type, then the land should reflect landowner differences. For example, a profit-maximizing NIPF landowner is more likely to own a pine plantation than a scenic mountain hardwood site. Thus, including land management variables such as plantations and distance to roads will account for these differences in landowners. Also, by including only farmer and other private landowners, the model will isolate only those landowners likely to have alternative management objectives.

III. THE ECONOMETRIC MODEL

The equation of interest is the hedonic equation (equation 7), where the marginal opportunity cost of timber (MOCT) is regressed on the amenity characteristics to determine a value for each characteristic. However, because marginal opportunity cost can only be observed when a harvest has occurred, i.e., when the first order conditions equal zero, this equation can be estimated only for landowners who have already harvested their timber. Thus, plots were included in the amenity value regression only if the landowner harvested during the survey cycle. Because the lack of amenity values on site may contribute to the decision to harvest, there is a possibility that the coefficient estimates (the hedonic prices) will be biased. This is an example of incidental truncation where the sample of amenity values is incidentally truncated by landowner decisions not to harvest. Sample selection bias is treated by using Heckman's two step correction method (Heckman 1979) and testing the hypothesis that sample selection bias exists in the amenity values regression.

Let the ordinary least squares model of the hedonic regression be

$$MOCT_i = \beta'x_i + \epsilon_i \quad (8)$$

Observations are included in the hedonic regression only if a harvest has occurred, thus harvesting is the selection mechanism. Harvesting occurs when the total benefits of

harvesting are greater than the landowner's reservation value for harvesting. Assume that landowners harvest if the marginal benefits of waiting are less than the marginal costs. Accordingly, harvest occurs if marginal costs less marginal benefits is greater than or equal to zero. Let Y_i^* represent the landowner's harvest decision where the landowner harvests if Y_i^* is greater than or equal to zero and does not harvest if Y_i^* is less than zero. The harvesting decision is defined b

$$Y_i^* = \gamma'w_i + u_i \quad (9)$$

where the w_i represent factors influencing the harvest decision.

The ordinary least squares regression of the hedonic model, which includes only plots that have been harvested, will lead to biased, inefficient and inconsistent estimates of the coefficients if landowners selected their way into the sample (by harvesting) and this decision is not accounted for in the estimation. The effect on the coefficient estimate is similar to the effect of omitting a variable that is correlated with variables included in the regression, i.e., the expected value of the MOCT will include an additional term.

$$\begin{aligned} E[MOCT_i | MOCT_i \text{ is observed}] &= E[MOCT_i | Y_i^* > 0] \\ &= E[MOCT_i | u_i > -\gamma'w_i] \\ &= \beta'x_i + E[\epsilon_i | u_i > -\gamma'w_i] \end{aligned} \quad (10)$$

where $E[\epsilon_i | u_i > \gamma'w_i]$ is not equal to zero, which is unlike the assumption in the classical regression model.

The error terms in the expectation, ϵ and u , are defined by a truncated joint density function

$$f(\epsilon, u | u > -\gamma'w) = \frac{f(\epsilon, u)}{\text{prob}(u > -\gamma'w)} \quad (11)$$

where $f(\epsilon, u)$ is bivariate normal,

$$f(\epsilon, u) \sim N(0, 0, \sigma_\epsilon, \sigma_u, \rho) \quad (12)$$

σ_ϵ and σ_u are the standard deviations of ϵ and u , and ρ is the correlation between ϵ and u . In the calculation of ρ from a finite sample, the value can be outside the -1 to 1 interval, and thus must be restricted to this interval in subsequent calculations. According to Greene (1995) this can represent a serious problem if the resulting standard error is negative.

To get the expectation of a jointly distributed variable, the marginal density of ϵ is needed, which can be obtained by integrating u out of equation 11. This results in

$$E[\epsilon | u > -\gamma'w] = \mu_\epsilon + \frac{\sigma_{\epsilon u}}{\sigma_u} \frac{\varphi\left(\frac{-\gamma'w - \mu_u}{\sigma_u}\right)}{1 - \Phi\left(\frac{-\gamma'w - \mu_u}{\sigma_u}\right)} \quad (13)$$

where the mean of ϵ and u are both zero,

$$\rho = \frac{\sigma_{\epsilon u}}{\sigma_\epsilon \sigma_u}, \quad (14)$$

$\phi(-\gamma'w) = \phi(\gamma'w)$, and $1-\Phi(-\gamma'w) = \Phi(\gamma'w)$ by symmetry of the normal distribution, so equation 10 can be rewritten as

$$E[MOCT|Y_i^* > 0] = \beta'x + \rho\sigma_\epsilon \frac{\phi(\frac{\gamma'w}{\sigma_u})}{\Phi(\frac{\gamma'w}{\sigma_u})}. \quad (15)$$

Letting λ represent ϕ/Φ , and β_λ represent $\rho\sigma_\epsilon$, the estimated equation would be

$$MOCT_i = \beta'x_i + \beta_\lambda \lambda + v_i \quad (16)$$

To estimate this equation and test for the significance of β_λ and sample selection bias, an estimate of λ , which is also referred to as the Inverse of the Mills Ratio (IMR), must be made. Heckmans' two step method is used to develop these estimates:

(1) Estimate the selection equation -- using a probit model. Use coefficients from this regression to calculate λ_i . Using the estimated coefficients and variables, $\gamma'w_i$ is calculated for each observation. The IMR estimate for each observation is calculated as the probability distribution function of $\gamma'w_i$, divided by the cumulative distribution function of $\gamma'w_i$.

(2) Estimate the hedonic equation -- using λ_i as an additional variable.

III. A. THE SELECTION MODEL--ESTIMATING THE PROBABILITY OF HARVEST

This model addresses the landowner's decision to harvest their timber stand.

Landowners are assumed to harvest if the marginal costs of delaying harvest are greater than or equal to the marginal benefits of delaying harvest. Although Y_i^* , the difference between marginal cost and benefit, is observed only for those stands that are harvested, a qualitative variable, Y_i , is observed for all stands, where

$$\begin{aligned} Y_i &= 1 \text{ if } Y_i^* > 0 \\ Y_i &= 0 \text{ if } Y_i^* < 0 \end{aligned} \tag{17}$$

The probability of harvest can be determined by:

$$\begin{aligned} \text{Prob}(\text{harvest}) &= \text{Prob}(Y_i^* > 0) \\ &= \text{Prob}(Y_i = 1) \\ &= \text{Prob}(u_i > -\gamma'w_i) \\ &= 1 - F(-\gamma'w_i) \end{aligned}$$

where $F(-\gamma'w)$ is the cumulative distribution function. Assuming the error is normal distributed, a probit model is used and the model is estimated using maximum likelihood. Model significance tests (χ^2) and significance tests on right-hand side variables (z-tests) will be conducted.

The variance of the estimation is calculated from the information matrix using the method of Berndt, Hall, Hall and Hausman (Greene 1993). The resulting standard errors

are used in calculating the z-statistic for testing the significance of the individual coefficients.

Because the probit model is nonlinear, the coefficients do not represent the marginal effect of a change in the independent variables on the probability of harvest. The marginal effects are calculated as:

$$\frac{\partial P(Y=1)}{\partial w_k} = \phi(\gamma'w) * \gamma_k \quad (18)$$

where ϕ is evaluated at the means of the right hand side variables. Strictly speaking, the marginal effects from the dummy variables must be calculated by using a zero or one value rather than the mean in the above formulation. The significance of the marginal effects are evaluated using the standard errors calculated by linear approximation of the asymptotic variance as derived in Greene (1993). The resulting z-values, and thus significance levels, will be the same as for the coefficients.

