How Joint is Joint Forest Production? An Econometric Analysis of Timber Supply Conditional on Endogenous Amenity Values

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ABSTRACT

In search of ways to enhance and sustain the flow of services from forests, policy makers in the public and private sectors look to forest sector models to project future forest uses. A major shortcoming of these models is a timber supply specification that inadequately accounts for suppliers choosing the structure of their forest capital to self-produce nontimber amenities. This inadequate characterization of resource use, if significant, can impede the development of sound forest policy, particularly in settings where forest owners possess diverse preferences for forest amenities. In this paper we develop and implement a timber supply model that is consistent with the idea of joint self-production of timber and nontimber amenities, such that timber supply is a function of an endogenous distribution of forest inventory that correlates to ownership and management characteristics. Using FIA data for the U.S. South and three-stage least squares procedures, we confirm that timber and nontimber amenities are jointly produced by private forest owners. We also note that owner and management characteristics influence joint production decisions. We believe that the parameters estimated through such an integrated empirical exercise could critically improve forest sector forecasting models and the related forest policy analysis.

> "…the structure of ownership matters in determining timber supply and changes in forest ownership can have significant aggregate impacts. However, accounting for ownership structure is rarely found in aggregate timber supply models. … So while these types of models [forest sector models] hold considerable promise for improving the precision of forecasts, their promise is inextricably tied to the quality of information provided by econometric models" (Wear and Parks 1994).

PROBLEM STATEMENT

For several decades, decisionmakers in the public and private sectors have turned to forest sector models to forecast changes in the use and management of forests. The attention was spurred initially by fear of timber shortages. While market signals, investment response, and technical change have mitigated timber scarcity in most developed countries, there is continued concern that these successful responses may come at a higher expense of foregone nonmarket forest outputs. The broader question, then, is how can managers sustain the proper mix of all socially valuable goods and services that forests produce? If nothing else, this question requires researchers to develop and provide a richer understanding of the more complex circumstances under which one of those outputs, timber, is produced. Certainly, more complex forest sector models are needed. In this paper, we develop and estimate a timber supply model that is consistent with the idea of joint self-production of timber and nontimber amenities, providing parameters that forest sector models can use directly.

The watershed event initiating the use of forest sector models in public policy in the U.S. was passage of the Forest and Rangeland Renewable Resource Planning Act of 1974 (RPA). RPA called for a periodic assessment of the supply and demand for the renewable resources of timber, recreation, range, water, and wildlife produced by the nation's forests. Elemental to the RPA assessment is the Timber Assessment Market Model (TAMM: Adam and Haynes 1980, 1996), a spatial equilibrium model of the U.S. forest sector, that is linked to a national-scale forest inventory model, ATLAS (Mills and Kincaid 1992). TAMM/ATLAS is still used extensively for policy analysis and has served as a point of departure for other significant modeling efforts in the U.S. The importance of land-based activities to mitigate the threat of climate change sparked development of the Forest and Agricultural Sector Optimization Model (FASOM: Adams et al. 1995). FASOM links the forest sector framework of TAMM/ATLAS to the national-level Agricultural Sector Model (ASM: Chang et al. 1992). In the late 1980s, the Forest Service embarked on a detailed study of forest resource conditions in the U.S. South – the "South's Fourth Forests". Recognizing at the time that TAMM/ATLAS's aggregation of the South's forest to two geographic points (Southeast and South-Central) would be insufficient for a regional study, Abt et al. (1989) developed the Subregional Timber Supply (SRTS) modeling system to perform the timber market/inventory analysis for the Fourth Forest study. Subsequently, SRTS has been used since then as a source of timber price and harvest projections for the public and private sectors (Abt et al. 2000; Murray et al. 2000).

These aggregate (regional, national, global) models either (1) characterize the level of forest inventory as a unidimensional explanatory variable (e.g., total volume of available growing stock) in the supply function, or (2) capture the dimension of age classes but impose an *ad hoc* decision rule such as harvesting all of the oldest timber first. The latter approach is consistent with a simplified capital theoretic model of optimal rotations when only timber values enter the objective function (Faustmann 1848), but it can be at odds with the way that much forestland appears to be managed. Our central assertion is that many landowners jointly produce timber, a traditional production good, and nontimber amenities that one's own forest can provide. This assertion is consistent with the utility theoretic model of timber supply examined by other researchers and discussed in more detail below. Thus, the oldest stands across the landscape are not always the ones that are cut in any given period. Some are preserved for their amenity value, perhaps, but not definitely, to be harvested another day. Given heterogeneous preferences and management within private ownership, the forested landscape reflects a range of age class-harvesting relationships.[1] The data from the southern U.S., perhaps the most significant timber supply region in the world dominated by a diverse mix of private ownership, supports the claim of heterogeneous age class structures across owner groups and regions. For example, more than half of all inventory in nonindustrial private forests (NIPF) in the U.S. South is in age classes older than 60 years, which is typically past the age of the pure timber optimum. In comparison, only 38% of forestland owned by the forest industry is in the same class. The purpose of this paper is to blend these empirical patterns with utility theory to develop a more robust aggregate timber supply modeling approach.

It would be naïve to approach these questions without an in-depth assessment of the literature on timber supply. So, in the next section, we briefly review the various ways in which researchers have studied timber supply, paying closer attention to studies that have attempted to incorporate nontimber amenity supply and ownership characteristics.[2] This literature review allows us to develop a stylized model of utility maximization that forms the conceptual basis for our empirical analysis. To implement this model, we need economic and ecological (forest distribution) data with substantial variation. Fortunately, the FIA data collected by U.S. Forest Service and described in this paper is spatially rich and explicit. We present the results of our econometric model of timber supply and forest inventory distribution and volume that confirm our hypotheses regarding the jointness of timber and nontimber amenity supply. Finally, we summarize our main conceptual and empirical findings.

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[1]One might argue that the range of harvest-age class relationships is more reflective of heterogeneity in the resource base than of heterogeneous preferences. For instance, remote or inaccessible stands may be less amenable to harvest and therefore evolve to older ages. However, heterogeneity of preferences and heterogeneity of resources are interdependent phenomena because people express their preferences by choosing the location and the type of forests they want to preserve. For example, hardwood stands in accessible areas such as the mountains or swamps are preserved for economic as well as ecological reasons.

[2]A richer description of the literature is presented in a longer manuscript from which this paper is drawn. This manuscript is available from the authors on request.

