The Influence of Conversion of Forest Types on Carbon Sequestration and other Ecosystem Services in the South Central United States.

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ABSTRACT

This paper estimates a forestland management model for the three states in the South Central United States (Arkanses, 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 hectare 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. If carbon credits allow for energy emissions offsets, however, there could be additional conversions of land to softwood pine plantations.

INTRODUCTION

One of the most important trends in US forestry is the expansion of planted pine forests in the South. Recent estimates suggest that pine plantations have increased by around 12 million hectares per year over the past 30 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 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 (FIA; USDA FIA, 2003) suggests that upland hardwood forests have from 45 to 80 t C/ha (1 t C = 1000 kg carbon), depending on site quality, whereas pine stands have 21 to 55 t C/ha. Economic forces that favor pine plantations over hardwood forests could have large implications for future carbon balances in forests of the Southern US. 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; and 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 above-ground carbon stocks, we also assess storage in product pools and potential credits for energy emission offsets. 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.

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 in each county is expressed as a multinomial logistic function with explanatory variables such as forest rent, agricultural rent, urban rent, land quality indices, and dummy variables for particular years. The functional form for the multinomial logistic model is expressed as,

(1) $$P_j = \frac{e^{\beta_j X}}{1 + \sum_{j=1}^{m-1} e^{\beta_j X}}, \; j = 1,,,m-1$$

The left-hand side of equation (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 following log of the ratios of proportions in different land uses can be expressed as a function of regressors and a normally distributed, independently and identically distributed (iid) error term, u_i:

(2) $$\ln\left(\frac{p_j}{p_m}\right) = \beta X + u_i$$

As noted in Hardie and Parks (1997), and Plantinga et al. (1999), equation 2 can be estimated as a single equation, or as a system when there are several land uses. Including all land use categories considered here, the model that we use is:

(3) $$\ln\left(\frac{PP_i}{A_i}\right) = (\beta_{0PP} - \beta_{0A}) + (\beta_{1PP} - \beta_{1A})X_{1i} + (\beta_{2PP} - \beta_{2A})X_{2i} +,,,,+\varepsilon_{PPAi}$$

$$\ln\left(\frac{NP_i}{A_i}\right) = (\beta_{0NP} - \beta_{0A}) + (\beta_{1NP} - \beta_{1A})X_{1i} + (\beta_{2NP} - \beta_{2A})X_{2i} +,,,,+\varepsilon_{NPAi}$$

$$\ln\left(\frac{UHW_i}{A_i}\right) = (\beta_{0UPW} - \beta_{0A}) + (\beta_{1UHW} - \beta_{1A})X_{1i} + (\beta_{2UHW} - \beta_{2A})X_{2i} +,,,,+\varepsilon_{UHWAi}$$

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 parameter estimates β, 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, if one assumes that rental values for planted pine will increase 1.0% per year over the next 30 years, one can estimate the rental value of land 30 years in the future, and use the value in the model to predict the area of land allocated to planted pine.

DATA SOURCES

Data to estimate this model was 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 1970's 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 was 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, NRI data for each state was interpolated between the years so the NRI data would conform to the years of the FIA data. FIA data available before the 1980's is not used in this analysis because no comparable county-level agriculture data from NRI is available for the 1970's.

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. (1997). The interest rate for timber investments is assumed to be 6%.

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). 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.

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 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 projected to be in planted pine, with approximately 30% in natural pine, upland hardwoods, and agriculture (Table 4).

In general, the model projects land areas consistently with actual data for the 1990's, although it under-projects the proportion of land in planted pine and agriculture, and over-projects land area in natural pine and upland hardwoods.

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. The USDA Forest Service Resources Planning Act (RPA) timber assessment suggests that sawtimber prices will continue to rise slightly, while pulpwood prices will decline slightly over the next 40 years (Haynes, 2003). For this study, we assumed that all forestland rents rise over the next 30 years, with the largest increases in rental rates occurring in planted pine (given larger projected management enhancements). Planted pine rental values are thus assumed to rise at 1.0% per year, with natural pine and hardwood rental rates rising at 0.5% per year. Agricultural rents are assumed to decline at 1.0% per year.

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. Agricultural land areas are not shown, although they are calculated. The results suggest that large areas of land are expected to convert to planted pine species over the next 25 – 30 years, rising from 2.7 million hectares to 6.8 million hectares 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.

