Journal of Forestry, 2022, 133–144
https://doi.org/10.1093/jofore/fvab048
Research Article - economics
Received November 12, 2020; Accepted August 16, 2021
Advance Access publication October 11, 2021

Research Article - economics

Price Premium Requirements for Growing Higher Quality Pine Sawtimber in Even-Aged Systems in the Southeastern United States

Arun Regmi[1], Donald L. Grebner[1,*], John L. Willis[2], and Robert K. Grala[1]

[1]Department of Forestry, Mississippi State University, Mississippi State, MS 39762, USA (arunregmiiof@gmail.com, don.grebner@msstate.edu, r.grala@msstate.edu). [2]Southern Research Station, USDA Forest Service, Auburn, AL 36849, USA (john.willis@usda.gov).

*Corresponding author: Email: don.grebner@msstate.edu

Abstract

Intensive pine silviculture has become the dominant management paradigm in the southeastern United States. Although productivity has been substantially increased by the combination of cultural, silvicultural, and genetic advancements, wood quality is sometimes sacrificed in intensive silviculture. Extending the optimal rotation allows trees to grow more timber, which may result in the production of better quality sawtimber; however, landowners may require incentives to do so. We simulated loblolly, slash, shortleaf, and longleaf pine for growth and yield using the Forest Vegetation Simulator (FVS) to determine sawtimber price premiums landowners would require to offset the costs associated with delaying the final harvest by 10 to 30 years in even-aged systems. Required incentives increased with the length of harvesting delay beyond the financially optimal rotation age. On medium productivity sites, landowners would be willing to delay the final harvest by 10 years for sawtimber price premiums of $5.06/ton (20.47%) for loblolly, $5.34/ton (21.6%) for slash, $4.56/ton (18.45%) for longleaf, and $6.71/ton (27.14%) shortleaf pine, respectively. Harvest delays of 10 to 20 years were financially justifiable, whereas extensions exceeding 30 years were prohibitively costly for all species. Delaying the optimal harvest could benefit landowners by generating a premium price for their sawtimber while providing important ecosystem services.

Study Implications: The study findings will provide a baseline resource for forest landowners and managers who are interested in growing higher-quality and larger-diameter pine sawtimber to longer rotation ages to obtain a premium price. The results will also be helpful to primary forest product industries (e.g., sawmills) who prefer high-quality pine sawtimber and are considering offering a price premium for higher-quality pine sawtimber. Findings can be useful for those interested in managing forests for multiple benefits (e.g., timber production, wildlife hunting leases, carbon credits, and other ecosystem service incentives), as managing stands on longer rotations can provide the dual opportunities of receiving price premiums for higher-quality sawtimber while simultaneously generating revenue from nontimber benefits, which may help justify delaying the final harvest. Our findings can also help make policymakers and forest managers more aware of the minimum price premiums required to offset the revenue loss accrued by delaying the final harvest.

Keywords: extended rotation, price premium, southern pine, rotation length

The southeastern United States is regarded as the leading region in North America for intensive silviculture and industrial timber production (Allen et al. 2005). In recent decades, forest landowners have increasingly focused on maximizing revenue by cutting small sawlogs (often 30–40 cm small-end diameter) on a 20–30-year rotation (Allen et al. 2005, Guldin 2011). Whereas many factors have contributed to the expansion of intensive silviculture (Sedjo and Botkin 1997, Fox et al. 2007, Howard et al. 2017), one of its primary advantages is the ability to quickly recover establishment costs and other initial investment expenditures (Guldin 2019).

Managing pine plantations with intensive silviculture also has potential consequences for some elements of the forest product industry. One specific concern is a decline in the quality of wood being produced (Zobel 1981, 1984, Barbour et al. 2003, Dobner et al. 2018). Here, wood quality refers to wood properties, such as growth ring tightness, latewood:earlywood ratio, and wood density, that are sought in solidwood products (Larson et al. 2001). Intensively managed pine plantations produce smaller-diameter sawtimber with lower wood density, a higher proportion of juvenile wood, and a smaller number of growth rings compared to naturally established pine stands (Zobel 1984, Biblis et al. 1998, Larson et al. 2001). The proportion of juvenile wood is a particularly important property in differentiating wood quality because it is considered to be relatively weak, less stiff, and inferior in quality to mature wood (Senft et al. 1985, Larson et al. 2001, Bendtsen and Senft 2007). Several studies have reported that the proportion of juvenile wood declines as a tree ages and puts on more latewood (Zobel et al. 1959, Zobel et al. 1972, Bendtsen and Senft 2007, Clark et al. 2007). For example, Carino and Biblis (2000) compared sawlog quality in 35–50-year-old loblolly pine plantations and found that wood quality for dimensional lumber improved with stand age and density. Thus, managing plantations on longer rotations may allow for the development of larger diameter sawtimber with the higher proportion of mature wood required for solidwood products.