REVIEW OF THE LITERATURE ON TIMBER SUPPLY AND AMENITIES

Two survey papers (Binkley, 1987; Wear and Parks, 1994) greatly facilitated our assessment of the literature on timber supply modeling. Thus, we begin by summarizing their main insights. We then review more closely the empirical literature on timber supply models that explicitly acknowledges the role of ownership characteristics in the context of nontimber forest services. To accomplish this, we separate this literature into simulation models of optimal rotation and the micro-econometric studies of utility maximization. Because of our interest in the empirical aspects of this literature, i.e., in identifying parameters for policy modeling, we focus mainly on the estimation studies by summarizing and reporting the estimated supply parameters in Table 1.

Overview of Timber Supply Modeling

Binkley (1987) defines timber supply modeling, i.e., the linking of ecological and economic components of forest sector analyses, as having developed along two lines. Long-run supply models examine a steady-state world in which price and costs are known and enough time is available for inventory levels to adjust. Short-run models, by contrast, recognize the significant fluctuations in harvest levels accompanying the observed fluctuation in timber prices and explain the relationship between annual harvest levels and prices conditional upon a fixed forest inventory relationship in place at a particular point in time. One branch of analysis that attempts to unify short- and long-run theories is the so-called “transition models” (Berck 1979, Lyons 1981). These models retain the normative elements of the earlier long-run theory, i.e., forest owners make decisions as though they were maximizing the net present value of timber receipts, and explicitly model the transition from the current timber inventory to the long-run steady state. Another branch of analysis interested in unifying short- and long-run models uses the household production model to include utility derived from both timber and nontimber outputs from the forest, and it also explicitly models the transition process (Binkley 1981). The advantage of this approach is that it explicitly considers nontimber benefits and timber growth dynamics along with income generation for landowners, and it links the forest sector, via income and wages, to the other sectors. Its major drawback is the substantive data needs for empirical estimation of preference and multiple output technology (necessarily dynamic) functions. In this paper, we draw on the household production framework to investigate the endogenous distribution of forest inventory—a condition that results from the joint production of timber and nontimber amenities—and use it to estimate an aggregate timber supply model.

Wear and Parks (1994) build on Binkley’s (1987) synthesis to define a general conceptual model of timber supply that provides the context for discussing both individual harvest and aggregate supply models. They specify timber supply volume as a function of forest age, management effort, and land quality. When alternative land uses are considered, optimum rotation depends on the current and expected prices of all of the potential forest products. They argue that supply formulations that account for the quality and vintage distributions of forest capital will be necessary for improving medium and long-run forecasts. These supply formulations will be especially important for examining the potential impacts of structural changes in forest production and timber markets. In addition, consistent aggregation of individual owners for both timber and amenity supply will be required to examine the implications of changing forestland ownership. Typical timber supply models are not always explicitly tractable to the theories of production and cannot distinguish forest capital structure (e.g., different age distribution with same timber volume). Wear and Parks conclude with a persuasive call for more empirical analyses that explicitly account for forest owner characteristics and for distributions of forest capital. Our paper responds specifically to these challenges.

Simulation Studies of Optimal Rotation with Amenity Values

A body of literature in timber supply modeling employs an optimal control approach to focus on the timber harvesting decision for forest landowners who consider amenity benefits from standing forests. The main objective is to determine the optimal rotation length, given a set of parameters such as prices, biological technology, and preferences change, and to simulate changes in the optimal length in response to changes in these given parameters. Therefore, these studies are successors to Hartman's (1976) seminal description of why and how amenity considerations lengthen optimal rotation. Typically, these studies draw their theory from the Binkley (1981) or Hartman (1976) models. Simulations are based on assumed functional forms and parameters that are drawn from empirical studies, expert opinion, and informed conjectures regarding supply and demand of forest products. Max and Lehman (1988), Swallow and Wear (1993), Provencher and Swallow (1998), and Tahvonen and Salo (1999) are examples of this line of investigation.

Micro-econometric Studies of Utility Maximization

Within the literature on timber supply modeling, a body of micro-econometric studies provides the estimated parameters of timber supply behavior by private landowners. By definition, this category of studies is positivist in that it describes how landowners do behave instead of how they should or would behave subject to analysts specification. This body of work uses a Fisherian utility maximization framework as a starting point to evaluate timber supply in the light of amenity and other considerations.[3] Using Binkley (1981) as a starting point and conceptual template for this literature, we discuss how various authors have subsequently enriched this modeling strategy and estimated parameters (Table 1).

In this framework, a representative private landowner is assumed to maximize utility by consuming goods and amenities, where utility is separable over time and commodity space, and is subject to an income and a production constraint. The technical production constraint links the landowner's scarce inputs, e.g., land or capital, to multiple products, timber, and amenity.

[3]By "Fisherian," we mean a construct that allows the analyst to conceive of decisionmakers separating their periodic production and consumption decisions. Production over time is organized to maximize the present value of the utility of consumption over time.

Amenity is conceptualized as self-produced recreation and/or aesthetics proxied by some form of forest inventory; most timber supply studies do not estimate amenity services.[4] Timber supply is derived using first-order conditions of a typical constrained maximization problem to be a function of prices, interest rates, and socio-demographics (income, occupation, and education) and bio-physical factors (tract size, species mix, and inventory characteristics). Survey data are typically used to estimate the timber supply model with some direct or indirect accommodations for amenity services.

In Binkley's (1981) analysis, because data on timber harvest quantities are not available, a random utility model (RUM) is used to approximate timber supply behavior by employing data on whether the timberlands were harvested. In essence, these limited dependent (0-1) models provide the elasticity of probability of harvest with respect to price, instead of the amount of harvest with respect to price. Estimated parameters reported in Table 1 show that these imputed elasticities range from 0.3 to 9.8. Table 1 also summarizes other features of the empirical study including location, data type, definition of dependent and independent variables, and estimation approach.

Holmes (1986) extended this line of research by explicitly modeling two joint decisions—to harvest and recreate—using data from a survey of landowners in northeastern Connecticut. Because the data were restricted to binary representations of timber and amenity outputs, he used a simultaneous logit model to capture the structural correlation across the two equations. Hyberg and Holthausen (1989) modeled the harvest timing and reforestation decisions in a multiperiod utility-maximizing framework. They estimated separate probit models for the binary harvest and reforestation data collected from a survey of landowners in Georgia. Dennis (1989 and 1990) adopted Binkley's theoretical model and estimated tobit equations to establish the relationship between the harvest decision and forest, owner, and economic characteristics from cross-sectional data of individual forest plots in New Hampshire. Amacher et al. (1998) used landowner survey data from Virginia to consider a range of decisions including harvest, reforestation, bequest, and nontimber activities. Some decisions were estimated using two-stage least squares.

