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ANALYSIS

The influence of conversion of forest types on carbon sequestration and other ecosystem services in the South Central United States

Brent Sohngen [a,*], Sandra Brown [b]

[a]*AED Economics, Ohio State University, 2120 Fyffe Rd., Columbus, OH 43210-1067, United States*
[b]*Winrock International, Ecosystem Services Unit, 1621 N. Kent Street, Suite 1200, Arlington, VA 22207, United States*

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Abstract

This paper develops a forestland management model for the three states in the South Central United States (Arkansas, Louisiana, and Mississippi). Forest type and land-use shares are estimated to be a function of economic and physical variables. The results suggest that while historically pine plantations in this region have been established largely on old agricultural land, in the future pine plantations are likely to occur on converted hardwood-forest lands. This shift in the supply of land for plantations could have large effects on above-ground carbon storage and other ecosystem services. Subsidies of approximately $12–27 per ha per year would maintain the area of hardwood forests and reduce carbon emissions from the above-ground and product pool carbon stocks over the next 30 years. Across the several scenarios considered, results suggest that maintaining hardwoods could be an efficient carbon sequestration alternative.

Keywords: Climate change; Carbon sequestration; Econometrics; Land use

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1. Introduction

One of the most important trends in U.S. forestry is the expansion of planted pine forests in the South. Recent estimates suggest that pine plantations have increased by around 12 million ha over the past 40 years (Haynes, 2003). These trends are perhaps not unexpected, given the relatively larger returns possible in softwood forest management (i.e., Siry, 2002), and they are likely to continue well into the future (Alig et al., 2003; Alig and Butler, 2004). In the past, most of the new plantations have been established on harvested natural pine sites or on old agricultural lands. It is unclear whether these trends will continue in the future, or whether hardwood forests will instead be converted more often to pine plantations. Although there have been numerous studies investigating the conversion of agricultural land to forestry (i.e., Hardie

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* Corresponding author. Tel.: +1 614 688 4640; fax: +1 614 292 0078.

E-mail addresses: Sohngen.1@osu.edu (B. Sohngen), sbrown@winrock.org (S. Brown).

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and Parks, 1997; Plantinga et al., 1999; Stavins, 1999; Ahn et al., 2000), few, if any, studies have explored the relationship between natural and planted pine stands, and hardwoods. The one exception we found is Alig and Butler (2004), who use different methods but arrive at similar conclusions about the conversion of forest types.

Potential shifts in forest species allocation across a region are of interest for a number of reasons. Conversion of hardwood forests to planted pine stands could cause large ecological changes, such as a reduction in carbon storage in the region's forests. Brown and Schroeder (1999) and Brown et al. (1999) show that hardwood forests have higher annual wood production and higher carbon stocks than softwood forests. The USDA Forest Service Forest Inventory and Analysis data (USDA FIA, 2003) suggests that upland hardwood forests have from 45 to 80 t C/ha (1 t C = 1000 kg carbon) on average, depending on site quality, whereas pine stands have 21 to 55 t C/ha on average. Economic forces that favor pine plantations over hardwood forests could have large implications for future carbon balances in forests of the Southern U.S. The existing studies on land use change or forest management change have not examined the consequences of these forest type conversions on ecosystem services, such as carbon storage.

This paper uses a land-use share model, following Hardie and Parks (1997), to examine the mix of upland hardwoods and softwoods in a three-state region of the South Central U.S.: Arkansas, Louisiana, and Mississippi. In this study we focus on upland forests only, and do not consider bottomland forests because most upland species cannot profitably be planted on bottomland hardwood sites. A land-use share model is developed including information on the mix of species in different forest types. Unlike most previous logit models exploring land use (i.e., Hardie and Parks, 1997; Plantinga et al., 1999; Ahn et al., 2000), this study focuses more explicitly on forest types and breaks forest land into planted pines, natural pines, and upland hardwoods. In addition to the empirical estimates from an econometric model, a forest projection model is developed to project forest stocks over a 30-year time period using the estimates of the share equations and assumptions about forest harvests.

The forest projection model estimates changes in forest stock based on inventory age classes, and product stock, at 10-year intervals. The projections are used to assess the implications that shifts in the distribution of different types of forests may have on baseline carbon storage in the region. Finally, the land-use share and simulation model are used to examine the types of subsidies that could be used to maintain the stock of hardwoods in this region. In addition to assessing storage of carbon in aboveground carbon stocks, we also assess storage in product pools and potential emissions from biomass energy production with residuals. The results of the scenarios and analysis show how alternative systems for crediting carbon in forests could lead to large changes in the forest landscape in the future.