While this equation is interesting in itself, and will be discussed in detail in the results section, its primary purpose in this analysis is to provide coefficients for use in calculating the IMR for use in the amenity values regression.

III.B. AMENITY VALUES REGRESSION -- ESTIMATING HEDONIC PRICES

The amenity values regression, equation 7, is the hedonic model, where the left hand side represents the marginal opportunity cost of timber (the marginal costs to timber

of waiting another year less the marginal benefits to timber of waiting another year to harvest). The right hand side variables are the quantities of the characteristics (x's) that are hypothesized to have positive amenity values and the selection variable, λ . The regression equation provides estimates of marginal prices for these characteristics and a test for significance of sample selection bias.

The estimated regression is:

$$MOCT = b'x_i + b_\lambda \hat{\lambda}_i + v_i \quad (19)$$

where $\hat{\lambda}$ is the calculated variable from the selection (probit) regression.

The coefficients from the selection model are $\hat{\phi}$, so $\hat{\lambda}$, the Inverse Mills Ratio (IMR), is estimated as

$$\hat{\lambda} = \frac{\varphi(\hat{\gamma}'w_i)}{\Phi(\hat{\gamma}'w_i)} \quad (20)$$

where w_i are the variables used in the selection regression. The probit model does not allow estimation of σ_u separately from the coefficient vector, thus σ_u is assumed to be equal to one.¹

The null hypothesis for the sample selection variable (λ) is $H_0 : \beta_\lambda = 0$. If the null hypothesis is not rejected, then the OLS estimates are unbiased and efficient. This means that there is no correlation between the decision to harvest and the marginal opportunit

¹ Although I assumed errors were normally distributed, simulations and other studies have shown that the estimation results are quite sensitive to this assumption (e.g., Lee 1983). This is an area for future study--at this time I confine the estimations to the two-step Heckman model as he described it.

cost of timber. If, however, the null hypothesis is rejected, then the OLS estimates would be biased and λ can be thought of as an omitted variable with the appropriate correction as noted above. In addition, the estimated coefficients will be inefficient, due to the inclusion of an estimated variable as a regressor.

Including the IMR corrects for the incidental truncation of amenity values caused by landowners decisions not to harvest. The coefficient on the IMR, β_λ , indicates whether the truncated mean is less than (coefficient is negative) or greater than (coefficient is positive) than the true mean. For example, if the coefficient is negative, then the correlation between amenity values and harvest decisions is negative and the estimated mean amenity value is less than the true mean amenity value.

In estimating equation (20), there are two complications to estimating the variance-covariance matrix. First, the variance is heteroskedastic because the variance is not constant across observations but is instead a function of the observations themselves. Assuming the values for λ were known, the heteroskedasticity is reflected in:

$$Var(v_i) = \sigma_\epsilon^2 (1 - \rho^2 (\lambda_i^2 + \alpha \lambda_i)) \quad (21)$$

Second, because the value of λ is not known but is estimated using the same parameters (γ) for all observations, a further source of correlation across observations is introduced into the variance. Thus, the standard errors must be recomputed. Greene (1993) provides the formula for correction (page 713) and implements the correction in the LIMDEP program selection module (Greene 1995).

As in the selection estimation, the hedonic regression is nonlinear, in this case due to the inclusion of λ . Thus, the marginal effect of a change in an independent variable on the marginal opportunity cost includes more than just the coefficient.

$$\frac{\partial MOCT}{\partial x_{ik}} = \beta_k - \rho \sigma_\epsilon \frac{\gamma_k}{\sigma_u} (\lambda_i^2 + |\alpha| \lambda_i) \quad (22)$$

The estimated values for the coefficients, standard errors, λ , α , and ρ would be used to calculate this derivative.

The marginal effects are the marginal hedonic prices I am seeking through this regression. The hedonic prices will be positive only when

$$\begin{aligned} (1) \beta_k > 0, \rho < 0, \gamma_k > 0 \\ (2) \beta_k > 0, \rho > 0, \gamma_k < 0 \end{aligned} \quad (23)$$

In other cases, the hedonic price will be negative or will be determined by the complete calculation of the marginal effect. The determination of whether prices are increasing at an increasing rate can be made only after complete calculation of the marginal effects, except in the case of (2) in equation 23.

IV. DATA AND HYPOTHESES

The primary data used in this analysis were obtained from USDA Forest Service plot surveys and from Timber Mart South price surveys. Because neither the timber value nor the amenity index data are collected directly, these values were calculated from the primary data as discussed below.

IV. A. PRIMARY DATA

IV.A.1. USDA Forest Service Forest Inventory Surveys

The data used for this study are from North Carolina, specifically from the Fifth (1983-1984) and Sixth (1989-1990) forest inventory surveys conducted by the Southern Research Station, USDA Forest Service. The survey plots are randomly located, and the forested plots are field measured for tree species and volume, as well as management and other site characteristics. Each plot consists of a plot center and several plot points. When one or more of the plot points are affected by management that does not affect all plot points, the affected points are moved in the subsequent survey. For statistical accuracy, I excluded all plots in which points had moved because of management changes. A total of 4409 forested plots were included from the Fifth survey, of which 1304 were farmer-owned plots and 1490 were other private owned. Corporate and leased

plots were not included in this analysis because management of these plots is assumed to be more consistent with profit maximization.

Using standard forest measurement techniques, the volume, diameter, height and quality of each tree is recorded. These values are then ‘expanded’ to a per acre level by estimating the number of trees per acre of this type and size. Site characteristics such as size, shape, accessibility, etc. are also observed. Limited data are available about landowners--the landowner is classified as public agency, farmer, corporate, forest industry, leased to industry, or other private. In recent years, more diverse forest measures were included in the surveys such as distance to water, evidence of recreation or grazing uses, suitability for wildlife habitat and other vegetation and biomass information.

The timber data are separated into five product classes based on diameter of the tree and species class (hardwood or softwood). For softwoods, five to nine inches is pulpwood, nine to eleven is chip-and-saw and greater than eleven is sawtimber. Different prices are associated with each product class. For hardwoods, five to eleven inches is pulpwood and greater than eleven is sawtimber. The product classes were assigned based on diameters in the Fifth survey, and were maintained into the Sixth survey because I did not find evidence that trees had progressed into a larger product category over the 6-7 year time frame.

The timber survey also includes an estimate of the harvest date for each harvested plot. Because the survey may occur up to 7 years after harvest, these estimates are most reliable for recently harvested plots. These estimates, combined with the stand age from

the previous survey provide a stand age at harvest for use in calculating the marginal benefits and costs from harvested stands.

IV. A. 2. Prices

Price data is taken from the monthly and quarterly surveys of Timber Mart South. These data are available for three regions in North Carolina, the mountains, piedmont and coastal plain. The annual average for each of the regions was used for years 1984 to 1990 for each of the five product classes. For some observations, there is no chip-and-saw price and the pulpwood price is used in its place.

These prices are stumpage prices, the price paid to the timber owner. By applying these prices to the precise mix of products and species on each plot, a value of plot-specific timber resources is obtained. However, two other factors could significantly affect a landowner's received stumpage price -- harvesting costs and transportation costs. Stumpage prices are net of harvesting and transportation costs, but application of average stumpage prices then assumes that these costs are identical for all harvested plots. Road transportation distances from plot to mill are not readily available, thus adjustments were made to stumpage prices to account only for unusually high or low harvesting costs. These adjustments are discussed below. The information available can be used to determine if the stand level harvesting costs would be more or less than the average thus providing a more site-specific estimate of stumpage price received.