Several authors have studied the role of owner characteristics on the timber supply decision, with the implicit assumption that amenity supply/demand or other forms of market imperfection are correlated with, if not proxied by, owner characteristics. Kuuluvainen and Salo (1991) study timber supply in the context of capital market imperfections and life-cycle preferences.[5] A timber supply function, estimated using Finnish micro data from 1982 to 1985, shows that the hypothesis of an imperfect capital market cannot be rejected because the owner characteristics, including

[4] We do not estimate amenity services either; instead, we explicitly control for it using econometric methods that account for endogeneity. See footnote 8 and the discussion of Lee (1998) on how to model amenity services.

[5] The role of capital market imperfection is conceptually similar to the role of nonmarket amenities, in that it implies that owner characteristics influence the supply of timber. Both are forms of market imperfection that contest the Fisherian separability assumption.

owner's age, have highly significant coefficients. Kuuluvainen et al. (1996) empirically identified NIPF objectives and linked them to observed harvesting behavior using survey data on 146 Finnish forests. Prior to estimation, forest owners were classified into four groups according to their ownership objectives by K-means clustering, and dummies for three clusters are included in the supply function. Their results show that "multiobjective owners" harvest significantly more than the other owner groups (self-employed owners, recreationist, and investors), all else equal. Newman and Wear (1993) compare the production behavior of industrial and nonindustrial private forest landowners in the southeastern U.S. using a restricted profit function. Although an identical profit function for both owner groups is rejected, the results indicate behavior consistent with profit-maximizing motives for both groups—with similar responses to input and output price changes. Marked differences in estimated shadow values for growing stock ($21/mcf for industry and $32/mcf for NIPF) and for land ($6/acre for industry and $23/acre for NIPF) suggest, however, that NIPF owners place a higher value on their standing timber and forestland because of amenity preferences. More recently, Prestemon and Wear (2000) estimated a disaggregated discrete choice probit model of timber harvest for three ownership categories (NIPF, industry, and government) in coastal plain southern pine stands of North Carolina. Implied price elasticities, calculated using bootstrap model estimates, showed that NIPF and industry were elastically responsive in the aggregate when, by the authors' construction, price increases are perceived by the supplier as temporary but much less elastically and usually negatively responsive when increases are perceived as permanent.[6] While most studies look for influences of landowner characteristics on harvesting decisions, Lee (1998) explicitly established the influence of amenity characteristics. This connection is established by regressing the marginal amenity value (calculated as discount rate*discounted sum of timber stumpage revenues less price*volume growth) on amenity characteristics (measured by several ecological indices) in a hedonic model, without including landowner characteristics. Four of nine amenity characteristics have a significant effect in the regression model. The critical contribution of Lee's research is to develop empirical measures of amenity in terms of wildlife habitat indices and to value them using hedonic analysis.

Lessons Learned

Our literature review identifies two major schools of timber supply modeling: a tradition that focuses on optimal harvest age and the age structure, and a second tradition concerned with the effect of owner characteristics and constraints on timber supply. The greatest strength of the optimal harvest models lies in explicitly modeling the choice of forest age or structure. From our perspective, the major shortcoming of the optimal control studies is the lack of empirical underpinnings. Moreover, the optimal control studies have tended to rely on Fisherian separation of consumption and production even in specifications with amenity services (Tahvonen and Salo, 1998), suggesting that attention to owner characteristics is inadequate. In comparison, the

[6] It is worth noting that their definitions of permanent/temporary are somewhat unconventional because they are based on simulated changes in an initial price and next period's expected price.

primary contribution of the microeconometric utility maximization tradition is the recognition of the role of owner characteristics on timber supply (because of uncertainty in prices and interest rates, nontimber amenities, imperfect capital markets, and forest taxation). The main problem is their lack of connection with the biological aspect of forests—age structure of the forest capital. Indeed, the earliest of these studies by Binkley (1981) recognized the need for more dynamic models that include capital assets together with forest inventory development. Consequently, we agree with Tahvonen and Salo's (1999: 107) assessment that "…both empirical and theoretical research call for an approach that combines the strengths of the two traditions and explains the relationship between forest owner factors and timber supply in terms of the optimal rotation problem." While Tahvonen and Salo take the simulation approach, our interest is in the practical aspects of timber supply modeling, particularly with regards to how we empirically integrate the structure of the forest capital as a proxy for amenity flows. By paying close attention to the structure of forest capital and ownership, we try to at least partially fill the gap between theory and empiricism in timber supply modeling approaches identified by Binkley (1987) and Wear and Parks (1994). In the next section, we present a stylized model of timber supply that draws on the literature review and our previous data explorations to define the conceptual basis for our empirical analysis.

CONCEPTUAL MODEL OF TIMBER SUPPLY WITH ENDOGENOUS DISTRIBUTION OF FOREST CAPITAL

Our basic goal is to develop a stylized model of a private landowner managing a forest for timber and nontimber amenities. We exclude public landowners because public lands comprise a small share of the timberland base in the US South and because it is difficult to develop a utility-profit maximizing structure that is generalizable for both public and private choices. We are interested in linking the distribution of forest inventory to ownership and management characteristics within a utility theoretic framework. Specifically, we adopt and modify Holmes' (1986) and Hyberg and Holthausen's (1989) interpretation of Binkley's (1981) model to show household production of amenities influence empirical specifications of timber supply.

We start with a simple biological growth equation, where volume of timber, v, is a function of the age of the stand, a; the amount of land, L; and the quality of land, q. Over an infinite horizon, an owner-manager of the forest can earn income from exogenous sources, E, and timber income from an infinite series of rotations. The timber income, evaluated when the forest is bare land, is the sum of an infinite (converging) series of timber income from the current and all future rotations less the sum of a perpetual series of annual rental payments, R, on L units of land. Following Binkley (1981) and Hyberg and Holthausen (1989), nontimber amenities are a function, n, of the amount of land owned, L, and the volume of timber on the land, V(a; L, q), that depends on the stand's age. Over the same infinite series of rotations, N represents the present value of the amenities. The forest owner-manager gets utility, U, from both income and nontimber amenities, and this is conditioned by their preferences, θ. The lagrangian framework for this decisionmaking and the derivation of the optimal time to harvest a forest stand is presented in Appendix A.

Based on the first-order conditions of this utility maximization, we get the familiar result that optimal rotation age, *a**, is one where the marginal benefits of delaying harvest equal the marginal cost (see equation A_6 in Appendix A). Marginal benefits are measured in terms of increased biological growth and net amenities; marginal costs equal the opportunity cost of the forest capital and of the land (bare land value). From this result, we can see that when the owner-manager is strictly maximizing profits, that is $U_N = 0$, and we get the Faustmann (1848) condition. Thus, U_N is critical because it reflects preferences of the land owner-manager indicated by θ. It has clear implications for the optimal choice of nontimber amenities, N*, and the optimal rotation, *a**. Consequently, by choosing N the owner-manager chooses a distribution of the forest capital or the density function of the forest over the long run. Wear and Parks (1994) describe this density function as $\phi(a, q)$, the relative frequency of land of quality q that is occupied by trees of age class *a*.

