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FUTURE LAND USE DECISIONS: TIMBER vs. AGRICULTURE

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The reversibility of land use is a key issue in the debate over the adequacy of the supply of farm land. With reversibility, changes in agricultural commodity prices can ensure a satisfactory supply of farmland. In general, it has been assumed that land which moves into residential, industrial or commercial use is irretrievably lost to agriculture, whereas land in forest, ranges, or deserts can reenter agricultural production whenever commodity prices rise sufficiently.

The purpose of this paper is to investigate the hypothesis that timber production is a residual land use. If this hypothesis is true, old fields which have entered timber production will revert to cropland if agricultural rents rise. Any gains in timber supply would then have to come from a decreasing forestland base. If, however, real timber prices rise at rates forecast for the next five decades (Adams and Haynes 1980), land currently used for timber production may not easily enter agricultural production. Some evidence that timber production enterprises will be able to compete successfully for marginal agricultural lands has appeared in studies of net returns to loblolly pine plantations in the Southeast (Hardie 1977) and Douglas fir plantations in the Northwest (Larson 1977).

Research in forest economics has given substantial attention to the optimum investment period for a timber crop. The Faustmann solution gives the harvest age which will maximize the return to a site which is assumed to produce timber indefinitely, provided prices, costs and the interest rate remain constant. Steady state price and cost assumptions are unsatisfactory for our purposes, however, for we wish to investigate the consequences of rising real timber prices. We therefore adapt the Faustmann soil rent model to allow for exogenous price and cost variation over time.

In this paper, we implement an empirical model which determines both the optimum harvest schedule and maximum net returns for a timber production site when prices and costs vary over time. The model also permits land to be shifted into agricultural production if economic returns warrant. This model is applied to representative sites in a region comprised of parts of Maryland, Delaware, Virginia and North Carolina. The economic model is presented in the next section. Then we summarize the biometric yield model and introduce the economic information used in the empirical analysis. The final section presents the results of the analysis and comments on the reversibility of land use between agriculture and forestry.

The Model

The general problem of planning timber harvests over a series of timber crops involves calculating the discounted net returns of various harvest schedules and choosing the schedule that gives the highest net present value. The return from any harvest depends on the physical productivity of the site, the market price of timber, and the costs of timber removal and reforestation. A general statement of the harvest schedule problem is:

$$R_t = \underset{A_i}{\text{Max}} \sum_{i=0}^{\infty} [P(T_i)\, Y(A_i) - C(T_i) + \lambda_i (T_i - T_{i-1} - A_i)]\, e^{-rT_i} \qquad (1)$$

where

R_t = net present return from the production of timber,

i = timber crop index,

A_i = age of stand at the i^{th} harvest,

$T_i = T_{i-1} + A_i$ = calendar date of the i^{th} harvest; let the T_i's be scaled such that $T_0 = 0$.

$P(T_i)$ = timber price at the i^{th} harvest,

$Y(A_i)$ = physical yield per acre,

$C(T_i)$ = per acre cost of establishing the i^{th} stand,

r = instantaneous discount rate,

$V(A_i) + P(T_i)\, Y(A_i) - C(T_i)$ = net return from the i^{th} harvest,

λ_i = Lagrangian multiplier

The yield function $Y(A)$ is expressed as a function of a single variable for convenience. In the empirical section its arguments will also include a measure of density and a site productivity measure. The theoretical yield function is assumed to be a concave increasing function of the age of the stand.

Model (1) is a formally consistent statement of the landowner's returns, but it is empirically intractable. More tractable versions can be obtained by adding various assumptions about the time paths of $P(T)$ and $C(T)$. For example, the Faustmann solution emerges if $P(T)$ and $C(T)$ are assumed to be constant or to grow at the relative rate r. Although this solution is widely recognized, its assumptions do not give an accurate reflection of the real world. To obtain a more realistic solution, we assume only that $C(T)$ and $P(T)$ will converge to constant values at some future date T_s. Then for j such that $T_j \leq T_s \leq T_{j+1}$, (1) can be written

$$R_t = \max_{\{A_i, A_f\}} \left\{ \sum_{i=0}^{j} \left[V(T_i, A_i) + \lambda_i (T_i - T_{i-1} - A_i)\right] e^{-rT_i} + \sum_{i=j+1}^{\infty} V(A_f) e^{-riA_f} \right\} \qquad (2)$$

where A_f is the Faustmann solution which in general satisfies

$$\partial V(A_f)/\partial A_f = rV(A_f)/(1-e^{-rA_f}). \qquad (3)$$

In (3), $V(A_f)$ is stationary: value increases only as a result of the physical growth of the trees.