The prices used in the estimation were 1984 for initial values, harvest year for harvested volumes and 1990 for terminal values of nonharvested plots. This assumes that

landowners were aware of prices in each year and made an annual decision about whether to harvest or not. This could be (and in some cases was) a problem if prices rose and/or fell over the period. Alternative assumptions, however, also lead to problems. Using a mid-point price for all values (initial, terminal, and harvested) assumes that landowners who harvest before 1987 got the 1987 price, that landowners who harvested after got the 1987 price and that all landowners knew this price at the beginning of the period. Using the 1984 price for all timber values assumes that landowners made the decision to harvest at the beginning of the survey period and did not change their decision in the face of rising or falling prices. Using a cycle-average leads to the same imprecision that the mid-point price does.

Using equations of harvest costs developed for five different harvesting systems (Cubbage et al. 1989), the lowest cost system was selected for each plot. Harvesting costs are a function of percent hardwood, total plot volume, mean stand diameter, and harvested volume per acre. Although slope may also influence harvesting costs, it was not included in these equations as they were principally done for the coastal plain and piedmont areas of the Southeast. Thus, the slope effect is included separately in the analysis of harvest probabilities.

The minimum cost system was selected for each plot, including harvested and nonharvested plots. Then, using the minimum system cost for harvested plots only, calculated the average harvesting cost by region (coastal plain, piedmont, mountains). Assuming the average harvesting cost corresponds to the average stumpage price, I adjust the price per cubic foot on each plot by the difference between the calculated plot cost

and the average regional cost. All prices and costs are in real 1987 year dollars. Prices vary by year, but cost estimates are considered constant over the 7 years included in the study.

IV. B. ESTIMATING EQUATIONS AND VARIABLES

The estimating equations are

$$\begin{aligned} P(\text{harvest}) &= f(\text{timber values}, \text{site characteristics}, \text{amenity characteristics}) \\ \text{MOCT} &= f(\text{amenity characteristics}, \text{selection variable}) \end{aligned} \quad (24)$$

Timber values are the net revenues associated with the marginal costs or benefits of waiting another year to harvest. Site characteristics include slope, distance to roads, distance to water, distance to urban development, evidence of erosion, evidence of grazing and presence of good cover. Amenity characteristics include a tree diversity index, a scenic beauty estimator, deer and bird habitat indices, and presence of large trees. The dependent variable of the first equation is 0 if a harvest did not occur and 1 if a harvest did occur. The dependent variable of the second equation is the marginal opportunity cost of timber (MOCT). Calculating the MOCT and the timber values requires a discount rate, which is not known and which could have a substantial effect on the landowner's decisions. The estimation and choice of a discount rate are discussed later in this chapter.

IV. B. 1. Timber values and marginal opportunity costs.

The MOCT is observed only when a harvest has occurred, where the assumed first order conditions of the Hartman land value are set equal to zero. At other times in the rotation, the marginal returns to waiting exceed the marginal costs of waiting. The timber benefits and costs equal each other only at the optimal Faustmann rotation age. These values are discussed below and the averages for harvested and nonharvested plots are shown in table IV-1.

Table IV-1. Timber values and information for harvested and not harvested plots.

	Harvested Plots	Not Harvested Plots
Marginal Timber Costs (\$1987)	4.78	2.87
Marginal Timber Benefits (\$1987)	1.68	2.79
Marginal Opportunity Cost (\$1987)	44.62	11.27 ¹
Stand Age (years)	49.8	42.3
Standing Timber Value in 1984 (\$1987)	973	444

¹ This value represents marginal benefits less marginal costs, but is not strictly the marginal opportunity cost because the plots have not yet been harvested.

Standing timber volume at time t for plot i (Q_{it}) is determined by first merchandizing each sample tree (k) in the survey into a product class (j) then using the estimate of tree volume by product (q_{jk}) and the estimate of trees per acres (TPA_{ik}) for plot i and sample tree k :

$$Q_{ijt} = \sum_{k=1}^K q_{ijk} * TPA_{ik},$$

for all products, j
for all plots, i

(25)

Marginal timber benefits are calculated from the difference between the initial stand value at the time of the initial survey, 1984, (t=I) and the ending stand value, calculated at the time of the ending survey, 1990, or the year of harvest (t=E). The initial stand value at the beginning of the survey equals the initial volume by product (Q_{it}) times the cost-adjusted price for that product ($P_{ijt} - C_i$).

$$V_{it} = \sum_{j=1}^5 Q_{ijt} * (P_{ijt} - C_i)$$
(26)

The ending stand value for nonharvested plots is the sum of the ending product volume times the cost adjusted product revenue in that year. The harvested value is the sum of the product volumes harvested times the product revenues in the harvest year. All values are in constant 1987 dollars.

Marginal value growth is represented in the first order condition (equation 6) as PQ_T . With five product classes, however, the value growth is more correctly given as:

$$G_i = \sum_{j=1}^5 P_{ij} \frac{\partial Q_{ij}}{\partial t}$$
(27)

Theoretically, this quantity change would represent the change in product values anticipated over the next year. Although one years' growth is unlikely to move a tree into a new product class, the presence of distinct product classes with quite different prices is

an issue in calculating the optimal timber rotation. The possibility exists for several revenue maxima based on product type. The model used here evaluates an optimal solution as the maximum of this year or next, and thus does not ensure that the global optimal revenue maximum is obtained. For example, while a local optimum could be to harvest this year because revenues from pulpwood are higher this year than next year, the global solution might be to wait 15 years and harvest as sawtimber. There are also significant issues with “nonconvexities” in production of timber (and amenities) (Swallow et al. 1990) but these will not be addressed in this paper

Because subsequent growth rates are unknown and because only total growth over the period from the 1984 survey is available, I use an annual average of the growth from the initial volume to the ending or harvest volume. Thus, I am using the average of growth over the last one to six years to proxy for growth in the next year. This results in a linear growth curve--clearly inconsistent with the widely accepted logistic growth curve assumed for most trees. However, I am dealing with a relatively small portion of the total growth curve and a linear approximation seems appropriate. Simple regressions of growth on time for pine plantation and natural pine types (McClure and Knight 1984) confirm that growth is best described as linear with respect to time. Addition of quadratic terms did not improve the regression for the ages covered in the yield tables (ages 10 to 50).

To get an average annual marginal benefit, the difference between the ending value and the initial value is divided by the number of years of stand growth. This is approximately 6 years for all nonharvested stands (the period of time in years and

quarters from the initial survey to the terminal survey), and is the number of years from the initial survey to the estimated harvest date for harvested stands.

$$MTB_i = \frac{V_{it_E} - V_{it_I}}{E - I} \quad (28)$$

Note that harvest costs are assumed constant over the cycle, so these costs do not affect the marginal benefits. There are two possible realities that conflict with this assumption (1) costs are not constant due to price or technology changes and thus could influence harvest timing decisions and (2) stands could change enough over the cycle to influence costs (e.g., diameter growth). For the latter, the maximum cycle is 6.75 years, which is unlikely to lead to many diameter class changes in stands of merchantable age.

Marginal timber costs (MTC) represent, loosely, the cost of time or the rent on the existing stand plus the rent on future timber rotations.

$$MTC_i = r \left[V_{it_E} + \frac{V_{it_E} e^{-rt_E} - k}{1 - e^{-rt_E}} \right] \quad (29)$$

The marginal cost is based on timber values either from the year of harvest if the plot was harvested or from 1990 if the plot was not harvested. Planting costs (k) were used only for plots that were currently in pine plantations, assuming that the forest use will remain constant. Planting costs were held constant at \$150 in 1987 dollars for all regions. This is an average of Southwide planting costs (Lee et al. 1992).