2. Land management econometric model

The econometric model estimates the proportion of land in different timber types and land uses. Land-use proportion models have been developed by various authors, mostly in the context of considering conversion from agricultural land to forests or vice versa (see Hardie and Parks, 1997). Following this earlier line of work, this paper estimates a logit model that predicts the shares of four types of land uses: planted pine, natural pine (including oak-pine), upland hardwoods, and agricultural land. Earlier studies using these techniques have aggregated forestland into a single forest type, whereas this study breaks forest shares into three different management types.

The proportion of land in one of these uses (planted pine, natural pine, upland hardwoods, and agriculture) in each county is expressed as a multinomial logistic function with explanatory variables such as forest rent for the type of forest, agricultural rent, urban rent, land quality indices, and dummy variables for particular years. Following Miller and Plantinga (1999), the functional form for the multinomial logistic model can be expressed as,

$$P_j = \frac{e^{\beta_j X}}{1 + \sum_{j=1}^{m-1} e^{\beta_j X}}, \qquad j = 1 \cdots m-1 \tag{1}$$

The left-hand side of Eq. (1) is the proportion of land allocated to usage j. X is the vector of independent variables and β is the vector of coefficients to be estimated. Under the assumption that P_j is distributed as a generalized extreme value distribution, the log-odds ratio (the ratio of P_j/P_m, for example) can be derived as a linear function of the parameters:

$$\ln\left(\frac{P_j}{P_m}\right) = (\beta_j - \beta_m)X \tag{2}$$

As noted in Hardie and Parks (1997), and Plantinga et al. (1999), parameter estimates for β_j can be obtained by setting $\beta_m = 0$, and assuming that the errors are normally and indentically distributed. For the land uses considered in our model, the specific equations estimated are:

$$\ln\left(\frac{\mathrm{PP}_i}{A_i}\right) = \beta_{0\mathrm{PP}} + \beta_{1\mathrm{PP}}X_{1i} + \beta_{2\mathrm{PP}}X_{2i} + \cdots + \varepsilon_{\mathrm{PP}A_i}$$

$$\ln\left(\frac{\mathrm{NP}_i}{A_i}\right) = \beta_{0\mathrm{NP}} + \beta_{1\mathrm{NP}}X_{1i} + \beta_{2\mathrm{NP}}X_{2i} + \cdots + \varepsilon_{\mathrm{NP}A_i}$$

$$\ln\left(\frac{\mathrm{UHW}_i}{A_i}\right) = \beta_{0\mathrm{UHW}} + \beta_{1\mathrm{UHW}}X_{1i} + \beta_{2\mathrm{UHW}}X_{2i} + \cdots + \varepsilon_{\mathrm{UHW}A_i} \tag{3}$$

where: PP_i = share of land in planted pine; NP_i = share of land in natural pine; UHW_i = share of land in upland hardwoods; A_i = share of land in agricultural (cropland only) uses; X_i: independent explanatory variables indexed to county i; β: vector of unknown parameters to be estimated; ε: normally distributed, iid error terms.

With the parameter estimates, the proportion of land allocated to the four land uses can be predicted for each unit of observation (counties in our case). The model can also be used to project future land uses by changing the vector X_i. For example, future rental values can be projected, and used to predict the area of land allocated to different types of forest and agricultural land uses.

3. Data sources

Data to parameterize this model were obtained from various sources. Forest type proportions over a historical period were obtained from the FIA database (USDA FIA, 2003). Researchers at the US Forest Service Southern Research Station have used the FIA data to compile the historical record of different forest types by county from the 1970s to the most recent surveys for the states (available on the website: http://www.srs.fs.usda.gov/econ/data/datatool.htm). Data on agricultural land were obtained from the US Department of Agriculture National Resources Inventory (NRI; USDA NRI, 2002). The FIA and NRI datasets were collected in different years in the three-state region of analysis (see Table 1), although the years overlap. To account for differences in years when the data was collected, NRI data for each state were interpolated between the years so the NRI data would conform to the years of the FIA data. FIA data available before the 1980s are not used in this analysis because no comparable county-level agriculture data from NRI are available for the 1970s.