To estimate carbon storage in forests over the projection period, it is necessary to model forest inventory. Timber stocks for the timber types in each county in the region are projected using the following equation:

$$(4) \qquad \text{Area}_{a+1,t+1} = \text{Area}_{a,t} - \text{Harvest}_{a,t} - \text{LUCO}_{a,t} + \text{Planted}_{a=0,t}$$

In equation (4), $\text{Area}_{a,t}$ is the area of land in age class "a" at time "t," $\text{Harvest}_{a,t}$ is the area of land harvested in the age class, $\text{LUCO}_{a,t}$ is the area of land that moves out of the species, and $\text{Planted}_{=0,t}$ is the area of land planted in a species. The area of land planted applies only when age is 0. 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).

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, and 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). In addition to tracking timber stocks on the landscape, 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 decay, or release carbon, at 0.5% per year, while pulpwood decay occurs at 1% per year. Finally, in addition to estimating carbon fluxes in the forest and within products, we also calculate an energy credit. Energy credits are the proportion of harvests used for energy purposes.

Under these assumptions, carbon stock projections and energy credits 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 X 10^{12} g) over the 30-year period, or approximately 5.4 Tg C/yr. 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/yr. 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.

Sensitivity and Policy Analysis

Several alternative scenarios of future expected land rental rates can also be considered. First, the possibility that rental rates for planted pine grow much more quickly than assumed above is considered. Specifically, 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 in order 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. The set of payments that just does this is $12 per hectare per year for 2000 – 2010, $20 per hectare per year for 2010 – 2020, and $27 per hectare per year for 2020 – 2030. Under these payments, the area of hardwoods remains relatively constant throughout the projection period. The second policy assumes the same 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 hectares per year to 251,000 hectares per year. These higher rental rates also increase the total area of forestland by 330,000 hectares in 2030 for the entire region. Emissions from changes in the above-ground carbon stock in forests also increase, from 5.4 Tg C/yr to 5.9 Tg C/yr. Additional product storage, however, 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/yr. The energy credit increases 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 substantially 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. Losses in natural pine, however, increase, and less overall land converts from agriculture into forests. Relative to the baseline, there are 210,000 fewer hectares 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/yr. The net effect when product market storage is considered increases relative to the baseline case to 2.9 Tg C/yr. This is somewhat surprising, but with lower harvests, there is also less decay from forest products. The energy credit declines with the 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/yr, and the net forest and product market storage increases to 3.1 Tg C/yr. The energy credit declines.

We have also conducted sensitivity analysis on the decay rates of product storage. We have explored alternatives up to 5% per year decay rates for carbon stored in pulp and paper products, and up to 2% per year decay rates for carbon stored in solidwood products. Storage in above-ground carbon does not change, however, total net storage in forests and product pools does shift. Increasing the decay rates alters net storage such that more annual net storage occurs in the two scenarios where softwood plantations are increasing the most. Total net storage is less for the two scenarios where hardwoods are subsidized. If decay 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 emissions offsets in the energy sector, the analysis suggests that 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.

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 estimate 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 hectares of planted pine will be established each year in the three state region over the next 30 years, while 35,000 hectares of natural pine, and 69,000 hectares 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/yr 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/yr).

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 to hold hardwoods constant ranged from $12 - $27 per hectare 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/yr to 3.1 Tg C/yr. It also increases the net storage of carbon in forests and products, to 2.9 Tg C/yr, 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 decay rates. Faster decay indicates that carbon benefits would accrue from shifting more land to softwood plantations whereas slower decay 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 decay rate estimates, carbon benefits would arise from maintaining and enhancing the hardwood stock.

Considering credits for energy offsets complicates the influence of potential carbon credits upon the landscape. Our results indicate the largest energy credits, at current rates of usage of biomass in the energy sector, would arise from expanding softwood plantations. Credits for fossil fuel emission reductions from biofuels usage in wood product mills thus would likely further enhance the prospects for additional conversion of hardwoods to softwoods in the South Central US.

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 US 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.

REFERENCES

Ahn, S., Plantinga, A.J., and Alig, R.J. 2000. Predicting future forestland area: A comparison of econometric approaches. *Forest Science*. 46:363-376

Alig, R.A., A.J. Plantinga, S. Ahn, and J.D. Kline. 2003. Land Use Change Involving Forestry in the United States: 1952 to 1997, With Projections to 2050. US Department of Agriculture, Forest Service, General Technical Report, PNW-GTR-587. Portland, OR.

Alig, R.A., and B.J. Butler. 2004. Projecting Large-Scale Changes in Land Use and Land Cover for Terrestrial Carbon Analyses. *Environmental Management*. 33 (4): 443-456.

Brown, S.L., and P.E. Schroeder. 1999. Spatial Patterns of Aboveground Production and Mortality of Woody Biomass for Eastern U.S. Forests. *Ecological Applications*. 9(3): 968-980.