Marginal opportunity cost of timber (MOCT), the left hand side of the hedonic regression, is the marginal cost less marginal benefits. This value is equal to the net amenity benefits only at the time of harvest, and in order to simplify the evaluation of the coefficients of the regression, the left hand side is modified as:

$$MOCT_i = (MTC_i - MTB_i)e^{rT_i^*} \quad (30)$$

IV. B. 2. Amenity Characteristics

For these characteristics, only the quantities need to be derived since the purpose of this estimation is to derive prices for these amenity attributes. Because most of the data are either in discrete measures or in complex estimates of cover, occupancy and species, I develop several indices to measure the nontimber amenity attributes. The formulas for these indices are taken from the literature on ecology, wildlife and scenic beauty. The averages for harvested and nonharvested plots are in table IV-2.

Table IV-2. Means of amenity characteristics for harvested and not harvested plots.

	Harvested Plots	Not Harvested Plots
Scenic Beauty Estimator	1.94	-4.05
Tree Diversity Index	1.98	1.94
Large Softwood Trees (#)	.69	.31
Large Hardwood Trees (#)	1.80	1.40
Wildlife Cover (0,1)	.93	.84
Deer Habitat Index (0-1)	.35	.34
Bird Habitat Indices (0-1)		
Prairie warbler	.06	.08
Downy woodpecker	.24	.16
Nuthatch	.01	.01
Pine warbler	.04	.04
Woodthrush	.07	.07
Red-eyed vireo	.02	.02
Pileated woodpecker	.05	.04

Scenic beauty: Scenic beauty is a characteristic of many forested areas, but is notoriously difficult to measure. Nonetheless, techniques have been developed to measure an index of scenic beauty based on subjective rankings of plot photographs (Brown and Daniel 1986). These rankings are then regressed on plot characteristics, resulting in coefficients that can be used with survey data to estimate a scenic beauty index. For this paper, I used the Rudis et al. (1988) index for southern pine stands. Although this may not be an accurate measure of the scenic beauty of non-pine stands, it is the only index estimate available that utilizes survey data. The scenic beauty estimator (SBE) is:

$$SBE = -13.56 + .38*SmSaw - .02*Saplings + .14*HWPole \quad (31)$$

where SmSaw is the number of small sawtimber sized trees per acre (11.0-20.9 inches dbh), Saplings represents the number of sapling sized trees per acre (1.0-4.9 inches dbh) and HWPole is the number of poletimber-sized hardwood trees per acre (5.0-10.9 inches dbh). The estimates for the North Carolina plots (-116 to 106) are within the range developed in the original paper (-125 to 104). The values are highest in the mountains and higher on harvested than on nonharvested sites. This is consistent with conventional wisdom that says the mountains are more scenic and older stands are more scenic. Note that the average age of harvested stands is nearly 50 years, while the average age of nonharvested stands is 42 (Table IV-1).

Tree diversity: The total value of biodiversity is a separate research topic with a growing literature (Gowdy 1997), so I focus on landowner values for the diversity of tree species only. I do not have adequate data on the diversity of shrubs, grasses, animals or insects on the sample plots to develop total vegetative biodiversity indices. Two of the most commonly used measures of diversity are the Shannon-Weiner (or Weaver) index (SW) and the Simpson's index (Barbour et al. 1980). The Simpson's index is a weighted average of the number of species per acre. SW is also a weighted average, but is intended to weight rarer species more heavily. Previous statistical tests of these indices reveal little difference in their characterization of actual forest stands (Swindel et al. 1989).

calculated the Simpson's and SW for the plots in my sample using both trees per acres

and basal area² values and found little difference in the plot level estimates. Thus, I use the only the SW index in the remainder of the analysis. The index is calculated as:

$$SW = \sum_{k=1}^K p_i * \log_2 p_i \quad (32)$$

where p_i is the proportion of total trees in species i .

Large trees: It is commonly presumed that large diameter trees, greater than 20 inches d.b.h., are highly desirable as amenities. This is part of the premise behind Hartman's original analysis as well as part of the presumed value of old-growth forests. In a study of valuation of wilderness attributes (using the hedonic travel cost method) Holmes et al. (1997) found that large trees were positively valued by wilderness visitors. Large trees, combined with little midstory and some understory would approximate the old growth forest that Hartman originally discussed in his work. Large trees also contribute to higher valued products, although this should be accounted for in the calculation of marginal timber values.

Presence of Cover: Most wildlife needs cover of some type, and this variable is used to represent the presence or absence of good cover. This is a subjective judgement made by the field survey crews based on their ability to see other crew members through the under- and mid-story vegetation. If wildlife is valued, cover should be desirable. However, the

² Basal area measures the square feet per acre of the cross-section of the standing timber.

presence of cover may also be indicative of a maturing stand, or possibly even one that has suffered some damage. In this case, cover would indicate a need for harvest.

Deer Habitat: White-tailed deer are ubiquitous in North Carolina, so maintaining deer habitat on an individual plot may have little impact on deer population in general or even on deer presence on that site. Further, there are complex spatial relationships in good deer habitat that cannot be adequately represented by stand level data or affected by stand level management, leading many wildlife biologists to reject the use of habitat suitability indices. However, there is no other method available for estimating habitat quality on over 2500 plots throughout North Carolina. One further complication is that deer habitat, like other types of habitat, does not universally improve as a forested plot ages. Instead, habitat may be optimal at moderately young and moderately old stand ages where there is both adequate food and cover.

The deer habitat suitability index (HSI) used is based on Crawford and Marchinton (1989). The index is:

$$HSI = \frac{3(D1 \times D4)^{1/2} + (D2 \times D3^2)^{1/3}}{4} \times \frac{2(D5) + D6}{3} \quad (33)$$

where D1 and D4 are measures of winter forage available, D2 and D3 are measures of amount and quality of mast and D5 and D6 measure the accessibility of agricultural land. D2 through D5 are readily available from the survey data. The index for the volume of winter food (D1) had to be estimated using the best available alternatives. The index of D1 required lbs/acre of oven-dry weight of green herbaceous standing crop in winter. For

this analysis, D1 was calculated by using the percent of each acre occupied by evergreen browse within 10 feet of the ground and assuming that the maximum index value was reached at 50 percent of the average available on all forested plots. The HSI values for harvested and nonharvested sites are shown in Table IV-2.

Wild Bird Habitat: With the same concerns as noted for deer habitat indices, a set of indices were developed for six species of wild birds. These indices were developed by Sheffield (1982) specifically for use with FIA survey data. The average index values for the different categories are shown in Table IV-2.

Prairie warblers prefer early succession forests with lots of understory. Wood thrush habitats are the opposite, mature stands with light understory, preferring in particular hardwood forests over 75 years old. Pine warblers, as expected from the name, reside almost exclusively in pine forests. Thus, habitat for these birds improves with higher pine stocking and basal area stands with little understory, though habitat does not necessarily improve with age. The red-eyed vireo is the most tolerant of the species evaluated because it will accept many different habitats, though pure pine stands are not desirable for these birds. Old hardwood stands with higher stocking in the understory would be the best habitat for the vireo.

The pileated woodpecker also prefers mature forests, but moderately aged stands provide good habitat if some nest trees (dead or decayed trees) are available. Water must be nearby and the plot must be in a predominantly forested area. While pileateds are not edge preferring species, downy woodpeckers seem indifferent to edges and thus are found

frequently in yards and along roadsides. Downy woodpeckers moderately old stands, though they prefer younger stands than pileated woodpeckers. Thus, lower basal area and smaller trees are acceptable. The brown-headed nuthatch prefers mature pine forests with little understory. Fire seems to improve habitat for these nuthatches.