Managing forests on longer rotations may also align with the objectives of landowners interested in a broad suite of ecosystem services (Roberge et al. 2016). For example, forests managed on a longer rotation can help sequester carbon for longer periods in standing timber and long-life wood products (Sohngen and Brown 2008, Röder et al. 2019). Likewise, cavities in older, large pine trees are considered optimal habitat for the endangered red-cockaded woodpeckers (*Picoides borealis)* (Bragg et al. 2015). Longer rotation lengths also have a positive affect on aesthetics, recreational values (Curtis 1997), water quality (Roberge et al. 2016), and microhabitat diversity (Lassauce et al. 2013). Thus, extending the final harvest beyond the financially optimal harvest age can not only improve wood quality by producing larger diameter sawtimber but also provide many ecosystem services (Zobel 1984, Roberge et al. 2016).

Numerous studies have considered the financial implications of increasing the rotation length to accomplish nontimber objectives such as carbon sequestration and wildlife habitat improvement. For example, several studies reported that the inclusion of carbon credits lengthens the financially optimal harvest age (Alavalapati and Stainback 2005, van Kooten and Sohngen 2007, Foley et al. 2009, Nepal et al. 2012, Susaeta et al. 2014) and makes pine plantations economically profitable (Huang and Kronrad 2006). Similarly, several other studies evaluated the economic trade-offs associated with multiple-use management of pine plantations for timber production or wildlife habitat and concluded that management regimes focused on timber production optimized land expectation value (LEV) in a shorter rotation than habitat centric regimes with relatively longer rotations (Barlow et al. 2007, Huang 2009, Davis et al. 2017). Collectively, these studies demonstrate that a longer rotation would increase the attainment of nontimber benefits; however, forest landowners required monetary compensation to justify forgone timber revenues resulting from the harvesting delay. To date, no studies have considered the economic prospect of extended rotation age to improve wood quality of southern pines.

Implementing a new management strategy typically introduces economic trade-offs. In the southeastern United States, forest landowners have increasingly focused on harvesting trees on short rotations to maximize the economic returns while sacrificing the quality of wood products (Allen et al. 2005). In contrast, extending the rotation age allows for the development of larger, higher-quality sawtimber that can be marketed to firms specializing in solidwood products. However, this comes with its own potential complicating factors. For example, delaying the final harvest beyond the financially optimal rotation age incurs net revenue loss over time. Consequently, forest landowners may prefer to harvest stands at the optimal rotation age from a financial perspective instead of waiting to obtain higher revenues from older stands but potentially facing a greater biological and financial risk. Thus, monetary incentives may be required to encourage forest landowners to delay the final harvest and forego an earlier return on investment (Davis et al. 2017). To our knowledge, no studies have evaluated the economic trade-off associated with delaying the final harvest to produce better quality timber. This void in the literature impedes the ability of forest landowners and researchers to evaluate the economic implications of managing forest stands for higher-quality pine sawtimber. Thus, the objective of this study was to evaluate the performance of four southern pines: loblolly pine (*Pinus taeda*), shortleaf pine (*Pinus echinata*), longleaf pine (*Pinus palustris*), and slash pine *(Pinus elliottii*) under even-aged management and determine the price premiums that may be required to incentivize a private landowner to take on the risk associated with increasing the rotation length by 10, 20, and 30 years. The information provided in this study will help landowners and firms make informed decisions about the production of higher-quality sawtimber.

Materials and Methods

Study Site

The Desoto National Forest in Mississippi was selected as a representative study site to collect data required for stand growth simulations. This site was selected because, first, the Forest Vegetation Simulator (FVS) model uses national forests as reference locations to simulate stand growing conditions. Second, the Desoto National Forest lies within the "232" ecoregion category that represents the Lower Coastal Plain and Coastal Flatwoods soil regions of Mississippi (Cleland et al. 2007; Figure 1). This ecoregion consists of mixed loblolly-shortleaf pine and longleaf-slash pine cover types and is assumed to have pine growth characteristics similar to large areas of the broader southern United States where intensive pine silviculture is practiced.

Model Description

The FVS model, developed and maintained by the USDA Forest Service, was used to simulate stand growth. The FVS-SN (southern) variant lacks a full regeneration model, which requires scheduling regeneration by specifying input densities[1]. The FVS-SN variant predicts yield based on five-year periodic growth increment data. This periodic increment was selected because FVS has been shown to overpredict growth at longer intervals and underpredict growth at shorter intervals other than the default interval (Dixon 2002). FVS keyword TIMEINT was used to specify management actions, such as thinning, optimal rotation age, and extended rotation age, that occurred in a specific year. The MANAGED keyword was used to specify that the stand was established under managed conditions, because plantations generally have higher diameter growth rates than unmanaged stands (Dixon 2002). In the SN variant, however, this keyword is not available for shortleaf pine. Computing variables with the SpMcDBH function was used to generate