To elaborate on this point, consider two cases. In the first case, the owner chooses N = 0 presumably because $U_N = 0$. The optimal rotation for this "Faustmann choice" is a^*_0 and the associated distribution of forest capital, $\phi^*_0(a^*_0, q)$. In the second case, the owner chooses N > 0 presumably because $U_N > 0$ and the utility from nontimber amenities at what would otherwise be the timber optimal rotation exceeds the foregone utility from delaying timber profits. The optimal rotation for this "Hartman choice" is a^*_N, and the associated distribution of forest capital is $\phi^*_N(a^*_N, q)$. As illustrated in Bowes and Krutilla (1985), $a^*_0 < a^*_N$ if $\partial N/\partial a > 0$, i.e., amenity benefits increase with age. In general $a^*_0 \neq a^*_N$ and therefore $\phi^*_0(a^*_0, q) \neq \phi^*_N(a^*_N, q)$. The main insight is that the choice of N conditions *a* and φ. Specifically, the optimal rotation age is determined by the price of timber (P) and capital (r), growth function parameters, land quality (q), landowner's characteristics (Θ), and exogenous income from non-timber sources (E).

To see how these insights influence timber supply modeling, we can draw on the derivation of aggregate supply in Wear and Parks (1994) to complete our model. To emulate their equation (6), aggregate supply from an owner-manager of L units of land of quality ranging from q- to q+ and age of standing timber from *a*- to *a*+ is

$$\begin{aligned} S &= L \bullet \int_{q-}^{q+}\int_{a^*}^{a+} V(a; L, q) \bullet \phi(a, q)\, da\, dq \\ &= g(p; \phi(a, q)). \end{aligned} \tag{1}$$

This is a standard characterization of supply as a function of current and expected prices and the distribution of the forest capital. Prices enter the supply equation through their effect on a*, which determines the portion of inventory to be harvested. As we have shown above, this distribution of forest capital is not exogenous and is conditioned by the choice of N, which depends on preferences of the owner-manager, θ. Were we to estimate a timber supply equation, we need to explicitly model the distribution of forest capital as a separate equation. In the simplest formulation:

$$\phi(a, q) \quad = \quad f(N; \theta) \,. \tag{2}$$

Consequently, we propose to modify the standard characterization of timber supply by using a three-stage estimation procedure that econometrically addresses the endogeneity of the distribution of forest capital, henceforth called the "forest inventory distribution." Empirical tractability necessitates that we find a metric of forest inventory distribution that captures the amenity values of interest. We propose the skewness of a collection of different aged stands aggregated across a representative supply unit as such a measure because a greater proportion of old growth, which growth will generally tend to skew the distribution further to the right, is a proxy for amenities. In the next section, we present an empirical model that discusses the econometric approaches for addressing endogeneity and the data available to implement our strategy.

Our empirical strategy is to estimate the timber supply function (equation [1]) and the forest inventory distribution (equation [2]) as a system of equations. We use a three-stage least squares (3SLS) procedure in which timber supply and forest inventory are endogenous variables and prices and preferences are exogenous. The 3SLS approach improves on a simple ordinary least squares (OLS) of the supply function by accounting for the endogeneity of forest inventory. 3SLS also improves on single equation methods that account for endogeneity, e.g., two-stage least squares (2SLS) or the instrumental variable approach in which we would instrument the endogenous forest inventory distribution variable in a second equation. In the 3SLS approach, by contrast, we estimate the two equations as a system and statistically use the information contained in the correlation of the errors of the two equations. Error correlation is likely to stem from the fact that the harvest and growing stock variables are drawn from the same data set.

DATA COLLECTION

We implement our model by primarily using U.S. Forest Service data on timberland area, timber inventory, and timber harvest, collected from 51 geographically defined Forest Inventory and Analysis (FIA) survey units. These FIA units are located across 12 states in the southeastern corner of the U.S. spanning from Texas to Virginia.[7] The FIA data are classified into species, ownership, management type, and 10-year age classes. The two species are softwood and hardwood. The ownership category can be divided into "industry," comprising industrial landowners, corporate owners, and land trusts (e.g., timberland investment management organizations, or "TIMOs"), and

[7]The twelve states constituting the "South" in this study are Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia.

"NIPF," which includes farmers and other private landowners.[8] Pine plantations, mixed pines, natural pines, upland hardwood, and lowland hardwood comprise the five management types. The classification of the data into age classes enables us to quantify the structure of the forest capital or the forest inventory distribution. Plantations have four 10-year age classes, and natural management types have six 10-year classes. In each case, the oldest age class includes all stands above the threshold age (40 for softwoods, 60 for hardwoods). For this data set, our unit of analysis is a "representative supplier" for an eco-geographical region, a species, an owner category, and a management type. An example representative supplier is the case of industry owners supplying softwoods from pine plantations in the Piedmont region of North Carolina. This data configuration exploits the spatial and temporal richness of the FIA data and gives us a sample of approximately 400 observations. The primary reason for this level of aggregation is that it provides a balance between the micro-level economic responses at the individual stand level, for which we have limited data, and economic signals at the market level. Because we are aggregating supply responses across stands of different age classes, we must derive a measure of the age-class distribution of forest inventory to capture the amenity production effect.

The FIA data are complemented by prices of sawtimber obtained from Timber Mart South (TMS), available for two regions per state (Norris Foundation, 2000). A geographic information system (GIS) was used to overlay the FIA eco-regions with the TMS regions. For eco-regions that lie in more than one TMS region, we follow the procedures outlined in Prestemon and Pye (2000) by calculating a weighted average price in which the weights are the quantities of harvest from each region. Moreover, because the harvest variable reflects activity since the preceding forest inventory, we use a price index that is the average of prices for the 10 years preceding the year in which the FIA survey was conducted. All prices are converted into 1990 dollars by dividing by the producer price index for the relevant year. Finally, we supplement the quantity and price data with census data on state incomes (NPA, 1999), converted into 1990 dollars.

To get a flavor of the type of analysis that is possible with this data set, we discuss the descriptive statistics in Table 2. The harvest from a representative supplier is 67 metric cubic feet (mcf). The distribution of forest capital is positively skewed, reflecting the fact that older trees have greater volumes. The mean of the forest capital volume is 10,200 mcf. Stumpage prices for softwood sawtimber are approximately $70/MBF higher than hardwood prices, reflecting the market's preference for better quality and more workable sawtimber. Finally, turning to the supplier characteristics, a little more than half of the supply units are NIPF and about a quarter and a third of our sample include natural and planted pinelands, respectively.