A number of additional variables were also collected for the analysis. All of the variables used and the sources for the data are presented in Table 2. Rental values for the three types of forestland are estimated by calculating site values for forests of different land quality classes. Site values depend on the yield of forests, the price of stumpage, and the costs of management. Yield functions for the specific species on several different site classes in the region were estimated directly from FIA data on growing stock volumes and merchantable components. Current prices for sawtimber and pulpwood were obtained for different regions in the three-state area. Mississippi prices were obtained from Mississippi State University Extension (Mississippi State University Extension Service), Louisiana prices were obtained from the Louisiana Department of Agriculture (Louisiana Department of Agriculture and Forestry), and Arkansas prices were obtained from Timber Mart South (TMS). Prices are available for specific regions in each state for the periods listed in Table 1 (although they are not available for individual counties). Current estimates of planting and management costs are obtained from Siry (2002), Rogers and Munn (2003), and Dubois et al.

Table 1
Inventory collection times for FIA and NRI data in the sample region

State	Years collected
Arkansas FIA	1988, 1995
Louisiana FIA	1974, 1984, 1991
Mississippi FIA	1977, 1987, 1994
All states NRI	1982, 1987, 1992, 1997

Table 2
Variables used in regression analysis

Variable	Description
D80	Dummy variable for inventories in the 1980s
TOTAL	Total sawmills in the region (see http://www.srs.fs.usda.gov/econ/data/datatool.htm)
PPRENT	Rental values for planted pine (estimated from net present value analysis)
NPRENT	Rental values for natural pine (estimated from net present value analysis)
UHWRENT	Rental values for upland hardwoods (estimated from net present value analysis
CROPRENT	Rental values for cropland (estimated from USDA crop yields for major crops in region, and regional crop prices and costs of production obtained USDA Economic Research Service)
MVR	Dummy variable for counties in the Mississippi Valley region
HIFARM	Dummy variable representing counties with more than 50% agricultural land
DENS	Population density (US Census)
LAT	Latitude of the county
PPHI	Proportion planted pine in high sites (USDA FIA)
NPHI	Proportion natural pine on high sites (USDA FIA)
NPAVSI	Natural pine average site index (USDA FIA)
UAVSI	Upland hardwoods average site index (USDA FIA)
PPLLSL	Proportion of planted pine that is longleaf/slash
NPLLSL	Proportion of natural pine that is longleaf/slash

(1997). The interest rate for timber investments is assumed to be 6%, as suggested by Siry (2002) for Southern forest investments.

Net present values for each timber type, site class, and price region were calculated using the Faustmann formula, adjusted for management. For instance, many planted pine stands are managed with thinning, which can increase the overall value of the stand. To account for this, when estimating site values, planted pine stands were assumed to undergo a moderate thinning regime. Annual rents were then imputed using the interest rate. Rental values for the major forest types used in the estimation model (planted pine, natural pine, upland hardwood) in each county were estimated as a weighted average across current site classes in each county.

Rental values for cropland were estimated using budgets from USDA Economic Research Service (ERS) Commodity Cost and Return Data. Regional crop budgets for several major crops (corn, soybeans, and cotton) grown in the region were obtained and used to estimate crop rental rates as net returns above variable costs for each state in $ per unit grown. Cropland rental rates for each crop in each county are estimated using county average yields (USDA National Agricultural Statistics Service) for the individual years in question. County average cropland rental rates for all crops are then estimated by weighting these values across the area of crops in each county.

Several additional variables are used in the analysis. The number of sawmills in a county is included as this variable is expected to influence changes in planted pine in particular (TOTAL). In addition, because the Mississippi Valley Region (MVR) has distinctly different soils than other regions of the southern US, and is dominated by bottomland hardwoods, a dummy variable is used to account for the counties in the MVR region of the three states (MVR). A dummy variable is also used to account for counties with particularly large areas of agricultural land (>50% agricultural land; HIFARM). County latitude in degrees (LAT) is included in the analysis to adjust for variation in climate from north to south. The proportion of planted and natural pine stands on high quality sites (PPHI, NPHI) and the average site index of natural pine and upland hardwoods (NPAVSI, UAVSI) are also included. Finally, given that some parts of the region have distinctly different soils that support long-leaf and slash pines, the proportion of these species is included.