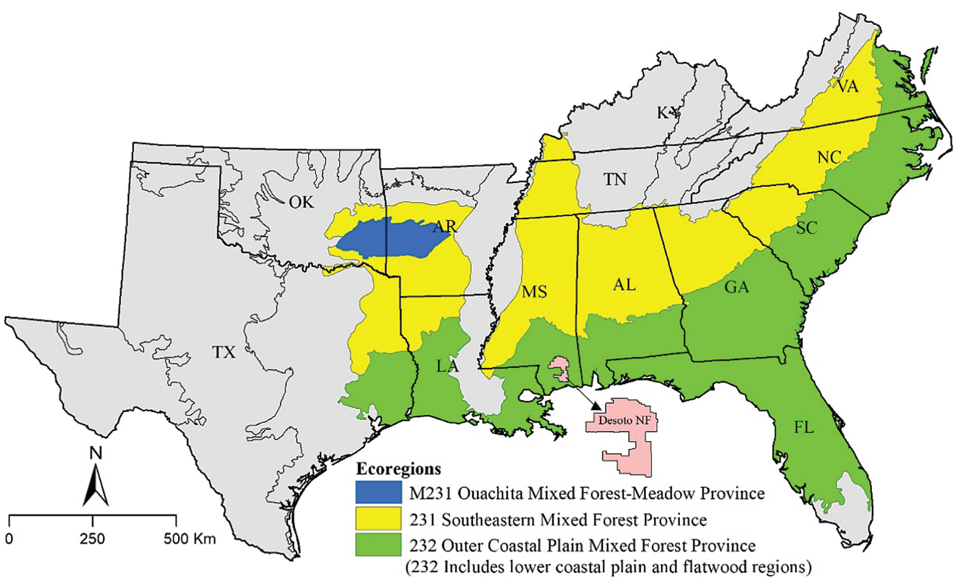

Figure 1. Study site and suitable habitat for southern pine species in the southeastern United States (Figure credit: Arun Regmi, 2019).

volume information for three different product types such as pulpwood [diameter at breast height (dbh) 16–23 cm], chip-n-saw (dbh 23–30 cm), and sawtimber (dbh > 30 cm) (Crookston and Dixon 2005).

Management Scenarios and Simulation

This study simulated the growth of the four most commonly managed southern pine species: loblolly pine, shortleaf pine, longleaf pine, and slash pine under multiple even-aged management scenarios across a range of site indices and planting densities (Figure 2). For interpreting results and discussion, an average representative site index of 27 meters (m) with a base age of 50 years was assumed to make the analysis consistent across species. Site indices of 24 m, 27 m, and 30 m (base age 50 years) were used for the sensitivity analysis. Thirty-six even-aged management scenarios (nine per species) consisting of a combination of planting densities and site indices were simulated (Figure 2).

The "bareground" option within the SN variant was used to establish plantations at initial planting densities of 1,537 (2.1 m × 3 m), 1,344 (2.4 m × 3 m), and 1,075 (3 m × 3 m) trees per hectare (TPH) (Londo et al. 2008, Guo et al. 2010). The simulation assumed bare root seedling survival rate to be 90% given a chemical and mechanical site preparation followed by a banded herbaceous weed control at year 1 (South et al. 2001). All management scenarios included a thinning from below. The frequencies, intensity, and timing of thinning were determined with Reineke's Stand Density Index (SDI) target (Reineke 1933). Stands were thinned to 35% of maximum SDI, the lower limit of full site occupancy, and at 55% of maximum SDI, where imminent mortality from self-thinning begins (Dean and Chang 2002). This study used maximum SDIs of 450 for loblolly pine and 400 for the other pine tree species (Ashton and Kelty 2018). A maximum of two thinning treatments were introduced and were scheduled to occur at least five years apart. The same thinning intensities were used for all scenarios regardless of the timing and frequency of thinning. Midrotation brush control was carried out two years after thinning to prevent interspecific competition.

Financial Analysis

Costs and Price Data

FVS provides yield output in cubic feet and board feet whereas price information is given in US dollar per ton. Thus, yield information was converted to tons using the conversion factors provided by Timber Mart-South (1 cubic meter [m^3] = 35.315 cubic feet [ft^3]). One short ton (2,000 lbs.) of green southern pine wood and bark has about 0.822 m^3 solidwood. The stumpage price of pine products was derived by taking the five-year average across the southern United States. Average prices for pulpwood, chip-n-saw, and sawtimber were \$9.93/ton, \$17.15/ton, and \$24.72/ton, respectively (Timber Mart-South 2013–2018). Stand establishment costs were obtained from Maggard and Barlow (2017). The costs for each management practice used in the simulations are presented in Table 1. Site preparation burning was applied only for simulations with longleaf pine.

Financial Analysis

Evaluation of LEV. The maximization of the LEV method was used to determine financially optimal management regimes for each species. The structural form of the LEV equation is written as (1):

$$LEV = \frac{NFV}{(1+r)^n - 1} \tag{1}$$

where *NFV* (US\$/ha) is the net future value at end of the rotation, n is the length of rotation, r is the real discount rate expressed as a decimal. All financial calculations were made using a 5% real discount rate, which is the commonly used real rate of return in financial analyses for nonindustrial private forest landowners in the southeastern United States (Bullard et al.