Brown, S. L., P. Schroeder, and J. S. Kern. 1999. Spatial distribution of biomass in forests of the eastern USA. *Forest Ecology and Management* 123:81-90.

Dubois, M.R., K. McNabb, and T.J. Straka. 1997. Costs and Cost Trends for Forestry Practices in the South. *The Forest Landowner Manual 31st edition* 56(2): 7 – 13.

Hardie, I.W., and Parks, P.J. 1997. Land use with heterogeneous quality: An application of an area base model. *American Journal of Agricultural Economics*. 77: 299-310.

Haynes, R. 2003. An Analysis of the Timber Situation in the United States: 1952-2050. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, General Technical Report, PNW-GTR-560. Portland, OR.

Louisiana Department of Agriculture and Forestry. Various Years. Quarterly Report of Forest Products. http://www.ldaf.state.la.us/divisions/forestry/default.asp

Mississippi State University Extension Service. Various Years. Mississippi Timber Price Report. http://msucares.com/forestry/prices/archives.html.

Plantinga, A.J., Mauldin, T., and Miller, D.J. 1999. An Econometric Analysis of the Costs of Sequestering Carbon in Forests. *American Journal of Agricultural Economics*. 81: 821-824.

Rogers, W.R. and I.A. Munn. 2003. Forest Management Intensity: A comparison of timber investment management organizations and industrial landowners in Mississippi. *Southern Journal of Applied Forestry*. 27(2): 83-91.

Row, C., R.B. Phelps. 1996. Wood Carbon Flows and Storage after Timber Harvest. In: Samplson, R.N. and D. Hair (Eds). Forests and Global Change, Volume 2: Forest

Management Opportunities for Mitigating Carbon Emissions. Washington, DC: American Forests.

Siry, J. 2002. Intensive Timber Management Practices. Chapter 14 in Southern Forest Resource Assessment. US Department of Agriculture, Forest Service, Southern Forest Research Station. (See: www.srs.fs.fed.us)

Stavins, R.N. 1999. The Costs of Carbon Sequestration: A Revealed Preference Approach. *American Economic Review*. 89 (4): 994-1009.

Timber Mart South. Various Years. Compiled data on timber prices for Arkansas. http://www.tmart-south.com/tmart/

USDA Economic Research Service. Various Years. Commodity Costs and Return Data http://ers.usda.gov/data/costsandreturns/testpick.htm

USDA National Agricultural Statistics Service. Various Years. Quick Stats: Agricultural Statistics Data Base. http://www.nass.usda.gov:81/ipedb/.

USDA NRI. 2002. US Department of Agriculture, Natural Resources Conservation Service, National Resource Inventory. http://www.nrcs.usda.gov/technical/NRI/

USDA Forest Service. 2002. Southern Forest Resource Assessment, A multagency effort led by the USDA Forest Service's Southern Research Station. www.srs.fs.fed.us.

USDA FIA. 2003. US Department of Agriculture, Forest Service, Forest Inventory and Analysis. Website: http://www.fia.fs.fed.us/

US Department of Energy, Energy Information Administration. 2004. Renewable Energy Trends 2003, with preliminary data for 2003. http://www.eia.doe.gov/cneaf/solar.renewables/page/trends/trends.pdf

Winjum, J. K., S. Brown, and B. Schlamadinger. 1998. Forest harvests and wood products: sources and sinks of atmospheric carbon dioxide. *Forest Science* 44:272-284.

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 1980's
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

Table 3: Parameter estimates of econometric forestland use model.

	Ln(PP/AG)		Ln(NP/AG)		Ln(HW/AG)	
	Param	SE	Param	SE	Param	SE
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 0.01 and *=significant at 0.05.

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

	Baseline Estimated		FIA Data	
	Hectares	Percent	Hectares	Percent
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%

Table 5: Forest area inventories and carbon stocks (Million tonnes carbon by the year given; 1 tonne = 1Mg = 10^6 g; 1 Tg = 10^6 Mg). PP= planted pine, NP = natural pine, and UHW = upland hardwoods

	2000	2010	2020	2030	Average Ann. Chg.
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	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	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 Stock	965.0	897.3	947.9	1032.5	2.2
E. Credit[1]		109.0	72.1	80.3	8.7

[1] E. Credit = Energy Credit = 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.

Table 6: Average annual change in forest area and carbon stock between 2000 and 2030 under alternative scenarios. PP= planted pine, NP = natural pine, and UHW = upland hardwoods.

	Baseline	Hi Plantation Est. Rates	Subsidize Hardwoods Only	Subsidize Hardwoods & 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/yr)			
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/yr)			
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
E. Credit	8.7	9.4	6.6	6.4