4. Econometric results

The results of the econometric analysis, based on 432 observations, are shown in Table 3. The regression is estimated as a seemingly unrelated system of equations. Many of the parameters are significant at the 1% or 5% level. As expected, higher rental values for planted pine, natural pine, or upland hardwoods increase the proportion of land devoted to the activity. Higher cropland rents increase the proportion of land devoted to agriculture. The MVR has a lower proportion of all types of forestland, as do counties with a higher proportion of farms.

Population density has a negative effect on the proportion of forestland relative to cropland. Higher latitude increases the proportion of forestland relative to agriculture, indicating increasing forestland areas further north in the region. This is particularly true for

Table 3
Parameter estimates of econometric forestland use model

	ln(PP/AG)		ln(NP/AG)		ln(HW/AG)	
	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.
Constant	−10.506	5.571	−19.451**	4.193	−26.399**	4.182
TOTAL	0.257**	0.092	0.344**	0.069	0.395**	0.069
D80	0.369	0.455	0.529	0.343	0.007	0.342
PPRENT	0.058**	0.010	−0.010	0.007	−0.028**	0.007
NPRENT	−0.012	0.016	0.038**	0.012	0.021	0.012
UHWRENT	−0.088**	0.020	−0.041**	0.015	0.027	0.015
CROPRENT	−0.013**	0.003	−0.017**	0.002	−0.016**	0.002
MVR	−2.195**	0.635	−1.966**	0.478	−1.272**	0.477
HIFARM	−3.461**	0.505	−2.842**	0.380	−3.208**	0.379
DENS	−0.007**	0.002	−0.005**	0.002	−0.004**	0.002
LAT	0.270	0.162	0.519**	0.122	0.699**	0.122
PPHI	0.227	2.528	4.387*	1.902	4.321*	1.897
NPHI	1.821	1.973	2.589	1.485	0.492	1.481
NPAVSI	0.421*	0.170	1.653**	0.128	0.312*	0.127
UAVSI	−0.014	0.158	−0.116	0.119	1.441**	0.118
PPLLSL	2.317	1.415	−2.779**	1.065	−3.233**	1.062
NPLLSL	4.185	2.943	5.630*	2.215	2.183	2.209

* Significant at 0.05.

** Significant at 0.01.

natural pine and hardwoods. The average site index for natural pines (NPAVSI) tends to increase the proportion of all types of forestland. Higher average site index for upland hardwoods (UAVSI) tends to decrease the proportion of pine and increase the proportion of hardwood. The proportion of planted pine that is longleaf/slash increases the overall proportion of planted pine, but reduces the proportion of natural pine and hardwood.

Approximately 9–12% of the land in the region is estimated to be in planted pine, with approximately 30% in natural pine, upland hardwoods, and agriculture in the baseline period (Table 4). In general, the model projects land areas consistently with actual data for the 1990s, although it under-projects the proportion of land in planted pine and agriculture, and over-projects land area in natural pine and upland hardwoods.

Table 4
Comparison of predicted land area values to FIA data for the mid 1990s

	Baseline estimated		FIA data	
	(ha)	(%)	(ha)	(%)
Planted pine	2,164,500	9.3	2,825,092	12.1
Natural pine	7,672,161	32.9	6,929,110	29.7
Upland hardwood	6,836,744	29.3	6,100,802	26.2
Agriculture	6,636,046	28.5	7,454,447	32.0
Total	23,309,450	100.0	23,309,450	100.0

5. Forest area and carbon projections

Projections of future land uses are made by adjusting the rental rates for future time periods, and re-projecting the area of land in alternative forest uses. In the 1990s, real southern pine sawtimber prices increased at 10–12% per year, and pulpwood prices increased 5–6% per year (Haynes, 2003). The USDA Forest Service Resources Planning Act (RPA) timber assessment suggests that sawtimber prices may continue to rise slightly over the next 20–40 years (0.2% per year), while pulpwood prices may rise 0.4% per year over the same time period (Haynes, 2003). Rental rates are a function of stumpage prices, growth rates, and technologies associated with removing timber stock. For this study we assume that the technology of growing trees and extracting additional products from the land continues to improve, and that prices rise at relatively modest rates so that planted pine rental rates increase at 1% per year. Natural pine and hardwood rental rates are also assumed to increase, although at more modest rates of 0.5% per year. The lower rate is used for these types because we assume that most technological advances occur within planted pine types.