IV. B. 3. Site Characteristics

These are characteristics of the plot itself, generally not affected by the management of the forest. For example, the slope of a site or the distance to urbanization are not affected by the landowner’s decision to harvest, but may influence the decision to harvest. The averages of these characteristics by harvested and nonharvested plots are shown in Table IV-3.

Table IV-3. Means of site characteristics for harvested and not harvested plots.

	Harvested Plots	Not Harvested Plots
Slope (percent)	6.0	11.6
Distance to Roads (10 ft)	14.2	13.5
Erosion (0,1)	.03	.04
Presence of Grazing (0,1)	.03	.03
Distance to Urban(100 ft)	84.0	79.3

Slope: Slope has been found to be a reliable indicator of harvest in previous studies (Wear and Flamm 1993), with steep slopes tending to reduce the probability of disturbance. Disturbance in their model is used as a proxy for timber harvest. Turner et

al. (1996), showed that slope reduces the probability of transition from forest to nonforest. Stands with steeper slopes would be both more difficult and more expensive to harvest. It is also possible that steeper slopes have less desirable standing timber than flat or nearly flat sites. The inclusion of harvesting costs and timber values should account for the timber aspects of steeper slope sites, but will not fully account for increased harvesting or access costs.

Distance to roads: The distance to a usable road is recorded in tens of feet and is an estimate made by the field survey crew. Harvesting costs would be greater with greater distance to roads so this variable would be expected to reduce harvest. Wear and Flamm (1993) also evaluated distance to roads, in this case the distance was to paved roads as recorded on satellite imagery. The marginal effect was significant, with increasing distance reducing the probability of disturbance. Turner et al. (1996) found distance to roads insignificant in influencing transition out of forest cover.

Erosion: In an enlightened world, private landowners would be less likely to harvest on sites subject to serious erosion. This variable is a subjective judgement of the field crew, where a one represents the presence of erosion problems and a zero indicates no serious erosion problems.

Grazing: Field crews make a call regarding the presence or absence of grazing on a forested plot. Signs of grazing include fencing, tree damage, stock trails, cows, etc. It is

unknown what influence grazing would have on timber harvesting. Grazing represents an alternative, possibly coexistent use of the plot and could either extend or shorten a rotation.

Distance to urban development: This distance is also measured in hundreds of feet and is a judgement call by the field crew. Forestry, as a business, tends to be a rural occupation, and thus I would expect the probability of harvest to increase with increasing distance from urban development. Forestry is also at it's most profitable when practiced over large tracts of land (Cubbage 1983), effectively precluding nearby development of an type.

Distance to water: This variable is measured in hundreds of feet and represents the distance to water from the plot center. The presence of water could be an amenit attribute (though not affected by harvest) or it could represent an impediment to or increased cost of harvesting timber.

Plantation: This is a zero for plots that are naturally regenerated and a one for plantations. Plantations may be managed differently than other plots.

IV. C. HYPOTHESES

The a priori hypotheses for the coefficients of the two regression equations are shown in Table IV-4. Marginal timber cost and benefit are expected to positively and negatively affect harvest, respectively. The marginal cost of timber represents the cost of waiting another year to harvest and the probability of harvest should increase as the costs of waiting increase. The marginal benefit of timber is the benefit of waiting another year to harvest, and thus the probability of harvest should decrease as the benefits to waiting increase.

Table IV-4. A priori hypotheses.

	Selection regression-- Prob(Harvest)	Hedonic regression-- Opportunity Cost
Marginal Cost of Timber	+	
Marginal Benefit of Timber	-	
Slope	-	
Distance to Roads	-	
Distance to Water	?	
Erosion	-	
Grazing	?	
Plantation	+	
Distance to Urban	+	
Scenic Beauty	-	+
Tree diversity	-	+
Large Softwood Trees	-	+
Large Hardwood Trees	-	+
Deer Habitat	-	+
Bird Habitat		
Prairie Warbler	-	-
Pine Warbler	-	-
Nuthatch	-	+
Woodthrush	-	+
Red-eyed vireo	-	+
Pileated Woodpecker	-	+
Downy Woodpecker	-	+

IV. D. DISCOUNT RATE

The discount rate plays an important role in determining the value of capital goods and in forestry in determining the optimal rotation age. It is commonly assumed that the private rate is higher than the socially optimal rate (e.g., Weitzman 1994, Cubbage and Haynes 1988). There is also a considerable literature devoted to examining the rate of discount for public projects (Mikesell 1974). Office of Management and Budget direction has ranged from 2 percent to 10 percent for publicly funded projects. The current rate used by the USDA Forest Service is 4 percent.

Although a different rate may be appropriate for analysis of private landowner behavior, determining the correct rate is difficult. According to Fisher (1930) the rate of return for private forest land should be equal to the real interest rate. Samuelson in 1976 decried the use of low discount rates in forestry and roundly criticized forestry professional for their fears of compound interest. Just et al. (1984) contend that there are times when a positive (or nonzero) rate may be inappropriate for evaluating public resource related projects, for example in a no-growth economy where consumption by current and future generations is held in equal regard.

Evidence from landowner behavior studies is mixed regarding whether or not landowners respond to changes in the interest rate (deSteiguer 1983, Lee et al. 1992). Several studies have estimated an effective forestry discount rate using quite different methods. These analyses assumed perfect and certain markets and assumed that landowners managed according to the Faustmann model. Berck (1981), after adjusting

for the then-extant capital gains tax rate, estimated a discount rate of 7 percent for private landowners. His concern with the pretax rate of 4.5 percent was that it was unreasonably low. After applying a 4 percent rate to individual stand decisions and then solving for the aggregate net rate of return by owner group, Wear (1994) estimated a real rate of 2.3 percent for industrial landowners and 1.8 percent for NIPF owners. Zinkhan (1988) estimated a 4.3 percent discount rate for southern timberland projects. This value was derived using an estimated industry beta, the expected market premium and the T-bill rate at the time.

The method of deducing an effective discount rate seems appropriate for landowners who are, in fact, profit maximizers. These groups include forest industry owners and possibly, forest plantation owners. This rate should equal the expected market rate that would apply to land valued not for timber, but for amenities. Previous research shows that these estimated rates are higher than the estimated rate for other private landowners, but I contend that this results from applying an inappropriate model (profit maximization) to utility maximizing landowners.

With price, quantity, growth, costs and rotation age fixed, I show below that an estimate of r using Faustmann when the true model is Hartman will consistently underestimate the discount rate. The hypothesis to be tested here is:

$$H_o: \text{if } A(t) > 0 \text{ but we assume } A(t) = 0, \text{ then } \hat{r} < r. \quad (34)$$

where the true model is Hartman (using r) but the assumed model is Faustmann (using \hat{r}).