With this data set at hand, our focus is on explaining timber supply and forest inventory distribution. Timber supply (*QS*) is defined simply as the sum of timber harvests for a representative supplier, as recorded in the FIA data set. In comparison, the definition of the forest

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[8]This broad categorization is justified in the statistical analysis using F and t-tests. That is, farmers and other private owners behave more like each other and less like the others, whereas industrial and corporate landowners exhibit sufficiently similar behavior.

inventory distribution variable is not as straightforward. We define forest inventory distribution for any representative supplier as the distribution of the inventory over the various age classes, and we use the skewness of the inventory (*GSSK*) as a metric of this distribution. A positive skew indicates a higher concentration of older age class inventory, and a negative skew indicates a high concentration of younger age class inventory. Despite some limitations of this summary metric, particularly with respect to the ecological information that it conveys, we believe that this is the best first approximation of a distribution measure that captures amenity values.[9] Without claiming that baseline skewness is zero, essentially we are arguing that amenities will be correlated with old growth, which will generally tend to skew the distribution further to the right than 'pure timber-forests'. Consequently, we would expect the skewness to reflect the influences of preference and amenity choice on timber supply. Specifically, we assert that more positively skewed distributions generate higher amenity values, all else equal. From a modeling standpoint, we treat it as a regressor in the timber supply equation and as the dependent variable in the forest inventory distribution equation.

In our economic characterization of timber supply, sawtimber price (*P*) and total inventory volume (*GS*) are the key exogenous variables.[10] That is, in addition to forest inventory distribution, we expect the economic returns to timber production as measured by prices and the biophysical forest capital as measured by the volume of inventory to have a strong bearing on timber supply. Because we have a biological accounting condition, which equates changes in inventory volume to growth net of supply, it is possible that inventory volume is also endogenous. We test the robustness of our empirical model to the assumption of exogenous inventory volume by adding an equation to our system to replace inventory with an estimate based on appropriate instruments.

With regard to the forest inventory distribution equation, management and owner characteristics are the best available regressors. Given the aggregated nature of the FIA data, these are measured by indicator or dummy variables for owner (NIPF = 1 if NIPF; = 0 if Industry), pine plantations (PP = 1 if pine plantations; = 0 if otherwise), and natural pine management (NP = 1 if natural pine; = 0 if otherwise). We supplement this with census data on state income to proxy for wealth effects, that is, for the influence of wealth on preferences.

THE EMPIRICAL MODEL OF JOINT PRODUCTION

Our empirical model is conditioned by the structure of the FIA and TMS data described in the previous section and our interest in generating parameters that can be directly inputed in timber-

[9] A referee suggested that volume of timber inventory could also proxy amenity. While we believe that the distribution is a better proxy than volume for the ecology of amenity production, from an implementation perspective we do estimate separate equations for timber inventory (next section) and therefore account for possible endogeneity from this source.

[10] Price is assumed to be endogenous at the regional level, but exogenous to the representative supply units within the region that are the points of observation for our analysis.

supply projection models.[11] We use a 3SLS model to estimate the timber supply, forest inventory distribution, and forest inventory volume equations (see Greene [1997] for details of the 3SLS model) for each species. Because we believe that production and, to a lesser extent, preferences cannot be substituted across these species groups, we estimate separate timber supply and forest inventory distributions and volume for softwoods and hardwoods. This nonsubstitutability or input specificity is true at least in the short run, i.e., one cannot produce softwood sawtimber with hardwood growing stock. Moreover, we choose a Cobb-Douglas functional form for timber supply—a first-degree linear approximation to any production technology. One of the practical benefits of estimating this functional form is that elasticity estimates are readily available from a set of estimated regression coefficients.[12] There are approximately 200 observations in the species specific regression models.

Our bio-physical forestry data are species specific and, thus, our estimating equations are as follows:

$$\ln(QS_i) = \alpha_1 + \beta \bullet \ln(P_i) + \gamma \bullet \ln(GS_i) + \delta \bullet GSSK_i + \varepsilon_1 \quad (3)$$

$\forall$ i = hardwood and softwoods

$$GSSK_i = \alpha_2 + \kappa \bullet NIP + \lambda \bullet INC + \omega \bullet PP + \mu \bullet NP + \varepsilon_2 \quad (4)$$

$\forall$ i = hardwood and softwoods

$$\ln(GS_i) = \alpha_3 + \psi \bullet NIP + \tau \bullet PP + \xi \bullet NP + \upsilon \bullet \ln(P_i) + \varepsilon_3 \quad (5)$$

$\forall$ i = hardwood and softwoods

where

QS	=	timber supply or harvest for each species, owner, management type group
P	=	price of sawtimber
GS	=	inventory in each species, owner, management type group
GSSK	=	skewness of inventory (across a distribution of five age classes) in each species, owner, management type group
NIPF	=	1 if NIPF; = 0 otherwise
PP	=	1 if pine plantation; = 0 otherwise
NP	=	1 if natural pine; = 0 otherwise
INC	=	state average income over data period

[11]For example, our choice of modeling two broad species categories - hardwoods and softwoods – reflects our finding that both the FIA data-base and timber supply projection models separately model and assess these two species aggregates.

[12]The coefficient on GSSK in the timber supply equation, however, is not the skewness elasticity because we employ a non-logarithmic version of this variable in order to include observations with negative skewness.

α = regression constants

ε = error (unobserved determinants)

ESTIMATION RESULTS

The results of the regression analysis are presented in Table 3a (softwoods) and 3b (hardwood). For comparison purposes, we present the results of three models: (1) the OLS model in columns 1 and 2; (2) 3SLS with endogenous inventory distribution in columns 3 and 4; and (3) 3SLS with endogenous inventory distribution and volume in columns 5 and 6. For each model, the estimated coefficients are presented in the first column and the probability value in the second column. The model "goodness-of-fit" statistics (χ^2 and probability values), presented in the bottom half of the tables, show that the models fit the data well in all models.[13]

Beginning with the softwood timber supply equation, we see that the model is relatively robust to the endogeneity assumptions, although as expected the size of the coefficients and the standard errors change. Sawtimber prices are a significant positive influence, reflecting the resource and opportunity costs of timber production. Our estimated elasticity, ranging from 1.27 to 0.6, is within the range of elasticities reported in the literature. As expected, timber supply is positively correlated with forest inventory volume because inventory is a fixed capital input. In Model 3, we note that a significant amount of explanatory power is drawn away from the price variable (an instrument for inventory volume) by the inventory volume variable itself. Finally, our data show that the skewness of the inventory distribution is negatively correlated with timber supply. One possibility is that it reflects a preservation strategy for older softwood stands, as described further below. We confirm the endogeneity of the forest inventory distribution and volume using an augmented regression version of the Wu-Hausman test (Davidson and MacKinnon 1993). The Wu-Hausman test statistics of -2.12 (Model 2) and 16.15 (Model 3) reject the hypothesis that forest inventory distribution and volume are exogenous (Table B-1). Details of the Wu-Hausman endogeneity test and its application to our case are presented in Appendix B.