By contrast, agricultural rents are assumed to decline at 1.0% per year. While crop yields for major commodities in this region (soybean, corn, cotton) have generally risen 1–2% per year according to the USDA Economic Research Service Commodity Cost and Returns Data, crop prices have fallen by similar amounts. Many input prices have risen, and consequently overall returns to growing crops in this region have fallen over the period 1975–2003. According to the Wescott (2005), these trends are likely to continue with prices for the major commodities in this region remaining relatively stable. For this analysis, therefore, we assume that crop rental values are declining at 1.0% per year over the next 30 years.

Table 5 (panel A) presents the projected land areas for each forest type and the change relative to the baseline projected value for the years 2010, 2020, and 2030. Because this study only considers above-ground carbon storage, and ignores soil carbon sequestration, agricultural land areas and carbon storage on agricultural lands are not shown in Table 5. The model predicts land use proportions, so total land in planted pine, natural pine, upland hardwoods and agriculture remains constant. Agricultural land areas can be calculated using the results on total land area shown in Table 4. The results suggest that large areas of land are expected to convert to planted pine species over the next 30 years, rising from 2.7 million ha to 6.8 million ha by 2030. All other land uses are projected to decline during the period. Most of the increase in planted pine offsets natural regeneration processes for hardwoods and natural pine. While the increase in planted pine represents an extension of current trends, upland hardwoods have also increased recently in this region as agriculture has converted to forests. These results indicate that less agricultural land overall shifts to forests in the future than in the past.

Table 5
Forest area inventories and carbon stocks (million tonnes carbon by the year given; 1 tonne = 1 Mg = 10^6 g; 1 Tg = 10^6 Mg)

	2000	2010	2020	2030	Average annual change
Panel A: Forestland area					
Million hectares					
PP	2.7	3.8	5.2	6.8	134.9
NP	7.6	7.6	7.2	6.6	−34.6
UHW	6.5	5.8	5.1	4.5	−68.9
Total forest	16.9	17.2	17.5	17.8	31.4
Panel B: Above-ground carbon stock in forests only (i.e., standing stock)					
Tg carbon					
PP	98.6	102.3	177.7	249.9	5.0
NP	468.5	372.3	334.1	322.7	−4.9
UHW	397.9	323.8	272.8	231.3	−5.6
Total forest	965.0	798.4	784.7	803.9	−5.4
Panel C: Carbon stock in forests and products					
Tg carbon					
PP	98.6	121.0	206.0	298.4	6.7
NP	468.5	427.6	426.4	445.6	−0.8
UHW	397.9	348.6	315.4	288.5	−3.6
Total forest	965.0	897.3	947.9	1032.5	2.2
E. Emiss.[a]		109.0	72.1	80.3	8.7

PP = planted pine, NP = natural pine, and UHW = upland hardwoods.

[a] E. Emiss. = Energy Emission = Carbon emission from using forest by-products in the energy stream over the previous 10 year period, i.e., for 2010, the 109.0 Tg is cumulative over harvests occurring during the period 2000–2009.

To estimate carbon storage in forests over the projection period, it is necessary to model forest inventory. For this analysis, forest inventories are projected by shifting the area of land in each age class over time, accounting for harvest removals and land use changes. Timber stocks for the timber types in each county in the region are projected using the following equation:

$$\mathrm{Area}_{a+1,t+1} = \mathrm{Area}_{a,t} - \mathrm{Harvest}_{a,t} - \mathrm{LUCO}_{a,t} + \mathrm{Regenerated}_{a=0,t} \tag{4}$$

In Eq. (4), $\mathrm{Area}_{a,t}$ is the area of land in age class a at time t, $\mathrm{Harvest}_{a,t}$ is the area of land harvested in the age class, $\mathrm{LUCO}_{a,t}$ is the area of land that moves out of the species, and $\mathrm{Regenerated}_{a=0,t}$ is the area of land regenerated in a species. The area of land regenerated applies only when age is 0. Planted pine species are assumed to be planted and natural pine and hardwood forests are assumed to regenerate naturally. Areas moving into and out of a timber type are estimated with the econometric model described above. The initial age class distribution for each forest type is obtained from USDA FIA (2003).

When land is shifted into forests from agriculture, for example, it enters through the term “$\mathrm{Regenerated}_{a=0,t}$”.