The true model is:

$$MLV = \frac{PQ(T)e^{-rT}}{1 - e^{-rT}} + \int_{x=0}^T A(x)e^{-rx} dx \quad (35)$$

The assumed model is:

$$SEV = \frac{PQ(T)e^{-\hat{r}T}}{1 - e^{-\hat{r}T}} \quad (36)$$

When analyzing harvesting behavior for estimating a discount rate, the behavior can be framed in terms of the first order conditions (FOC), where the first derivative with respect to time (t) is set equal to 0. Because both of these models use the same data for all harvested plots, rearranging both FOC so that PQ_T/PQ is on the right hand side will allow us to demonstrate that an estimated discount rate from the Faustmann model must be greater than the true rate from the Hartman model. For the true model (equation 35), the FOC with respect to time are:

$$\frac{\partial MLV}{\partial T} = PQ_T - r(PQ + SEV(r)) + A(T) = 0 \quad (37)$$

The assumed, or modeled, FOC with respect to time are:

$$\frac{\partial SEV}{\partial T} = PQ_T - \hat{r}(PQ + SEV(\hat{r})) = 0 \quad (38)$$

Solving equation 37 for PQ_T/PQ results in:

$$\frac{PQ_T}{PQ} = \frac{r}{1 - e^{-rT}} - \frac{A(T)}{PQ} \quad (39)$$

and for equation 38:

$$\frac{PQ_T}{PQ} = \frac{\hat{r}}{1 - e^{-\hat{r}T}} \quad (40)$$

Because both of these models are estimated from the same data, the left hand side of equations 39 and 40 are equal. Thus, since PQ and A(t) are greater than zero by assumption, it must be true that:

$$\frac{r}{1 - e^{-rt}} > \frac{\hat{r}}{1 - e^{-\hat{r}t}} \quad (41)$$

which happens only if $\hat{r} < r$. This result also holds true when there are planting costs and/or annual costs. Thus, the estimated rate for a Hartman maximizer using a model of Faustmann maximization will be lower than the actual rate.

Assuming all landowners have the same discount rate, then the discount rate for the (assumed) true Faustmann maximizers, such as forest industry owners, can be estimated. This rate would then be applied to other landowners. A second alternative is to assume that pine plantations are more likely to be owned by profit maximizers than by utility maximizers. The estimated discount rate for plantations would then be applied to natural stand management. The estimated rate (using the Faustmann model) for other private owners, and in particular, non-plantation owners, is hypothesized to be considerably lower than the estimated rate for true Faustmann maximizers (i.e., plantation owners or forestry industry owners).

Using the plot level data and adjusted regional prices, an effective discount rate is deduced by assuming the landowner's objective is to maximize profits. Given harvest

age, volume, price and owner class, nonlinear least squares is used to estimate the discount rate in the first order condition (equation 38).

The results of these estimations are in Table IV-5. The estimate of the discount rate is significant for all three ownership groups. For the owners deemed to be most Faustmann-like, forest industry, the effective rate was estimated at 4.1 percent, while the rate for the owners assumed to be least Faustmann-like was 2.9 percent.

Table IV-5. Estimates of effective discount rates by landowner group.

Owner Group	Estimated discount rate	t-value	R-squared
Public	.027*	2.49	-.15
Forest Industry(1)	.041*	10.82	.01
Other Private(2)	.029*	15.08	.04

* indicates significance at the .05 level

(1) Forest industry includes forest industry owned land, leased land, and corporate ownerships.

(2) Other private includes farmer and all other nonindustrial private owners.

Table IV-6 has the estimates for the planted and natural stands. The estimate for planted stands is significant, as is the model itself, with the model explaining 67 percent of the variation in the data. The effective discount rate was 6.2 percent. For the natural stands, the effective rate was 2.9 percent. Note that the rate for natural stands is the same as the rate for other private owners. The assumption here is that owners of planted stands, whether industrial or nonindustrial, have an ownership objective of maximizing

profits, while the owners of natural stands have alternative objectives, including valuing forest amenities. The contribution of on-site amenities is tested in the next section.

Table IV-6. Estimates of effective discount rates by management type.

Management Type	Estimated discount rate	t-value	R-squared
Planted stands	.061*	19.20	.67
Natural stands	.029*	10.58	.03

* indicates significance at the .05 level.

Based on these regressions, I conclude that private landowners' real discount rate is between 4 and 6 percent, and that the lower estimates for some owner or management groups reflect nonmarket values of standing forests rather than different time preferences. The analysis that follows uses a rate of 6 percent, with sensitivity analysis conducted at the 3, 5 and 7 percent levels.

V. THE RESULTS

The estimates of the sample selection model of amenity values on amenity quantities at a real discount rate of 6 percent are presented in tables V-1 and V-2 below. Sensitivity analysis using alternative discount rates is included in section V.C. The regression models were both significant and the hypothesis of no selection was rejected. Thus, the sample selection variable is used in the final model presented in table V-2.

V.A. PROBABILITY OF HARVEST -- THE SELECTION MODE

The data were significant in predicting the probability of harvest and the model itself was significant at the .05 level (table V-1). Overall, the model correctly predicted harvest/no harvest on 89 percent of the plots. The model predicted only 6 plots as harvested using an ad hoc probability cut-off of .50. Note that the probit model solved using maximum likelihood is not designed to correctly predict observations, in particular in the situation where only 11 percent of the observations were harvested.

Many of the site, economic and amenity variables were significantly different from zero. Because the probit model is nonlinear, the marginal effect of a change in a variable on the probability of harvest are not captured solely by the coefficient. The

equation for the marginal effects is shown in equation 19 and the calculated effects are shown in table V-1.

The significance and sign on the marginal timber benefit and cost variables do not reject the hypothesis that NIPF landowners are Faustmann optimizers. While some site characteristics are significant, most of the amenity characteristics are not significant in predicting the probability of harvest. The specific variables are discussed below.

Slope: The results indicate that an increase in slope percentage reduces the probability of harvest. Increasing slope by 10 percent leads to a 2 percent reduction in the probability of harvest. Slope can increase harvest, access and transportation costs in ways that were not included in the model, thereby reducing the probability of harvest by increasing costs. Slope may also serve as a proxy for more desirable, mountainous locations. It is not known if amenity or cost considerations lead to the reduced probability of harvest.

Distance to Water: Proximity to water could be viewed as either an amenity asset or as an increase in timber harvesting costs, both of which would reduce the probability of harvest. The coefficient and marginal effect are significant and positive, indicating that sites farther from water are harvested earlier. An increase of 100 feet from water increases the probability of harvest by .07 percent. It is not known whether this significance results from the positive amenity value of water or from the additional harvest and access costs of sites near water.

Table V-1. Results of regression of the probability of harvest on site, economic and amenity variables.

Variable	Coefficient	Standard Error of the Coefficient	Marginal Effect	Standard Error of the Marginal Effect
Constant	-2.0780	.1870	-.3290	.029
Slope	-.0140*	.0030	-.002*	.0004
Distance to water	.0040*	.0010	.0007*	.0002
Marginal Benefits	-.0538*	.0114	-.0085*	.0018
Marginal Costs	.0399*	.0060	.0063*	.0009
Plantation	-.0398	.3571	-.0630	.0562
Erosion	-.0357	.1822	-.0057	.0289
Cover	.3962*	.1169	.0628*	.0183
Tree diversity	.0809**	.0495	.0128**	.0078
Large Softwoods	.0278**	.0166	.0044**	.0026
Grazing	.0929	.2038	.0147	.0323
Large Hardwoods	.0076	.0094	.0012	.0015
SBE	.0039*	.0015	.0062*	.0024
Distance to Roads	.0013	.0025	.0021	.0040
Distance to Urban	.0022*	.0010	.0004*	.0002
Prairie Warbler	-.2261***	.1746	-.0358***	.0276
Downy Woodpecker	.3626*	.1297	.0574*	.0205
Nuthatch	.7723***	.5346	.1223***	.0846
Pine Warbler	.0629	.3159	.0098	.0500
Woodthrush	-.5365**	.2877	-.0850**	.0454
Vireo	.0858	.3067	.0136	.0486
Pileated Woodpecker	.4535***	.3365	.0719***	.0533
Deer	.2403	.2284	.0381	.0362

*, **, *** represent significance at the .05, .10 and .20 levels.