A second possibility we wish to consider is that the returns to the site will increase if it is returned to agricultural production. To introduce this possibility, we define the soil rent accruing to the site as

$$R_s = \text{Max}\,[R_t, R_a].$$

R_a is the rent given that the site first produces timber and is then shifted to agriculture. R_t is the maximum net return from the perpetual timber enterprise given by equation (2).

To compute R_a, we solve a harvest scheduling problem which allows for a switch to agriculture

$$R_a = \underset{\{A_k, n\}}{\text{Max}} \sum_{k=0}^{n} [V(T_k, A_k) + \mu_k(T_k - T_{k-1} - A_k)]e^{-rT_k} + [\int_{T_n}^{\infty} M(t)e^{-rt}dt - S(T_n)]e^{-rT_n}. \quad (4)$$

$S(T_n)$ is the cost of removing slash and other debris, extracting stumps and preparing the land for agriculture. $M(t)$ is the annual return to land in agriculture. Thus (4) chooses the harvest ages or rotation length's, A_k, and the date to switch to agriculture, T_n.

In summary, the solution to the problem of determining R_s is given by

$$\text{Max} \begin{cases} \underset{\{A_t, A_f\}}{\text{Max}} \sum_{i=0}^{j} [V(T_i, A_i) + \lambda_i(T_i - T_{i-1} - A_i)]e^{-rT_i} + \sum_{i=j+1}^{\infty} V(A_f)e^{-riA_f} \\ \\ \underset{\{A_k, n\}}{\text{Max}} \sum_{k=0}^{n} [V(T_k, A_k) + \mu_k(T_k - T_{k-1} - A_k)]\, e^{-rT_k} + \int_{T_n}^{\infty} [M(t)e^{-rt}dt - S(T_n)]e^{-rT_n} \end{cases} \quad (5)$$

The empirical analysis based on (5) is introduced in the next section.

An Application

Our results rely in part on a survey of loblolly pine plantations in the study region. Among the sites sampled were a subset of old-field plantations, containing trees established on land previously used for agricultural purposes. The growth and yield functions developed for these plantations provide a good opportunity for applying model (5). The results of the analysis should be representative of the farmland-timberland margin, since the survey region is a highly productive timber area, has a viable agriculture sector, and the loblolly pine is one of the two most commercially important timber species in the United States.

The model requires a set of biological relationships, a discount rate, timber price forecasts and projections of timber production costs, market land rents and reforestation or land clearing costs. Long range price forecasts have been developed by Adams and Haynes and have been used in the 1980 national timber assessment and outlook (U.S. Forest Service). Cost and rent data for the study region present a more serious limitation, for the existing data series are inadequate to forecast these variables over even a single rotation.

These data considerations lead to the key assumption of the empirical analysis: prices and costs are allowed to vary independently over only one timber rotation; thereafter they assume steady state values. This decision takes cognizance of the fact that the yield estimates have little validity for timber stands over 50 years of age and that the available stumpage price forecasts do not extend beyond five decades. It also reflects the fact that historical time series for costs and agricultural rents span only 22 and 58 years, respectively. Because the land use decision is assumed to take place after a single rotation, the optimization indicated by model (5) can be accomplished by inspecting all feasible alternatives and choosing that which maximizes the infinite stream of net returns to the land.

Computation of the various soil rents comprising model (5) is accomplished by first estimating the sawtimber and pulpwood yields for rotations ending at five year intervals between 20 and 45 years of age. Then the Faustmann soil rent, the site rent when prices and costs vary over the first rotation, and the site rent when the land returns to agriculture after harvest are computed.

The Faustmann alternative assumes real prices and costs remain at 1980 values. The variable price and cost option assumes real prices and costs become constant as of the harvest date of the first stand of trees. In the option in which the land use changes, agricultural land rents are projected to the harvest date, the future value of the land in its agricultural use is determined, and this value is then discounted to 1980. These options are computed for three levels of soil fertility, a range that includes most of the existing plantations, and for real discount rates of 3 and 5 percent.