This means that when agricultural land is converted to forests, the forests are assumed initially to be at age 0. Over time, these forests will grow and accumulate carbon according to the yield functions calculated for this region and described above. When land shifts from forests into non-forest uses, wood material from land-use change is assumed to enter markets. The region is assumed to be a price taker on US and global timber markets, so that these additions to the market have no effect on price trends. While this assumption abstracts from the complexity of local markets in the region, large sub-regional price differences are unlikely to hold for the entire 30-year projection period. Thus, if hardwoods are harvested and converted to pine plantations, the wood material from these harvests are assumed to enter markets, but to have no influence on prices.

Traditional timber harvesting where species are regenerated in the same type also occurs within the region. This harvesting is assumed to occur at fixed rates throughout the projection period. That is, 100% of planted pine stands above 40 years are harvested each decade, 25% of the natural pine stands above 40 years are harvested every decade (2.5% per year), and 11% of the hardwood stands above 40 years are harvested every decade (1.1% per year). These estimates are derived from the FIA data, which suggests that 4.7% of (all) pine stands and 1.1% of hardwood stands are managed or otherwise affected by harvesting operations each year.

Growing stock volume in each period is derived from the inventory projections using timber yield functions estimated from USDA FIA (2003). Growing stock volume is then converted to carbon stocks using biomass expansion factors from Brown and Schroeder (1999). Carbon stocks in products are tracked using rates suggested by Row and Phelps (1996) and Winjum et al. (1998). First, we assume that when a softwood stand is harvested, 28% and 12% of the stand, respectively, are stored in solidwood and pulpwood products initially, 37% is used for energy, and the rest decays onsite. Onsite decay is assumed to occur immediately in our analysis. For hardwood stands, we assume that 13% and 15% of carbon, respectively, is stored in solidwood and pulpwood products initially, 41% is used for energy, and the rest decays onsite. Second, solidwood products are assumed to turnover at a rate of 0.5% per year and release carbon, while pulpwood i turns over at a rate of 1% per year. The term “turnover” is used to describe future emissions from wood products. Finally, in addition to estimating carbon fluxes in the forest and within products, emissions due to energy production are also calculated using the proportions above. Energy emissions are the carbon associated with the proportion of harvests used to produce biomass energy. Presumably, these emissions would offset emissions from using other sources of fuel to produce the same energy. If crediting systems eventually emerge to provide credit for using biomass fuels, these emissions could be used as credits against the use of fossil fuels for generating power.

Under these assumptions, carbon stock projections and energy emissions for the baseline case are shown in panels B and C of Table 5. The standing stock of carbon in forests is projected to decline by 162 Tg C (1 Tg = 1×10^{12} g) over the 30-year period, or approximately 5.4 Tg C/year. All of this loss results from reductions in the standing stock of carbon in natural pine and upland hardwoods, and the conversion of these stocks to planted pine. These reductions are more than made up by increases in the stock of carbon in forest products, however, so the total stock of carbon in forests and products in the region increases by 67.5 Tg C over the same projection period, or 2.2 Tg C/year. The largest gains in the marketed products occurs in natural pine, as large areas of natural pine forests are harvested and converted to planted pine stands.

5.1. Sensitivity and policy analysis

Several alternative scenarios of future expected land rental rates can also be considered. First, it is possible that rental rates for planted pine grow much more quickly than assumed above. For this case, a scenario where pine plantation rental rates are assumed to grow at 1.5% per year (rather than the 1.0% per year used above) is examined. Second, two policies are explored to maintain forests in hardwoods and natural pine stands. For environmental reasons, policy makers may wish to develop policies that encourage hardwood forest establishment or maintenance to ensure diversity across the landscape. One policy assumes a set of subsidy payments to landowners who maintain or invest in hardwood stands. The subsidy payments are designed as annual rental payments large enough to hold the area of hardwoods approximately constant across the 30-year analysis period. We assume that landowners recognize that these payments will continue indefinitely. They have no effect on rotation ages because they are contingent only on maintaining the cover type, and not upon the time in cover or the age of the trees.[1]

The set of payments that maintains the current total area of hardwood forests is $12 per ha per year for 2000–2010, $20 per ha per year for 2010–2020, and $27 per ha per year for 2020–2030. These subsidy payments are set such that the overall area of hardwoods remains constant throughout the projection period. The payments rise over time because the opportunity costs associated with maintaining hardwood versus shifting land to pine plantations rises as pine plantation rental rates rise. The second policy considered assumes the same size subsidy payments, but also pays individuals to hold or establish natural pine stands.