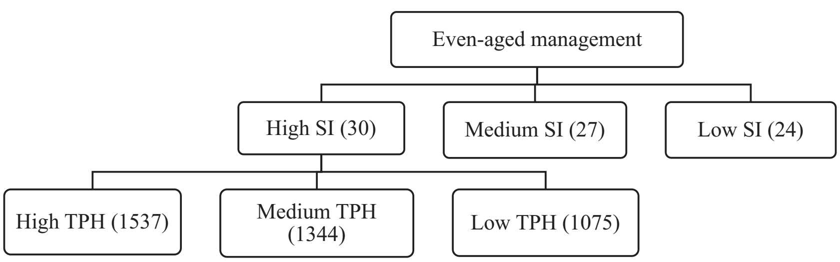

Figure 2. Even-aged forest management scenarios representing combinations of site indices and planting densities for simulating growth of southern pine species. SI = site indices (m) with the base age 50 years; TPH = trees per hectare.

Table 1. Silvicultural practices, timing, and costs for all management scenarios for southern pines in the southeastern United States.

Practice	Cash flow (US$/ha)	Year
Mechanical site preparation	348.39	0
Chemical site preparation	195.11	0
Site preparation burning	61.80	0
Precommercial thinning	393.98	5/10[a]
Per seedling cost (bareroot)	0.12	0
Planting labor cost	149.28	0
Banded herbaceous weed control	141.12	1
Midrotation release	153.50	2 years post thin

[a]Five years post-regeneration for loblolly and slash pine, 10 years post-regeneration for longleaf and shortleaf pine. (Source: Maggard and Barlow 2017).

2002). A sensitivity analysis was also conducted using 3% and 7% real discount rates to evaluate the impact of changing discount rates on LEVs, compensatory rates, and price premiums and reflect a potential change in market conditions.

The financially optimal management regimes with maximum LEV were identified for each pine species. Then, LEVs were calculated for 10, 20, and 30 years beyond the financially optimal rotation ages for evaluating two different trade-off values: (1) annual compensatory rates and (2) price premiums, necessary to justify growing southern pines on longer rotation ages. Compensatory rates were calculated in terms of land value (i.e., compensation required per unit forest area, US$/ha), whereas price premiums were calculated as a price premium required per unit sawtimber volume in terms of stumpage price (i.e., US$/ton). Financially optimal LEVs were considered as base values and compensatory rates and price premiums were calculated based on these base levels.

Evaluation of compensatory rates. Compensatory rates were calculated by converting periodic compensatory rates to annual rates. Periodic compensatory rates required for growing higher-quality pine sawtimber by delaying the final harvest by 10, 20, and 30 years beyond the optimal financial rotation age were calculated by subtracting the LEV at an extended rotation age from the optimal LEV (i.e., base LEV value), which is written as (2):

$$\text{Periodic Compensatory Rate (PCR)} = \text{Optimal LEV} - \text{LEV}_n \tag{2}$$

where, LEV_n is LEV at 10, 20, and 30 years beyond the base LEV.

A periodic compensatory rate was then converted into an annual compensatory rate for the respective rotation extension periods, which is structurally written as (3):

$$\text{Annual compensatory rate} = \frac{\text{PCR} \times i(1+r)^{\Delta n}}{(1+r)^{\Delta n} - 1} \tag{3}$$

where PCR is a periodic compensatory rate (US$/ha), r is a real discount rate, Δn is 10, 20, or 30 years (rotation extension periods).

Evaluation of price premiums. Because sawtimber price premiums are measured in terms of stumpage price (US$/ton), stumpage price required at an extended rotation age (SP_E) to justify the final harvest delay was calculated using an equation (4) further derived from (1), which is written as:

$$\begin{aligned} \text{LEV} &= \frac{\left[\text{FV}_{\text{R(pulp+CNS+Sawtimber)}} - \text{FV}_\text{C}\right]}{(1+r)^n - 1} \\ \text{FV}_{\text{R(sawtimber)}} &= \text{LEV}\left[(1+r)^n - 1\right] + \text{FV}_\text{C} - \text{FV}_{\text{R(pulp+CNS)}} \\ \text{SP}_\text{E}\ (\text{US\$/ton}) &= \frac{\text{LEV}\left[(1+r)^n - 1\right] + \text{FV}_\text{C} - \text{FV}_{\text{R(pulp+CNS)}}}{\text{V}_{\text{sawtimber}}} \end{aligned} \tag{4}$$

where LEV is land expectation value (US$/ha) at an optimal rotation age, n is extended rotation age (the rotation length extended by 10, 20, and 30 years past the optimal rotation age), FV_C is the future value (US$/ha) of all costs at the end of the rotation, FV_R is the future value (US$/ha) of all revenues from the pulp, chip-n-saw, and sawtimber at the end of the rotation, $V_{sawtimber}$ is sawtimber volume (tons/ha) at the end of the rotation, and r is a real discount rate.

A required sawtimber price premium for growing higher-quality southern pines by postponing the financially optimal harvest was then determined by subtracting current market stumpage prices (SP_C) from SP_E as follows (5):

$$\text{Sawtimber price premium (US\$/ton)} = \text{SP}_\text{E}\text{-}SP_\text{C} \tag{5}$$

where SP_E is the sawtimber stumpage price required for an extended rotation age and SP_C is the current sawtimber stumpage price in the market (i.e., $24.72/ton).

For the management regimes that produced a negative LEV, "break-even" price premiums were calculated such that they would yield a nonnegative LEV of $0/ha, so that the given management regimes would be financially acceptable at the given discount rate.