Harvested plots = 308

Nonharvested plots = 2491

$\chi^2 = 186.44$ significance = .0000

Marginal Benefits of Timber: In this model, the marginal benefits variable represents the benefits of waiting another year to harvest. Thus, one would expect that as the marginal benefits increase, the probability of harvest would decrease. Thankfully, this is what the model shows, through both the coefficient and marginal effects. For every additional dollar of marginal benefit the probability of harvest is reduced by .9 percent.

Marginal Cost of Timber: This variable represents the marginal cost of waiting another year to harvest. Thus, the coefficient is hypothesized to be, and is, positive. The marginal effect, also significant and positive, shows that a one dollar increase in costs leads to a .6 percent increase in the probability of harvest.

Plantation: Plantations have a negative, though insignificant effect on the probability of harvest.

Erosion: The presence of erosion problems on a plot has a negative but insignificant effect on harvest.

Presence of Cover: This is a dichotomous variable indicating whether or not good wildlife cover is present on the plot. If valued for habitat, cover would be expected to decrease the probability of harvest. In this estimation, presence of good wildlife cover increases the probability of harvest (significantly) by 6.3 percent. The variable could,

however, also represent a mature stand with a distinct understory, indicating that it is prime for harvesting.

Tree diversity: This index is intended to represent biodiversity of tree species. If this index accurately measures landowners preferences for tree diversity, then I hypothesize that the coefficient would be negative. Although only significant at the .10 level, increases in this index lead to increased probability of harvest (1.3 percent for every unit increase in the index). Thus, more diverse stands are more likely to be harvested.

Large trees: Trees over 20 inches in diameter do not significantly affect the probability of harvest. The coefficients for both softwood and hardwood trees are positive, but not significant at the .05 level. Because the timber value has been incorporated into the marginal benefits and costs, any remaining effects would be due to amenity considerations. Large softwood trees are significant at the .09 level.

Grazing: The presence of grazing is positively, but insignificantly correlated with the probability of harvest.

Scenic Beauty Estimator: This variable is an estimate derived from surveys and plot characteristics of southern pine stands. Thus, its application to all plots in North Carolina is certainly questionable. No alternative source of SBE was found that would utilize available data, however. The scenic beauty estimator was found to significantly increase

the probability of harvest by .6 percent for every unit increase in the SBE index. This may occur because older stands are considered more scenic, and are also more likely to be harvested.

Distance to roads: The distance from the plot to a road is positively but insignificantly correlated with the probability of harvest.

Distance to Urban Development: The null hypothesis in this case could be based on the premise that development leads to increased clearing and harvest. Or the null could be based on the premise that active forest management is more likely to occur at greater distances from urban development. The latter hypothesis is not rejected by the data. The probability of harvest is increased by .04 percent for every 100 feet of distance from built up areas.

Prairie Warbler Habitat: The suitability of a plot for providing prairie warbler habitat is negatively correlated with the probability of harvest. Significant at only the .20 level, this implies that better habitat is less likely to be harvested. This is consistent with these warblers preferences for early successional forests.

Downy Woodpecker Habitat: This habitat type represents plots that are average age or older, with some understory. Again, if habitat is valued this coefficient will be negative, reducing the probability of harvest. However, in this estimation, increases in down

habitat quality lead to significant increases (5.7 percent for every point increase in the index) in the probability of harvest.

Nuthatch Habitat: Quality of this habitat is positively correlated with probability of harvest at the .20 level. This is not consistent with the a priori hypothesis that higher quality nuthatch habitat would correlate with reduced harvest.

Pine Warbler Habitat: This coefficient is positively but insignificantly correlated with probability of harvest.

Woodthrush Habitat: This bird prefers a habitat of mature, climax hardwood stands, thus I would expect a negative correlation between harvest and better habitat. The results are as expected, where an increase in the habitat index leads to an 8.5 percent reduction in the probability of harvest, although the significance level is only .06.

Red-Eyed Vireo Habitat: Habitat quality for this adaptable bird is positively but insignificantly correlated with probability of harvest.

Pileated Woodpecker Habitat: Pileated habitat is positively correlated with harvest at the .20 level, possibly reflecting an increased probability of harvest in older stands preferred by these birds.

Deer Habitat: Deer habitat suitability index is positively but insignificantly correlated with the probability of harvest. The lack of significance could be due to generally high amounts and quality of this habitat available.

V. B. AMENITY VALUES -- THE HEDONIC MODE

The amenity values model regresses the marginal opportunity cost of timber (using a 6 percent discount rate) on the quantities of the amenity characteristics and the calculated sample selection variable (λ). The estimated coefficient on the selection variable (β_λ) is then used to calculate the standard errors corrected for selection. The amenity values model is significant ($F(13,294) = 19.06$) and the adjusted R^2 is .43. As discussed below, few of the coefficients are significant, implying that much of the explanatory power of the model lies in the inclusion of the selection variable, which was negative and significant in the model. The correlation coefficient was held at -1 in the estimation, indicating that the estimated correlation coefficient was outside the acceptable range. The estimated standard error was positive, however, and equal to 129.26.

V.B.1. Coefficient Estimates

Only two coefficients are significant at the .05 level, tree diversity and the selection variable. Tree diversity is negative and significant, implying that an increase in diversity is something landowners are willing to pay to reduce. The negative and

significant coefficient on λ , as well as $\rho=-1$, implies that the mean amenity value in the estimated model is less than the true mean amenity value. Including the non-harvesters in the estimation by using Heckman's correction resulted in unbiased estimates.

V.B.2. Marginal Effects--Hedonic Prices

The impact of a change in the right hand side variable on the total amenity value (marginal opportunity cost of timber) is determined by the partial derivative (equation 23) with respect to that variable. This is nonlinear, and thus not equal to the coefficient alone. The coefficients, marginal effects, standard errors and significance are reported in Table V-2.

Tree Diversity: As with the coefficient estimate, the marginal effects of tree diversity are negative and significant. An increase of one unit in the Shannon-Weiner index reduces amenity values by \$15.60. This implies that a landowner would be willing to pay to reduce tree diversity. Recall, however, that each of these hypothesis tests is actually a joint test of the significance of the coefficient and the use of the index to represent amenities. I believe that the SW index does not represent landowner amenity preferences with respect to tree diversity.³

³ The Simpson index using basal area and trees per acre as well as the Shannon-Weiner using trees per acre were also tested, but the signs and significance did not differ from those reported.

Table V-2. Results of regression of the marginal opportunity cost of timber on amenity characteristics and the selection variable.

Variable	Coefficient	SE of Coefficient	Marginal Effect	SE of Marg. Effect
Constant	322.8571	39.257		
Tree Diversity	-24.9150*	7.2833	-15.6016*	7.2835
Scenic Beauty	.2820	.2410	.7349*	.2410
Prairie Warbler	28.4443	27.602	2.4261	27.602
Downy Woodpecker	-2.5003	20.243	39.2211*	20.244
Nuthatch	-23.5949	81.588	65.2682	81.589
Pine Warbler	-44.7287	48.757	-37.6001	48.758
Woodthrush	-1.4208	43.936	-63.1515***	43.937
Vireo	23.2516	46.673	33.1199	46.674
Pileated Woodpecker	-35.3229	51.086	16.8558	51.087
Large Softwoods	1.4170	2.5721	4.6107**	2.5721
Large Hardwoods	-1.1210	1.4265	-.2509	1.4265
Deer Habitat	-36.8801	34.280	-9.2339	34.281
λ	-137.2774*	19.248		

* = significance at .05 level
 ** = significance at .10 level
 *** = significance at .20 level
 AR² = .43 ρ = -1 SE = 129.26

Scenic Beauty: While the coefficient for the scenic beauty estimator is not significant in the amenity values model, the calculation of the marginal effects reveals that a change in the SBE leads to a positive change in amenity values. The hedonic price of the scenic beauty index is thus \$.73/unit. A one unit change in this index could result from either an increase in sawtimber sized trees (+3/acre), an increase in hardwood poletimber trees

(+7/acre) or a decrease in sapling sized trees (-50/acre). Thus, for example, the value of an additional sawtimber sized tree for estimating scenic beauty is approximately \$.24.