The results in Table 6 show that higher pine plantation rental rates nearly double the establishment of pine plantations. Annual rates of establishment rise from 135,000 ha per year to 251,000 ha per year. These higher rental rates also increase the total area of forestland by 330,000 ha in 2030 for the entire region. Emissions from changes in the above-ground carbon stock in forests also increase, from 5.4 Tg C/year to 5.9 Tg C/year. Additional product storage offsets these additional losses from above-ground storage, so that the net effect, when product storage is considered, is the same, 2.2 Tg C/year. Energy emissions increase due to larger harvests arising from conversions of hardwoods and the additional supply of softwood material.

The two subsidy scenarios show that emissions from above-ground carbon pools can be reduced if hardwoods and natural pine stands are preserved. Subsidizing hardwoods only reduces the annual loss of these forest types so that hardwoods remain nearly constant across the 30-year period. When only hardwoods are subsidized, losses in natural pine increase, and less overall land converts from agriculture into forests. Relative to the baseline, there are 210,000 fewer hectares of forestland in 2030 when hardwoods are subsidized. The hardwood subsidy raises the opportunity costs for establishing new pine plantations on all types of land, including agricultural land. The net effect on above-ground carbon stocks is positive, reducing annual carbon losses from forests to 3.1 Tg C/year. The net effect when product market storage is considered increases relative to the baseline case to 2.9 Tg C/year. This is somewhat surprising, but with lower harvests, the carbon emission from forest product turnover is also lower. Energy emissions decline with lower total harvest from the region. If the same subsidies are used both for natural pine and hardwoods, emissions from above-ground carbon storage can be further reduced to 2.7 Tg C/year, and the net forest and product market storage increases to 3.1 Tg C/year. Energy emissions decline.

Table 6
Average annual change in forest area and carbon stock between 2000 and 2030 under alternative scenarios

	Baseline	High plantation estimated rates	Subsidize hardwoods only	Subsidize hardwoods and natural pine
Million hectares per year				
PP	135	251	78	54
NP	−35	−92	−59	−37
UHW	−69	−117	4	8
Total	31	42	24	25
Changes in above ground C stock (Tg/year)				
PP	5.0	8.4	3.2	2.5
NP	−4.9	−6.6	−4.6	−3.5
UHW	−5.6	−7.7	−1.7	−1.8
Total	−5.4	−5.9	−3.1	−2.7
Changes in above-ground and product C stock (Tg/year)				
PP	6.7	10.0	4.8	4.2
NP	−0.8	−2.4	−1.3	−0.3
UHW	−3.6	−5.4	−0.7	−0.8
Total	2.2	2.2	2.9	3.1
Energy emission	8.7	9.4	6.6	6.4

PP = planted pine, NP = natural pine, and UHW = upland hardwoods.

We also conducted sensitivity analysis on the turnover rates of product storage, exploring alternatives up to 5% per year for carbon stored in pulp and paper products, and up to 2% per year for carbon stored in

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[1] The rental payments do influence land conversion decisions at the margin, however, and some landowners who convert from one use to another could harvest trees earlier than economically optimal without the subsidy payment.

solidwood products. Storage in above-ground carbon does not change; however, total net storage in forests and product pools does shift. Increasing the turnover rate alters net storage such that more annual net storage occurs in the scenarios where the area of softwood plantations increases. Total net storage is lower for the scenarios where hardwoods are subsidized. If turnover rates for product storage are higher, shifting stands towards softwood plantations provides net benefits to the atmosphere.

The results illustrate the trade-offs that could arise when designing policies to enhance storage. If only above-ground carbon is credited or if both above-ground carbon and market storage are credited, then subsidizing hardwood and natural pine maintenance, and hardwood establishment can be a useful tool for enhancing carbon storage. If credits are also provided for emission offsets in the energy sector, the analysis suggests that in the short term, there would be incentives to expand the stock of softwoods. We have not conducted a full life-cycle analysis of energy uses during harvesting, transportation, and processing wood products, however. Currently, the wood processing sector in this region produces 50–80% of its energy from biomass sources (US Department of Energy, Energy Information Administration, 2004), so any increase in harvesting and processing would also lead to additional fossil fuel emissions with current energy technologies. Additional analysis would need to be conducted to assess the full energy conserving potential of these alternative scenarios.