Results

Financial Analysis of Even-Aged Management

Table 2 illustrates the financial analyses for each species at each site index, assuming a 5% real discount rate. As expected, LEVs and compensatory rates rose as the site index increased, whereas optimal rotation lengths decreased as the site index increased. The medium planting density (1,344 TPH) was financially optimal for all species under all considered management scenarios. Except for longleaf and shortleaf pines on low-quality sites (SI 24), all site-species combinations produced positive LEVs. On the medium-quality site (SI 27), financially optimal rotation ages were 33, 36, 46, and 48 years, yielding LEVs of $1662.65/ha for loblolly pine, $998.85/ha for slash pine, $240.68/ha for longleaf pine, and $317.53/ha for shortleaf pine, respectively (Table 2).

Annual compensatory rates necessary to replace the forgone timber revenue from delaying the optimal rotation age by 10, 20, and 30 years were $45.37/ha, $68.47/ha, and $79.89/ha for loblolly pine; $34.45/ha, $49.12/ha, and $58.54/ha for slash pine; $19.20/ha, $29.85/ha, and $35.19/ha for longleaf pine; and $27.06/ha, $34.13/ha, and $38.77/ha for shortleaf pine, respectively. Similarly, price premiums necessary to justify extending the financially optimal rotation ages were $5.06/ton, $17.77/ton, and $37.92/ton for loblolly pine; $5.34/ton, $16.73/ton, and $36.9/ton for slash pine; $4.56/ton, $16.25/ton, and $34.65/ton for longleaf pine; and $6.71/ton, $18.28/ton, and $37.22/ton for shortleaf pine, respectively.

On the lower quality site (SI 24), longleaf and shortleaf pine produced negative LEVs of −$105.56/ha, and −$81.10/ha, respectively. Thus, required break-even price premiums for making 10-, 20-, and 30-year rotation extensions financially viable were $5.32/ton, $9.62/ton, $20.68/ton, and $41.01/ton for longleaf pine; and $3.19/ton, $8.62/ton, $20.65/ton, and $40.95/ton for shortleaf pine, respectively.

Yield Table

Table 3 represents total merchantable volume (US ton/ha) produced at the financially optimal rotation age and extended rotation ages, including diameter classes and quadratic mean diameter. Results indicated that delaying the final harvest allowed trees to increase in size and merchantable volume. On the medium productivity sites (SI 27m), maximum tree diameter was 43 cm for loblolly and slash pine at optimal rotation age, whereas delaying the final harvest by 10, 20, and 30 years increased diameter to 51 cm, 58 cm, and 66 cm for loblolly pine and 53 cm, 56 cm, and 61 cm for slash pine, respectively. Similarly, for longleaf and shortleaf pine, the maximum tree diameter was 43 cm at the optimal rotation age; diameter increased to 48 cm, 53 cm, and 61 cm for shortleaf pine and 46 cm, 48 cm, and 51 cm for longleaf pine at the corresponding delayed harvest ages. A similar trend was observed for the total merchantable volume. For example, loblolly pine accumulated a total merchantable volume of 355.76 ton/ha at the optimal age whereas it increased to 667.95 ton/ha at 30 years of rotation extension.

Discussion

This is the first study to conduct a comparative financial analysis for each of the four major commercially managed southern pine species to evaluate price premiums for higher quality sawtimber grown to a longer rotation age. The study findings are applicable to the forest products industry and forest landowners throughout the southeastern United States. Besides species considerations, we evaluated price premiums in terms of stumpage price (US$/ton) for pine sawtimber that is grown beyond the financially optimal harvest age. In contrast, several previous related studies evaluated economic trade-offs of managing pine stands for timber production, wildlife habitat, and/or carbon sequestration, and reported compensatory rates required for alternative management regimes in terms of land value (i.e., US$/ha) (Carley and Grado 1999, Huang and Kronrad 2006, Barlow et al. 2007, Huang 2009, Davis et al. 2017). Except for the price premium, the trend of LEVs and compensatory rates for a given site quality and discount rates reported in previous studies are consistent with our results; however, LEVs and compensatory rates vary. The discrepancy in LEVs and compensatory rates with past studies could be due to their focus on a single pine species and the use of different growth and yield models. In this study, we used the FVS model, not only because of its ability to simulate a wide range of tree species but also to maintain consistency in the analysis. A recent study by Davis et al. (2017), which used FVS to model loblolly pine growth, also found a similar trend in LEVs and compensatory rates for extending

Table 2. Results of financial analysis illustrating timber harvest timing (year), land expectation value (US$/ha), periodic compensatory rates (US$/ha), annual compensatory rates (US$/ha/yr.), and price premiums (US$/US ton) for growing higher-quality pine sawtimber on longer rotation ages for each site index (SI) with base age 50 years at 3% and 5% real discount rates and planting density (1,344 TPH) for southern pines in the Lower Coastal Plain and Coastal Flatwoods, Mississippi, USA, 2019.