Regression estimates of the softwood inventory distribution shows that management and owner characteristics have the expected statistically significant influences on the inventory distribution. The coefficient on the NIPF dummy variable is significant and positive, suggesting NIPF preferences for amenities relative to industry owners. The coefficient on the income variable is not significant, presumably because the income effect is confounded by the owner and management dummy variables. The negative coefficients on the two management dummy variables suggest that pine plantations and natural pine stands tend to have a younger distribution of age-classes than mixed pine and hardwood management types

[13] Plots of residuals against fitted values do not show any obvious patterns or trends. We do, however, find some evidence of heteroskedasticity based on Cook-Weisberg tests. Robust estimation of the individual equations, which allow different regression error for observations in different ecological regions, reduce the standard errors of coefficients, all of which are already statistically significant. While we do not simultaneously estimate 3SLS with cluster-specific errors, our overall conclusions for 3SLS are not affected because the coefficients are statistically significant even without correction for heteroskedasticity.

In the softwood inventory volume regression, we see that management and owner characteristics have the expected statistically significant influences on inventory volume. We find that inventory in planted pine is smaller than mixed pine and hardwood inventory, whereas it is greater in natural pine than in mixed pine and hardwood inventory. The positive coefficient on price suggests that landowners exhibit an economically rational response to higher softwood prices by increasing their forest holdings. That is, there is a resource costs of holding timber inventory, and higher prices attract investments in timberland and inventory development (e.g., higher management intensity).

For the hardwood supply equations (Table 3b), we note that the model is more sensitive to the endogeneity assumption than the softwood supply equation, with Models 2 and 3 generating consistent and asymptotically efficient estimates. Most striking is the significant positive influence of sawtimber prices and the estimated elasticities of 0.32 to 0.96 that are within the range of elasticities used in the literature. The volume of timber inventory is also positively correlated with timber supply as expected. In Model 3, we note that the endogenous inventory volume variable, instrumented by the price variable, is no longer significant. Consequently, the explanatory power for the price variable is higher. Models 2 and 3 show that the skewness of the forest inventory distribution is positively correlated with timber supply. Potential reasons for this are discussed below. We confirm the endogeneity of the forest inventory distribution and volume, based on the Wu-Hausman test statistic of –3.65 (Model 2) and 12 (Model 3) reported in Table B-2.

A simultaneous regression of the hardwood inventory distribution shows that management and owner characteristics have the expected statistically significant influences. The coefficient on the NIPF dummy variable is not significant in Model 2 and is significant in Model 3. The statistical significance is potentially confounded, to some extent, by the income proxy, which is positively correlated with the skewness of the forest inventory, as expected.

Finally, as in the case of softwoods, the estimated equation for hardwood inventory volume shows that management and owner characteristics and price have the expected statistically significant correlation with inventory volume. We find a positive coefficient on the NIPF dummy variable because NIPF endowments of forest inventory are greater than industry holdings. We find that inventory in mixed and natural pine stands is much smaller than in pure hardwood stands. The positive price coefficient suggests that landowners exhibit an economically rational response to higher hardwood prices. In the case of hardwoods, higher prices are more likely to enhance inventory by maintaining forests as a profitable land use, rather than inducing more intensive management, which has limited opportunity for hardwoods.

The difference in the skewness parameter between the hardwood and softwood supply equations merits further scrutiny because it is our proxy for the amenity effect. The softwood parameter is negative, indicating that softwood old growth is less likely to be harvested and more likely to be preserved. One intuitive explanation of this is that stands that survive to the oldest age classes are more likely to be revealing landowner decisions to obtain old growth amenity values. This is because softwood is typically a commercial species that is more likely to be harvested at younger ages. In contrast, the skewness coefficient in the hardwood equation is positive, suggesting that hardwood forests skewed toward the oldest classes tend to generate more timber harvests. This behavior is likely to reflect the treatment of hardwood inventory as a reserve stock in which harvesting is largely confined to the older (slower-growing) stands. Thus, the simple rule of thumb of harvesting the oldest stands first (a Faustmann-like rule) more accurately characterizes hardwood supply than softwood supply in this region. For this data set, the preservation objective dominates the harvesting incentive for the older softwood forests, whereas the opposite is true for the older hardwood forests.

The theoretical credibility and empirical plausibility of the results presented in this section support our hypotheses regarding the simultaneity of timber and nontimber amenity supply decisions by private forest landowners. They also support the influence of owner and management characteristics on joint production decisions. Three features of this approach are noteworthy. First, it is important to estimate an equation system to implement our model of joint production of timber and nontimber amenities. Second, by accounting for endogeneity (e.g., for forest inventory distribution and volume) we can estimate consistent and efficient parameter estimates for timber supply. Third, in our stylized characterization of forest management, we see the explanatory power of variables such as the skewness of the forest inventory and dummy for ownership and management.[14]

SUMMARY AND CONCLUSIONS

A major shortcoming of forest sector models is a timber supply specification that inadequately accounts for suppliers choosing the structure of their forest capital to self-produce nontimber amenities. This inadequate characterization of resource use, if significant, can impede the development of sound forest policy, particularly in settings where forests are owned by a heterogeneous group of private entities possessing diverse preferences for forest amenities. In this paper we develop and implement a timber supply model that is consistent with the idea of joint self-production of timber and nontimber amenities. In the southern U.S., over 90% of the forestland base is privately owned; thus, the region provides an excellent empirical setting for this topic. To the extent that the nontimber amenities are correlated with the structure of forest capital, ownership, and management, econometric models can consistently estimate the parameters of timber supply.

Our literature review identifies two major schools of timber supply modeling: a tradition that focuses on optimal harvest age and the age structure, and a second tradition that is concerned with the effect of owner characteristics and constraints on timber supply. Consequently, there is a

[14]A superior alternative is to develop FIA plot-level ecological indices of wildlife habitat, such as those employed by Lee (1998) for North Carolina, to directly measure amenity supply. One of the authors is currently building this type of a model for North Carolina. At this point in time, however, it is not practical to develop and employ such data for the entire U.S. South.

need for an approach that combines the strengths of the two traditions and explains the relationship between the characteristics of forest owner and timber supply in terms of the optimal rotation problem. Our interest is in the practical aspects of timber supply modeling—particularly with regards to the empirical integration of the structure of the forest capital with the characteristics of owners.