One subset of the biometric relationships used in the empirical analysis estimates tree heights and stand densities, which are expressed as the number of trees per acre. These estimates then become inputs into another subset of equations used to predict per acre yields. The yield relationships are published in Burkhart <u>et al</u> (1972).

Table 1 gives equations and selected values for the economic forecasts and projections used in the analysis of the land use tradeoff. The prices in Table 1 are calculated from the U.S. Forest Service "equilibrium" forecasts. Costs and agricultural rents are assigned different values, chosen to span what we regard as the relevant range of future values for these variables. Those particular alternatives in Table 1 which are labeled "extrapolations" extend the historical trends embodied in the available data series. The other alternatives come from parametric variation of the coefficients in the interpolation equation for the extrapolations. The annual costs included in the table reflect current land taxes for woodland in the study region.

Results

Results for representative loblolly pine plantations in the study region are displayed in Tables 2, 3 and 4. Each table gives the optimum harvest ages and discounted net returns for one of these options. Results in Table 2 come

Table 1

Economic Values Used in the Soil Rent Analysis

Item**	Projected Values					Interpolation Equation*		
	1990	2000	2010	2020	2030	intercept	slope	exponent
Stumpage Prices								
sawtimber	89	112	138	164	191	69.72	1.46	1.13
pulpwood	6.22	7.04	7.99	9.06	10.21	5.67	.027	1.31
Costs at Harvest								
low	92	94	96	97	99	90.1	.0265	1.57
extrapolation	99	105	111	116	121	90.1	1.53	.77
high	106	116	126	135	143	90.1	2.78	.75
Annual Costs	2.5	2.5	2.5	2.5	2.5	2.5	0	0
Agricultural Rents:								
low	15	15	16	16	16	14.8	.0302	1.00
medium	16	17	18	19	19	14.8	.1280	.94
extrapolation	17	19	21	23	26	14.8	.1900	1.03
high	18	21	24	28	32	14.8	.2645	1.06

*Equation form: $Y = a + bT^c$ where T is time. T=10 at 1990.

**Units of measure are as follows:

sawtimber - dollars per 1000 board feet
pulpwood - dollars per cord
costs and rents - dollars per acre

from the Faustmann assumptions. Real prices and costs are set at their 1980 values for the successive timber crops in this option. Prices and costs for option 2, presented in Table 3, are assumed to follow the trends given in Table 1 for one rotation, and then to take the values attained at the end of this rotation for the subsequent timber crops. The results given in Table 4 for the third option are also derived from the price and extrapolated cost trends of Table 1. But in this option, the site reverts to agricultural production after one timber crop. The Faustmann solution is introduced to provide a benchmark against which to assess the generalized model (5). The other two options comprise the two alternatives built into this model.

As the tables indicate, optimum harvest ages generally follow theoretical expectations. Rotation lengths decrease with increases in site productivity, decrease with increases in discount rates, increase with increases in timber price trends, and decrease marginally with increases in the agricultural land rental rates. Overall, the optimum harvest ages remain within a 10 year interval, with the same age being optimum over a relatively wide range of net returns. This interval may not include the true optimum for the low site index and low discount rate case. Harvest ages for the Faustmann solution are generally shorter than they are for the other options. They are also insensitive to the changes introduced in the timber price-harvest cost ratio (cf. Clark 1976, pp. 262-3). Real prices are comparatively higher relative to costs in the Faustmann solutions derived for the subsequent crops in Table 3, yet the optimum harvest ages are the same as those of the traditional analysis summarized in Table 2.

One rather outstanding result is the crucial importance of the site productivity index to the discounted net returns. If the real discount rate is

Table 2
Option 1: Results from the Soil Rent Analysis Given the Faustmann Soil Rent Model

	3% Discount Rate			5% Discount Rate		
	Site	Site	Site	Site	Site	Site
Item	50	60	70	50	60	70
Harvest Ages	40	35	35	35	35	30
Discounted Net Returns*	81	348	1047	-32	76	375

*in dollars per acre.