		High SI (30 m)				Medium SI (27 m)				Low SI (24 m)			
r	Species and variables	Optimal	10-year	20-year	30-year	Optimal	10-year	20-year	30-year	Optimal	10-year	20-year	30-year
	Loblolly pine												
3%	Harvest year	15, 22, 34	44	54	64	16, 24, 34	44	54	64	17, 25, 40	53	63	73
	Land expectation value	6389.79	5472.92	4464.98	3346.30	5271.98	4719.06	3813.29	2939.68	3964.33	3370.09	2717.21	1971.77
	Periodic compensatory rate		916.87	1924.81	3043.50		552.92	1458.69	2332.30		594.24	1247.11	1992.56
	Annual compensatory rate		107.49	129.38	155.28		64.82	98.05	118.99		69.66	83.83	101.66
	Price premium		4.24	10.95	23.27		2.89	9.44	19.56		4.05	10.42	22.38
5%	Harvest year	15, 22, 32	42	52	62	16, 24, 33	43	53	63	17, 25, 35	49	59	69
	Land expectation value	2254.48	1714.47	1134.80	656.10	1662.60	1312.36	809.32	434.63	1073.61	832.52	456.93	141.53
	Periodic compensatory rate		540.00	1119.67	1598.37		350.25	853.28	1227.97		241.09	616.67	932.08
	Annual compensatory rate		69.93	89.85	103.98		45.36	68.47	79.88		31.22	49.48	60.63
	Price premium		6.66	19.64	42.87		5.06	17.77	37.92		4.32	15.46	35.12
	Slash Pine												
3%	Harvest year	15, 23, 35	45	55	65	17, 25, 38	48	58	68	19, 27, 41	51	61	71
	Land expectation value	5063.26	4272.33	3440.51	2609.76	3791.79	3309.66	2681.86	2014.79	2741.14	2416.91	1912.27	1398.83
	Periodic compensatory rate		790.93	1622.75	2453.50		482.13	1109.93	1777.00		324.23	828.87	1342.32
	Annual compensatory rate		92.72	109.07	125.18		56.52	74.60	90.66		38.01	55.71	68.48
	Price premium		4.45	11.30	22.37		3.39	9.35	19.50		2.79	8.57	17.90
5%	Harvest year	15, 23, 33	43	53	63	17, 25, 36	46	56	66	19, 27, 38	48	58	68
	Land expectation value	1636.58	1197.15	716.26	354.49	998.82	732.79	386.72	98.96	530.76	337.31	62.76	-151.68
	Periodic compensatory rate		439.42	920.32	1282.08		266.03	612.11	899.87		193.46	468.01	682.44
	Annual compensatory rate		56.91	73.85	83.40		34.45	49.12	58.54		25.05	37.55	44.39
	Price premium		6.69	20.04	41.66		5.34	16.73	36.90		4.90	16.16	34.13
	Longleaf pine												
3%	Harvest year	19, 28, 44	54	64	74	21, 31, 50	60	70	80	24, 35, 55	65	75	85
	Land expectation value	3468.27	3031.13	2461.46	1931.85	2426.65	2062.21	1613.70	1218.25	1589.15	1359.62	1053.33	759.92
	Periodic compensatory rate		437.14	1006.81	1536.41		364.44	812.95	1208.40		229.53	535.82	829.22
	Annual compensatory rate		51.25	67.67	78.39		42.72	54.64	61.65		26.91	36.02	42.31
	Price premium		3.24	9.05	17.21		3.56	9.70	18.00		3.14	8.58	16.59
5%	Harvest year	19, 28, 41	51	61	71	21, 31, 46	56	66	76	24, 35, 50	60	70	80
	Land expectation value	721.39	497.47	203.52	-31.74	240.68	92.46	-131.38	-300.34	-105.55	-199.37	-337.41	-456.16
	Periodic compensatory rate		223.92	517.87	753.13		148.21	372.06	541.02		93.82	231.85	350.60
	Annual compensatory rate		29.00	41.56	48.99		19.19	29.85	35.19		12.15	18.60	22.81
	Price premium		5.08	16.25	34.42		4.56	16.25	34.65		4.53	14.21	31.52
	Break-even price premium									5.32	9.62	20.68	41.01

Table 2. Continued

r	Species and variables	High SI (30 m)				Medium SI (27 m)				Low SI (24 m)			
		Optimal	10-year	20-year	30-year	Optimal	10-year	20-year	30-year	Optimal	10-year	20-year	30-year
	Shortleaf pine												
3%	Harvest year	21, 31, 47	57	67	77	23, 33, 49	59	69	79	26, 37, 56	66	76	86
	Land expectation value	3318.19	2920.55	2376.77	1871.42	2703.87	2377.98	1933.28	1504.62	1781.58	1511.76	1169.09	858.33
	Periodic compensatory rate		397.63	941.42	1446.77		325.89	770.59	1199.25		269.83	612.49	923.26
	Annual compensatory rate		46.61	63.28	73.81		38.20	51.80	61.18		31.63	41.17	47.10
	Price premium		3.00	8.47	16.06		3.01	8.16	15.66		3.22	8.72	16.20
5%	Harvest year	21, 31, 46	56	66	76	23, 33, 48	58	68	78	26, 37, 52	62	72	82
	Land expectation value	585.92	318.81	53.49	-158.75	317.53	108.51	-107.81	-278.45	-81.09	-202.49	-358.95	-486.07
	Periodic compensatory rate		267.11	532.42	744.67		209.02	425.34	595.98		121.40	277.86	404.98
	Annual compensatory rate		34.59	42.72	48.44		27.07	34.13	38.77		15.72	22.30	26.34
	Price premium		6.86	18.70	38.26		6.71	18.28	37.22		5.17	15.98	34.12
	Break-even price premium									3.19	8.62	20.65	40.95

the optimal rotation age to establish wildlife-centric management regimes.