The lessons from the literature review allow us to build a utility-theoretic characterization of supply of timber and nontimber amenity using the household production framework. Landowners manage their forests for an optimal mix of timber and nontimber amenities. The key insight of our conceptual model is that timber supply is a function of an endogenous distribution of forest inventory that correlates to ownership and management characteristics.

Our empirical goal is to estimate the timber supply and the distribution and volume of forest capital as a system of equations. We use 3SLS procedures in which timber supply and forest inventory distribution and volume are endogenous variables and prices and preferences (proxied by ownership and management characteristics) are exogenous. All models generate theoretically credible and empirically plausible parameter estimates and confirm our hypotheses regarding the simultaneity of timber and nontimber amenity supply decisions by private forest landowners. We also note that owner and management characteristics influence joint production decisions. In addition to empirically characterizing the level and distribution of forest inventory, this exercise generates consistent parameters of timber supply functions. Ultimately, we believe that the parameters estimated through such an integrated exercise could critically improve forest sector forecasting models and the related forest policy analysis.

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Table 1. Summary of micro-econometric studies of timber supply.

Study	LHS and technique	Elasticities	Other right-hand side variables
Binkley (1981) New Hampshire; 5-year panel	0 = Not harvest 1 = Harvest Logit	0.8 – 3.8	Area, income, age, education
Holmes (1986) Connecticut, cross-section	0 = Not harvest 1 = Harvest 0 = Not recreate 1 = Recreate 2 logits	n.a. n.a.	Income, forested acres, reforestation costs, timber prices, tech assistance, recreation and aesthetic value (scale)
Hyberg and Holthausen (1989) Georgia, cross-section	0 = Not harvest 1 = Harvest 0 = Not reforest 1 = Reforest 2 logits	n.a. n.a.	Income, land value, total and forested acres, reforestation costs, timber prices, tech assistance and extension
Dennis (1989) New Hampshire; thin panel	0 = Not harvest >0 = Harvest volume Tobit	7.7 – 4.1 price 1.1 – 0.9 stock	Stock, white pine%, red oak%, collar color, income, education
Dennis (1990) New Hampshire; thin panel	0 = Not harvest 1 = Harvest Probit	3.9 – 2.8 price 0.4 – 0.5 stock	Stock, white pine%, 3Y Treasury rate, collar color, income
Kuuluvainen and Salo[a] (1991) Finland; thin panel	Harvest volume Tobit	0.8 – 2.2 price 0.2 – 0.4 stock	Age (four dummies), loan (dummy), interest rate, wealth, income, area, farmer (dummy)
FASOM[b] (1993) National; time series (51-89)	OLS	0.3 SW 0.4-0.5 HW	
Newman and Wear[c] (1993) Southeast U.S.; cross-section	Profits, sale SURE	0.22 – 3.4	Stock, acres
Kuuluvainen et al. (1996) Finland; thin panel	Harvest volume Tobit; 3 separate	0.41 price 0.99 stock	Stock, ownership (four based on opinions), wealth, age
Lee[d] (1998) FIA; cross-section	0 = Not harvest 1 = Harvest	n.a.	Ecological indices, distance, forest cover, erosion
Prestemon and Wear[e] (1998) FIA; panel	0 = Not harvest 1 = Harvest Probit	0.29 – 9.8	Distance to road
Amacher et al. (1998) Virginia, cross-section	0 = Not harvest 1 = Harvest Several probits	n.a. n.a.	

n.a. = not available.

[a]TAMM—D. Adams and Haynes (1996) provide a number of industry supply elasticity estimates. The first set is based on time series data (1951 – 1989) and is categorized by lumber/softwood plywood/OSB and by 12 regions. The second set corresponds to private timber supply.

[b]The reported elasticities vary for the 0 and non-0 suppliers.

[c]Newman and Wear (1993) decompose estimates by owner, SR/LR, and sawtimber/pulpwood: NIPF (SR 0.22 – 0.33; LR = 3.38 – 0.35) and I (SR 0.27 – 0.58; LR 1.85 – 2.45)

[d]Lee focuses on a separate regression of amenity values (or marginal opportunity cost of harvest).

[e]The reported elasticities vary for sawtimber and pulpwood.

Table 2. Descriptive statistics of variables used in the empirical model.

Variable description		Unit	Mean	Std. Dev
QS	Timber supply for each species, owner, management type	1,000 ft^3	67	258
GSSK	Skewness of inventory (across five age classes) in each FIA unit, species, owner, management type	Number	0.83	0.73
GS	Inventory in each species, owner, management type	1,000 ft^3	10,208	16,236
Psw	Price of softwood sawtimber	$/1,000 ft^3	163	34
Phw	Price of hardwood sawtimber	$/1,000 ft^3	94	20
Nipf	1 if NIPF; 0 if otherwise	0 or 1	0.53	0.50
Np	1 if natural pine; 0 if otherwise	0 or 1	0.25	0.44
Pp	1 if pine plantation; 0 if otherwise	0 or 1	0.33	0.47
Inc	State average income management	$(Billion)[a]	11,0874	84,101

[a]$1990.

Table 3a. Three-stage least squares analysis of softwood timber supply, forest inventory distribution, and inventory volume (N=190).

	Model 1: OLS		Model 2: 3SLS GSSK endogenous		Model 3: 3SLS GSSK & LGS endogenous	
Equation variable	**Coeff**	**Pval**	**Coeff**	**Pval**	**Coeff**	**Pval**
LQS						
LPRICE	1.272	0.000	1.262	0.000	0.595	0.090
LGS	0.979	0.000	0.986	0.000	1.586	0.000
GSSK	-0.192	0.005	-0.288	0.002	-0.367	0.003
Constant	-9.087	0.000	-9.053	0.000	-13.114	0.000
GSSK						
NIPF			0.188	0.009	0.199	0.005
NP			-0.895	0.000	-0.852	0.000
PP			-1.169	0.000	-1.178	0.000
INC			0.0000002	0.625	0.0000001	0.745
Constant			1.236	0.000	1.230	0.000
LGS						
NIPF					0.130	0.155
NP					0.533	0.000
PP					-0.293	0.031
LPRICE					1.101	0.000
Constant					6.798	0.000
		Pval.	LREM	Pval.	LREM	Pval.
Model statistics	F(3, 200) = 152.9 Adj R^2 = 0.69	0.000	χ^2 (3) = 482.9	0.000	χ^2 (3) = 161.0	0.000
			GSSK		GSSK	
			χ^2 (4) = 211.5	0.000	χ^2 (4) = 211.0	0.000
					LGS	
					χ^2 (4) = 51.2	0.000

Table 3b. Three-stage least squares analysis of hardwood timber supply, forest inventory distribution and inventory volume (N = 204).