Table 3
Option 2: Results from the Soil Rent Analysis Given Variable Prices, Costs and Perpetual Timber Production

	3% Discount Rate			5% Discount Rate		
	Site	Site	Site	Site	Site	Site
Item	50	60	70	50	60	70
Harvest Ages						
first crop	45	45	40	40	40	35
subsequent crops	40	35	35	35	35	30
Discounted Net Returns*						
low costs	383	999	2466	66	302	917
extrapolated costs	376	991	2458	63	299	913
high costs	369	983	2449	60	295	910

*in dollars per acre.

Table 4
Option 3: Results from the Soil Rent Analysis Given Land Shifts to Agricultural after One Rotation

	3% Discount Rate			5% Discount Rate		
	Site	Site	Site	Site	Site	Site
Item	50	60	70	50	60	70
Harvest Ages	45	45	40	35	40-35**	35
Discounted Net Returns*						
low rent	424	861	1821	107	302	804
medium rent	453	890	1849	117	310	813
extrapolated rents	497	934	1894	131	322	827
high rent	544	981	1942	145	337	845

*in dollars per acre.

**Age 40 for low and medium rent, age 35 for extrapolated and high rent.

Computer time supplied through the Computer Science Center, University of Maryland.

fixed at 3 percent, the discounted net returns for the site index 70 plantations are almost 1,200 percent higher than those for the site index 50 site. This difference is not as great for the variable price timber production option 2, but net returns are still 554 percent higher if production takes place on the best sites instead of the poorest. This difference is moderated when land use is assumed to shift to agriculture: soil rents on the premium sites are 281 percent higher than they are on the poorest sites. For all alternatives, however, the results strongly suggest that high productivity timber sites have the best timber production investment potential.

An increase in the discount rate substantially decreases the present value of the net returns. For the high productivity lands in option 2, an increase in the discount rate from 3 percent to 5 percent decreases discounted net return from $2,458 per acre to $913 per acre, a 63 percent drop. For option 3, soil rent decreases 56 percent. Similar decreases result for the site index 60 and 50 plantations. For option 2, discounted net returns drop 70 and 83 percent, respectively, while for the land use shift option discounted net returns decrease 66 and 70 percent. Variation associated with the choice of discount rate is so substantial in the formulated alternatives that unrealistic soil rent values result when discount rates are varied much beyond the 3-5 percent range.

The effect of the model's price, cost, and rent assumptions can be gauged by comparing Table 2 with Tables 3 and 4 for a fixed discount rate and site productivity index. Net returns are naturally higher for the dynamic cases than for the Faustmann case, because prices and rents in Table 1 generally grow faster than costs. But harvest age comparisons are valid. Under the price-cost assumptions of Table 1, the Faustmann harvest age is uniformly lower than that for the perpetual timber or the switch to agriculture cases.

Comparisons about the relative gains of perpetual timber vs. agriculture are also valid. Given a 3 percent discount rate and a 70 site index, discounted net returns increase 135 percent when option 2 is ocmpared to the Faustmann case and 80 percent when option 3 is compared to option 1. Relative gain in soil rent due to the generalization of the model's price, cost and agricultural rent assumptions is therefore greater for the perpetual timber production case. This pattern also holds for the site index 60 sites but it reverses for site index 50. In the latter case, net returns increase 364 percent when options 1 and 2 are compared and 514 percent when options 1 and 3 are compared.

The optimum choice of land use varies with the quality of the site but not necessarily as one might expect. Given the options considered in Tables 3 and 4, the results indicate that the site index 50 lands would earn more if they were switched into agricultural production at the end of the first rotation, but that the best sites would be more profitable if they are left in timber production. This result may be due, in part, to the use of an average agricultural rent for all sites. Such an average would over-value the agricultural alternative for the poor sites and undervalue it for the high sites. This inherent bias can be partly compensated for by using the low rent option in Table 4 for site index 50 and the high rent option for site index 70. Even if this is done, however, the conclusions about the optimum land use pattern remain intact. The best sites would earn more in timber production then they would if shifted to agriculture. The average site's best use would vary depending on the discount rate, and the poorer site's best alternative would be agricultural production.

These comparisons represent our test of the hypothesis that prime timberland is easily converted to agricultural production. Given the limitations of the data, the model and the necessity of forecasting decades into the future, the results indicate that irreversibilities of land use are present at the extensive margin for agricultural cropland. Old fields with better soils receive greater returns in timber production and are not likely to revert to agricultural use. These results are limited to a single region of the United States, but they may be indicative for other lands on the timberland-cropland margin.

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