Prairie Warbler Habitat: The coefficient for this bird habitat is positive but insignificant in explaining amenity values or delay in harvest.

Downy Woodpecker Habitat: The marginal effect of downy habitat on amenity values is positive and significant, although the coefficient itself was not significant. Down woodpeckers prefer moderately old (60+ years), medium basal area stands with a high number of saplings and some decay in large trees used for nesting. For example, an increase in nesting trees per acre from 0 to 8 results in an increase of .166 in the index value, which is worth approximately \$6.51.

Nuthatch Habitat: This coefficient is positively but insignificantly correlated with amenity values.

Pine Warbler Habitat: This habitat, primarily high basal area pine stands, is insignificantly (negative) correlated with amenity values.

Woodthrush Habitat: Habitat for these birds, which prefer mature forests, is negative and significant at the .20 level. This implies either that woodthrush habitat is not desired as an amenity, or that the habitat index is measuring some other undesirable forest attribute.

Red-Eyed Vireo Habitat: The non-specific habitat requirements for this bird are positively, though insignificantly correlated with amenity values.

Pileated Woodpecker Habitat: An edge-abhorring species, the habitat index for pileateds is negatively and insignificantly correlated with amenity values.

Large Softwood Trees: Significant at the .06 level, an increase in large softwood trees appears to be valued as an amenity. A hedonic price of \$4.61 is estimated for each softwood tree greater than 20 inches d.b.h.

Large Hardwood Trees: The coefficient on the number of these trees per acre was negative and insignificant, implying that there were no discernible amenity value for large hardwoods in this regression.

Deer Habitat: Deer habitat is negatively and insignificantly correlated with amenity values.

V.C. SENSITIVITY ANALYSIS

The model was also estimated using discount rates of 3, 5 and 7 percent to illustrate how the choice of discount rate affected the model results. The results of the

selection regression using the alternative discount rates are shown in table V-3. Although the coefficients and values change, the models are all significant. The higher interest rate models result in higher amenity values for each plot since the optimal timber-onl decision with a higher discount rate would be to harvest earlier, increasing the time between the calculated optimal and the actual harvest. Thus, the right hand side of the hedonic regression, the marginal opportunity cost of timber, is higher and more coefficients are significant as the discount rate increases.

Table V-3. Marginal effects from regression of MOCT on amenity characteristics using discount rates of 3, 5 and 7 percent (standard errors in parentheses).

	3 %	5%	7%
Tree Diversity	-6.5 (9.3)	-12.4** (7.7)	-18.8* (7.0)
Scenic Beauty	0.6** (0.3)	0.7* (0.3)	0.8* (0.2)
Prairie Warbler	10.4 (25.7)	4.4 (29.1)	0.5 (26.6)
Downy Woodpecker	30.2 (25.7)	35.4** (21.3)	43.2* (19.6)
Nuthatch	68.9 (103.2)	65.5 (85.8)	67.1 (78.8)
Pine Warbler	-29.7 (61.5)	-34.8 (51.2)	-40.5 (47.1)
Woodthrush	-56.1 (55.9)	-59.7*** (46.3)	67.2*** (42.4)
Vireo	20.9 (59.3)	29.2 (49.1)	36.8 (45.1)
Pileated Woodpecker	-1.1 (64.9)	10.9 (53.8)	22.8 (49.3)
Large Softwoods	-0.7 (3.3)	2.8 (2.7)	6.5* (2.5)
Large Hardwoods	-0.8 (1.8)	-0.5 (1.5)	-0.1 (1.4)
Deer Habitat	-17.4 (43.6)	-10.6 (36.1)	-8.5 (33.1)
Mean MOCT	\$21.60	\$36.26	\$53.49
AR²	.58	.48	.40
λ	-178.1* (23.9)	-145.9* (20.0)	-131.1* (18.9)

* = significance at .05 level
 ** = significance at .10 level
 *** = significance at .20 level

Table V-4 includes the results of the ordinary least squares regression of marginal opportunity cost of timber on the amenity characteristics using a 6 percent discount rate. The inclusion of the selection variable, which was significant in the selection model for all discount rates, reduces the significance of the tree diversity, scenic beauty, large softwood trees and downy woodpecker habitat. The signs for all variables significant at the .20 level and below are consistent with the marginal effects estimated in the Heckman model. The adjusted R^2 drops to .25 when the selection variable is not included.

Table V-4. Ordinary least squares regression of MOCT on amenity characteristics.

	Coefficient	Standard error
Constant	37.5*	2.7
Tree Diversity	-13.0*	1.1
Scenic Beauty	0.5*	0.3
Prairie Warbler	-0.3	3.7
Downy Woodpecker	24.4*	3.1
Nuthatch	18.7***	13.5
Pine Warbler	1.5	6.8
Woodthrush	-8.1***	6.1
Vireo	-0.1	7.1
Pileated Woodpecker	-7.1	7.9
Large Softwoods	10.1	0.5
Large Hardwoods	0.1	0.3
Deer Habitat	-8.8**	5.2

AR² = .25
 ** = significance at .10 level
 * = significance at .05 level
 *** = significance at .20 level

VI. CONCLUSIONS

The use of hedonic methods to discern landowner values for forest-based amenities results in some positive marginal hedonic prices. Although these results are encouraging, there are also some negative hedonic prices and much unexplained variation. The test of sample selection indicates that landowners' decisions to harvest are correlated with their amenity values, implicitly confirming the Hartman model. The results on the marginal timber benefits and costs confirm that landowners also value income. Neither the Hartman nor the Faustmann models can be rejected as appropriate models for NIPF behavior, although the Hartman model explains variation based on both timber and amenity characteristics.

Using the hedonic model to estimate landowner amenity preferences on a large scale will be useful in measuring regional forest sustainability and in designing and evaluating forestry assistance projects. By developing measures of landowner amenity values through time, the contribution of forest amenities to national welfare through natural resource accounting will also be possible. This model provides useful information for developing regional timber supply models by incorporating amenity values in landowner harvest decisions.

The most important step to improving the usefulness of this model would be to improve the measures of amenity values. The indices used, with the exception of the scenic beauty estimator, have not been tested in measuring preferences. Thus the

measure of tree diversity may meet an ecologist's definition of biodiversity, but not a landowner's definition. Because all of the indices are constructed from the same forest data, one alternative is to use the original forest measures rather than the constructed indices. Another alternative is to develop measures that reflect what is known about landowner preferences, e.g., retention of 'park-like' atmosphere. Either of these alternatives could reduce collinearity concerns, but they may also be more difficult to interpret.

Further examination of selection bias using non-normal distribution assumptions or using alternative econometric techniques may improve the fit and estimation of the model. Because landowner data is limited, interactions between landowners and amenity values were not identified in this paper. Thus, addition of landowner characteristics may improve the estimation and usefulness of the model.

VII. LITERATURE CITED

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