	Model 1: OLS		**Model 2: 3SLS GSSK endogenous**		**Model 3: 3SLS GSSK & LGS endogenous**	
Equation variable	**Coeff**	**Pval**	**Coeff**	**Pval**	**Coeff**	**Pval**
LQS						
LPRICE	0.315	0.233	0.454	0.074	0.961	0.002
LGS	0.911	0.000	0.754	0.000	-0.038	0.905
GSSK	0.076	0.456	0.660	0.001	3.077	0.002
Constant	-4.069	0.001	-3.384	0.006	1.471	0.620
GSSK						
NIPF			0.011	0.865	0.091	0.062
NP			-0.548	0.000	-0.627	0.000
PP			-1.310	0.000	-1.281	0.000
INC			0.000001	0.063	0.0000004	0.192
Constant			1.412	0.000	1.417	0.000
LGS						
NIPF					0.525	0.000
NP					-2.546	0.000
PP					-3.739	0.000
LPRICE					0.596	0.012
Constant					10.772	0.000
		Pval.	LREM	Pval.	LREM	Pval.
Model statistics	$F(3, 186) = 321.1$ Adj $R^2 = 0.84$	0.000	χ^2 (3) = 885.9	0.000	χ^2 (3) = 208.3	0.000
			GSSK		GSSK	
			χ^2 (4) = 263.2	0.000	χ^2 (4) = 259.9	0.000
					LGS	
					χ^2 (4) = 1151.2	0.000

APPENDIX A. LAND-OWNER'S OPTIMAL CHOICES: INFLUENCE OF AMENITY PREFERENCE ON OPTIMAL ROTATION

The owner-manager's objective is to maximize utility, U, from both income and nontimber amenities, and this is conditioned by their preferences, θ. This decision is subject to the following constraints. First, we have a simple biological growth constraint such that volume of timber, v, is a function of the age of the stand, a; the amount of land, L; and the quality of land, q. The volume at age a is

$$V(a; L, q) = \int_0^a v(a; L, q)\,dt \qquad (A\_1)$$

Second, total income available for consumption is the sum of income from exogenous, E, and timber sources. The timber income, evaluated when the forest is bare land, is the sum of an infinite (converging) series of timber income from the current and all future rotations less the sum of a perpetual series of annual rental payments, R, on L units of land:

$$\pi = E + \frac{Pe^{-ra}}{(1-e^{-ra})}\int_0^a v(a; L, q)\,dt - \frac{RL}{r} \qquad (A\_2)$$

Third, nontimber amenities are a function, n, of the amount of land owned, L, and the volume of timber on the land, V(a; L, q), that depends on the stand's age. Over the same infinite series of rotations, N represents the present value of the amenities.

$$N = \frac{\int_0^a n[L, V(a; L, q)]e^{-rt}\,dt}{(1-e^{-ra})} \qquad (A\_3)$$

Therefore, we can describe the decisionmaking in a lagrangian framework presented below.

$$\ell_{\pi,N,a} = U(\pi, N; \theta) + \lambda\left[N - \frac{\int_0^a n[L, V(a; L, q)]e^{-rt}\,dt}{(1-e^{-ra})}\right] + \mu\left[\pi - E - \frac{Pe^{-ra}}{(1-e^{-ra})}\int_0^a v(a; L, q)\,dt + \frac{RL}{r}\right] \qquad (A\_4)$$

The first-order conditions of this utility maximization are as follows:

$$1.\ \ell_\pi = 0 \Rightarrow \quad U_\pi = -\mu$$

$$2.\ \ell_N = 0 \Rightarrow \quad U_N = -\lambda$$

(A_5)

$$3.\ \ell_a = 0 \Rightarrow \quad (-\mu)PV_a(a;L,q) \quad + \quad (-\lambda)\frac{e^{-ra}}{1-e^{-ra}}\left[\frac{n(L,V(a;L,q)}{r} - N\right] \quad =$$

$$(-\mu)rPV(a;L,q) \quad + \quad (-\mu)r\left[\frac{e^{-ra}}{1-e^{-ra}}P\,V(a;L,q)\right]$$

By re-arranging terms, we get the Hartman (1976) result for the optimum time to harvest a stand generating income and amenity, expressed in utility terms. Note, the net annual amenity benefits expressed in the second term on the right-hand side are an expanded version of the term used in the Hartman formulation:

$$(U_\pi)PV_a(a;L,q) \quad + \quad (U_N)\left[\frac{e^{-ra}}{1-e^{-ra}}\right]\left[\frac{n(L,V(a;L,q)}{r} - N\right] \quad =$$

$$(U_\pi)rPV(a;L,q) \quad + \quad (U_\pi)r\left[\frac{e^{-ra}}{1-e^{-ra}}P\,V(a;L,q)\right] \qquad \text{(A\_6)}$$

APPENDIX B. WU-HAUSMAN TEST FOR ENDOGENEITY OF FOREST DISTRIBUTION (*GSSK*) AND VOLUME (*LGS*)

We hypothesize that forest distribution (*GSSK*) and forest inventory volume (*LGS*) are endogenous in the timber supply equation and investigate this endogeneity using a Wu-Hausman test (1978). A general implementation of Wu-Hausman's specification test compares an estimator that is known to be consistent with an estimator that is efficient under the assumption being tested. The null hypothesis is that the efficient estimator is consistent and efficient estimator of the true parameters. As opposed to a direct test of *GSSK*'s and *LGS*'s endogeneity, Davidson and MacKinnon (1993, 236-242) have noted that this Wu-Hausman test is best interpreted as evaluating whether OLS is a consistent estimator for the model. The null hypothesis is that the model was generated by an OLS process, and the test is performed under the assumption that the instrumental variables are consistent. As an alternative to the Wu-Hausman test, Davidson and MacKinnon suggest an augmented regression test that is based on the same asymptotic requirements as the Hausman test. Basically, we form the augmented regression by including the predicted value of forest inventory distribution (*GSSKhat*) and volume (*LGShat*) as a function of all exogenous variables and include the prediction in an OLS regression. The statistical significance on the coefficients on the predicted variables is a diagnostic of endogeneity. In augmented regression softwood and hardwood timber supply *GSSKhat* and *LGShat* are statistically significant at greater than 99% level of confidence.