6. Conclusion

This analysis explores forest type adjustments in the U.S. South. In the past 30–50 years, substantial areas of softwood pine plantations have been established, mostly on abandoned agricultural land. At the same time, the area of upland hardwood forests has also expanded in the region. In the future, however, these trends may be reversed, as hardwood forests are converted to softwood pine plantations (i.e., Alig and Butler, 2004). Large conversions of upland hardwood forests and natural pine forests to more intensively managed pine plantations could have substantial impacts on ecological outcomes and carbon sequestration in particular. This study is one of the first to analyze these potential impacts combining economic and ecological data and modeling.

A multinomial logit share model is used to produce a model predicting the share of land in softwood pine plantations, natural pines, hardwoods and agricultural land in three South Central States: Arkansas, Louisiana, and Mississippi. Past models have considered aggregated forest areas rather than specific forest types. The results indicate that future establishment of softwood pine plantations is likely to occur at the expense of hardwood forests and natural pine forests rather than agricultural land. For example, the baseline results of the analysis project that 135,000 ha of planted pine will be established each year in the three-state region over the next 30 years, while 35,000 ha of natural pine, and 69,000 ha of upland hardwood forests are lost each year. Faster-than-anticipated growth in rental rates for softwood pine plantations could further increase the area of pine plantations and reduce the area of upland hardwoods and natural pine.

As natural pine and upland hardwood forests tend to hold substantially more carbon per hectare, the conversion of natural stands to planted stands could reduce overall carbon storage in above-ground carbon stocks. Under the baseline conditions, above-ground carbon is projected to decline by 5.4 Tg C/year over the 30-year period. Of course, most of the conversions involve harvests that store carbon in forest products, and the net effects of losses in above-ground storage and gains in product storage are projected to be positive (2.2 Tg C/year).

A policy scenario is examined to hold hardwood forests constant throughout the 30-year projection period. Holding hardwood forests constant could have environmental benefits by maintaining the natural forest cover on many sites, by improving biodiversity, and by increasing carbon stored in above-ground components. Subsidies required to hold hardwoods constant ranged from $12 to $27 per ha per year. Holding the area of hardwoods constant through the projection period reduces the emission of carbon from above-ground sources from 5.4 Tg C/year to 3.1 Tg C/year. It also increases the net storage of carbon in forests and products, to 2.9 Tg C/year, suggesting that the subsidies could have an environmental benefit. Using the same subsidy to maintain natural pine and upland hardwoods would further reduce carbon losses from above-ground stocks and net forest and product stocks.

These results raise an interesting issue regarding the storage of carbon on the landscape versus storage of carbon in the product pool. Currently, the Kyoto Protocol rules only consider storage of carbon on the landscape, without considering storage in wood products. Our sensitivity analysis on wood product storage suggests that the results are highly sensitive to the estimated turnover rates. Faster rates indicate that carbon benefits would accrue from shifting more land to softwood plantations whereas slower rates indicate that subsidies to maintain and enhance the hardwood stock would provide more carbon benefits. The U.S. is not part of the Kyoto Protocol, and can therefore develop its own rules and parameters for carbon accounting. If the rules the US develops do allow credits for carbon storage in products, this analysis indicates that, using the most conservative turnover rate estimates, carbon benefits would arise from maintaining and enhancing the hardwood stock.

Considering credits for energy emission offsets complicates the influence of potential carbon credits upon the landscape. Our results indicate the largest energy emissions, at current rates of usage of biomass in the energy sector, would arise from expanding softwood plantations—mainly because overall harvesting increases. Credits for fossil fuel emission reductions from biofuel usage in wood product mills thus could potentially further enhance the prospects for additional conversion of hardwoods to softwoods in the South Central US. We have not conducted a full life-cycle analysis, nor have we addressed potential adjustments in rotations and other changes that could occur if incentives for biomass energy were adopted.

These results thus illustrate not only the potential effects of continued conversion of softwoods to hardwoods, but also several issues associated with developing crediting systems for carbon sequestration. Without carbon sequestration credits, the Southern U.S. is likely to see substantial conversion of hardwood forests to softwood pine plantations in the future. This will reduce total storage of carbon in above-ground forest carbon pools, and forest product pools. Subsidies for maintaining the current area of hardwoods would increase total carbon stored in these two pools. Consideration of credits for wood biomass to offset energy emissions, however, suggests additional conversion of hardwoods to softwood plantations. Given the relatively large adjustments in total potential annual storage across the scenarios, how carbon credits are specified (i.e., what components get credited and what do not) could have large effects on the forest resource beyond the most commonly considered mechanism for storage—adding new forests on old agriculture.

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