As expected, our findings indicated that LEVs and compensatory rates increased as site index increased, which is consistent with previous studies (Barlow et al. 2007, Huang 2009, Mills and Stiff 2013, Davis et al. 2017). This trend is not surprising considering that growth and yield increased with site quality, which resulted in higher opportunity costs associated with delaying the final harvest on high-quality sites. Following a similar trend, results showed that harvesting higher-quality sawtimber on more productive sites required higher price premiums; however, absolute differences in price premiums are not substantial across site quality. This could be due to the use of constant product prices in financial analyses, as our analysis evaluated price premiums based on sawtimber volume and stumpage price. Another reason could be the lack of consideration of premium forest products, such as utility poles and supplemental revenue streams from nontimber products such as pine straw, which could have increased the financial competitiveness of longleaf pine.

A sensitivity analysis indicated discount rates as another highly influential factor in compensatory rates and price premiums. Due to the time value of money, the impact of the discount rate was higher on revenue received in later years. Revenues generated later in the rotation discounted heavier than that those generated in earlier years and impact increased with a discount rate increase. Hence, LEVs and compensatory rates decreased as the discount rate increased (Table 2). In contrast, price premiums increased with an increase in the discount rate. One possible explanation for this trend could be the proportion of sawtimber volume produced. Higher discount rates resulted in relatively shorter rotation ages and a lower proportion of sawtimber volume than longer rotations. Thus, at higher discount rates, a higher price premium would be required to justify the final harvest delay.

Factoring in site quality and species effects, the price premium for delaying the final harvest by 10 years generally ranged from \$4.56/ton (18.5%)[2] to \$6.86/ton (27.8%). The few exceptions to this pattern occurred on lower-quality sites (SI 24m) where negative LEVs were produced for shortleaf pine and longleaf pine. This is because longleaf and shortleaf pine feature relatively conservative early growth patterns and produce less sawtimber volume than loblolly and slash pine (Schultz 1997, Boyer 1999). Also, the FVS-SN variant does not allow the use of the MANAGED

Table 3. Yield table presenting diameter and merchantable volume (in US tons) obtained from optimal and extended rotation ages of the even-aged system on an average site at a 5% real discount rate.

Species and variables	Optimal rotation	Extended rotation		
		10-year	20-year	30-year
Loblolly pine				
Harvest year	33	43	53	63
DBH class (cm)	28–43	30–51	33–58	36–66
Total merchantable volume (ton/ha)	355.76	494.63	589.30	667.95
QMD (cm)	35.1	40.6	45.2	49.3
Slash pine				
Harvest year	36	46	56	66
DBH class (cm)	25–43	28–53	30–56	33–61
Total merchantable volume (ton/ha)	330.75	441.03	525.62	586.11
QMD (cm)	33.5	38.9	43.2	47.0
Longleaf pine				
Harvest year	46	56	66	76
DBH class (cm)	28–41	28–46	30–48	33–51
Total merchantable volume (ton/ha)	370.93	471.18	550.18	621.05
QMD (cm)	31.8	35.8	39.4	42.2
Shortleaf pine				
Harvest year	48	58	68	78
DBH class (cm)	28–41	28–48	30–53	33–61
Total merchantable volume (ton/ha)	426.97	532.91	620.53	703.76
QMD (cm)	33.3	37.3	40.4	43.4

QMD = quadratic mean diameter.

function for shortleaf pine, which negatively affects growth rates. The break-even price premium required to make longleaf and shortleaf pine economically viable on lower-quality sites were \$9.62/ton (38.9%) and \$8.62/ton (34.9%), respectively. Furthermore, for a 20-year rotation extension, the maximum price premium was \$20.68/ton (68.77%), including break-even price premiums, and it varied among all species and across site quality. Nevertheless, the price premium required to extend the rotation by 30 years was substantially larger (>100%) than the assumed base price (i.e., \$24.72) for pine sawtimber across all species and site quality. This shows that growing higher-quality sawtimber on extended rotation ages by 10 years might be financially viable, although a 30-year rotation extension may be prohibitively costly. In the case of a 20-year rotation extension, although the price premium seemed financially obtainable, justification may depend on the discount rates, market demand for large-diameter trees, and consumer preference. For example, our findings show that at the lower discount rate (3%), the price premium required for a 20-year extension was comparable with the price premium required for a 10-year extension at the higher discount rate (5%) (Table 2). Similarly, sensitivity analysis showed that, at a 7% discount rate, most management regimes produced negative LEVs at the optimal harvest age and thus required higher price premiums. This suggests that management regimes favoring sawtimber from older stands might be feasible but in market conditions reflecting lower discount rates; however, landowners would receive less premium than in the management regimes with higher discount rates (Table 2).

Across species, the compensatory rates required for delaying the final harvest were considerably higher for loblolly pine, followed by slash pine, shortleaf pine, and longleaf pine. This pattern could be attributed to differences in early growth among species, as loblolly and slash pine attain more volume earlier on most sites than longleaf and shortleaf pine, resulting in larger timber revenue (Schultz 1997). Thus, loblolly pine required greater compensation to justify a larger revenue loss. Alternatively, price premiums were slightly more for shortleaf pine, followed by slash pine, loblolly pine, and longleaf pine. Thus, from the perspective of a required price premium, implementing a longer rotation for longleaf and shortleaf pine might be favorable to produce better quality pine sawtimber while providing other ecosystem services (e.g., wildlife habitat). Likewise, compensatory rates for loblolly pine were about 50% more than those required for longleaf and shortleaf pines for the same rotation extension period. Thus, from a productivity perspective, the financially optimal rotation age for shortleaf and longleaf pine was 46 and 48 years, respectively, whereas that of loblolly and slash pine was 33 and 36 years, respectively. This implies that although compensatory rates were higher for loblolly and slash pine, forest landowners can receive timber revenues earlier from these pine stands than from longleaf and shortleaf pine stands. Early revenue will thus help offset the additional compensation amount paid for loblolly and slash pines.

Limitations

One limitation of this study is that we did not incorporate the revenue from nontimber benefits in the financial analysis. If revenues from nontimber products (e.g., a hunting lease or pine straw raking) were incorporated in the financial analysis, the LEVs would have increased and may have affected species differently. Mills and Stiff (2013) stated that including revenue from straw raking can make longleaf pine more financially competitive with loblolly pine. The production of utility poles was another important factor this study did not consider. This was not feasible using FVS projections because FVS does not provide the percentage of poles produced. Furthermore, pole standards are somewhat subjective and depend on location. Minimum required premiums were determined on top of the stumpage price at the stand level provided by Timber Mart-South. Thus, the quantified price premiums might not be sufficient to incentivize delaying the optimal harvests, because several factors, including buyer interest, log characteristics (e.g., log grade), and logger capacity to log and haul large-diameter trees, may affect the efficacy of a price premium.

Conclusions

We simulated the growth and yield of the four primary commercially managed southern pine species under even-aged management scenarios to determine the price premiums required for delaying the final harvest age. Growing sawtimber on longer rotations could yield higher price premiums, as the tree will continue to add biomass with time. However, the compensatory losses in LEV increase rapidly as the delay in the final harvest increases, with negative LEVs occurring when delays reach 30 years. Among species, loblolly pine is more profitable, with shorter rotations than other pine species, and thus required higher compensation to extend the rotation. There was no substantial difference in price premium among the pine species across site quality indices or discount rates.

Extending the final harvest to grow high-quality southern pines reduces LEVs in the absence of revenue compensation. We conclude that sawtimber price premiums ranging from $4.56/ton to $37.92/ton varying by site and species could justify rotation extensions in the range of 10 to 30 years. The study findings will help forest landowners in deciding whether to manage their forests for growing higher-quality pine sawtimber. In the southeastern United States, several forestry incentive programs (e.g., Longleaf Pine Initiative) provide financial support (e.g., cost-share) to landowners to manage their forests for different conservation objectives, such as reforestation, wildlife habitat management, sustainable forestry practices, and water conservation. Enrolling in such incentive programs could help landowners offset some of the costs associated with delaying the final harvest. Moreover, delaying the harvest may also benefit landowners by generating a premium price for their sawtimber while providing important environmental services (e.g., wildlife habitat, aesthetics, and recreation).

This research provides a baseline for future inquiries examining the prospects of growing higher-quality pine sawtimber on longer rotations. Potential future areas for research include determination of the minimum price premium that landowners would be willing to accept to change a final harvest decision, determination of whether there is market demand for high-quality pine sawtimber, identification of species preferred most by both landowners and market (e.g., sawmills), and quantification of how a delayed harvest strategy affects other industries requiring smaller trees (e.g., pulp and paper manufacturers, bioenergy and biomass processing facilities). Future research can also explore the impact of pine species on producing nontimber forest products and benefits.

Endnotes

1. Input specification of control variables [FVS-SN (southern) variant]: Location code (80702-Desoto National Forest in Mississippi); Ecological unit codes (232 Bj); Slope (0); Aspect (0); Elevation (30m); and Projection cycle length (5), and Stand Density Index (450 for loblolly pine and 400 for longleaf, slash, and shortleaf pine). Input values were specified using FVS keywords: STDINFO, SITE CODE, STDINFO, and SDIMAX.
2. Sawtimber price premium values were presented in percentages assuming base sawtimber price of $24.72/ton.

Funding

This material is based upon work that is supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture (USDA), McIntire-Stennis project under accession number 1014085 and in part by the USDA Forest Service. The findings and conclusions in this publication are those of the author(s) and should not be construed to represent an official USDA, Forest Service, or United States Government determination or policy.

Conflict of Interest

Authors declare no conflict interest.

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