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Forest land use responses to wood product markets

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ABSTRACT

Land use measurements collected by the Forest Inventory and Analysis (FIA) program allow for monitoring and modeling changes among a detailed set of land use categories. We analyze these data in the southeastern United States to test hypotheses regarding the influence of timber and other land rents, population growth, and various topographic position variables on transitions among rural and developed land uses. This region provides a complete and recent set of land use and forest measurement, is the most important and dynamic timber production region in the world, and increasingly is the focus of international policy debates regarding wood based bioenergy. This analysis is the first to link specific land use changes with forest conditions for modeling rural land use response. While previous studies have relied on aggregate measures of timber values, the detailed forest condition measures allow for site-specific estimates of timber quasi-rents, providing new and unique insights into the influence of timber market conditions on land use changes. Results provide an empirical analysis of the influence of timber rent on transitions to all other uses and specifically show that higher timber rents reduce transitions of forests to all other rural land uses as well as to developed land uses. The latter finding is unique and provides support for the claim that stronger timber markets enhance the area of forests and alter patterns of land use change including patterns of development in the southeastern United States.

1. Introduction

Land use patterns and changes are organized by numerous co-occurring factors related to human activities and the biophysical environment. In the southeastern United States, land use has been especially dynamic with a changing and diverse mix of agricultural, forestry, and developed uses in most areas. Over the past three decades, forest area has increased (Wear and Greis, 2013) while crop production has declined overall and become concentrated in several subregions, e.g. Florida, and the Mississippi Delta (Nickerson et al., 2011). At the same time, the South is among the fastest growing regional economies in the United States with commensurate growth in urban and other developed land uses (Wear, 2011). Assessments of forest conditions and likely future changes have raised questions about the long term trajectory of forest area as changing markets for goods and services from rural land uses interact with urban expansion (Wear and Greis, 2013). Recent policy debate regarding the sustainability of wood energy production from the region, especially in the form of pellets traded to Europe, raises questions about the potential for growing demands for forest products to stimulate derived demand for forest land and expansion in the overall forest land base (NRDC, 2015).

The objective of this study is to examine the influence of various factors, including timber, crop, and pasture rents on land use transitions in the southeastern United States with special attention placed on the potential response of existing forest land to changing forest market conditions. Like previous studies of land use changes (Plantinga et al., 1999; Hardie et al., 2000; Kline and Alig, 2001; Ahn et al., 2002; Plantinga and Ahn, 2002; Lubowski, 2002; Lubowski et al., 2008), we assume that land use choices are based on rent maximization consistent with the theories of Ricardo and von Thünen. Our study and its focus on forest transitions utilizes a previously unavailable dataset describing land use changes linked to the detailed forest condition metrics of the U.S. Forest Service FIA forest inventory, allowing for precise estimates of land use transitions and timber values and rents. Previous studies have utilized the National Resource Inventory dataset that cannot support a detailed assessment of forest conditions and valuations.

While the primary focus of FIA is on monitoring forest conditions, the sampling design covers all land uses across a regular grid and is assumed to produce an equal probability sample (Bechtold and Patterson, 2005). In our study area detailed land use has been collected on all inventory plots (including those with non-forest uses) since 2000. Inventory protocol now assigns detailed land use classes for the entire

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FIA plot set at stationary fixed points. The area frame structure of the inventory allows for estimating the full areal extent of land uses and land use transitions. The National Resource Inventory Program (U.S. Department of Agriculture, 2015) used in previous studies, is built on a different sampling scheme focused on agricultural conditions, and is limited to nonfederal land ownership. The FIA land use measures are based on comparable land use categories but include federal lands.

Furthermore, FIA's detailed observations of forest conditions allow us to develop a much more precise accounting of implied timber rents for all forested plots. While previous studies have relied on a single hypothetical forest management option using a Faustman formulation for planted pine or average stumpage prices at county or regional scales to proxy for timber rents (Mauldin et al., 1999; Plantinga et al., 1999; Kline and Alig, 2001; Ahn et al., 2002; Plantinga and Ahn, 2002), our calculation of timber rents derives from detailed observations of forest attributes and relevant timber prices for each forest plot. This allows us to empirically assess the maximum expected net present value for each forest plot defined by specific harvest options, critical information for addressing our study objectives.

2. Study area

Our study area is the southeastern region of the United States defined by the thirteen states from Florida to Kentucky and Virginia, and including eastern parts of Oklahoma and Texas (Fig. 1). The southeast contains a wide variety of ecosystems sustaining diverse array of flora and fauna (Golladay et al., 2016). The physiographic regions of the southeast include portions of the Atlantic Coastal Plain, the Appalachian Highlands, the Interior Highlands and Piedmont, Mississippi Delta, and the Interior Plains (Alig et al., 2003). Forest is the dominant land use in the study area and several states were estimated to be > 65% forested. The southeast is the largest producer of timber in the country (Wear and Greis, 2013). About 89% of forests are privately owned, of which one third are corporate land owners and two thirds are individuals or families (Butler and Wear, 2013). Corporate forests are largely held by real estate investment trusts and timber investment management organizations, but also include forest industry. Urbanization and development in general have accelerated in recent decades in the vicinity of large metropolitan areas especially those along the Atlantic and Gulf coasts and throughout the Appalachian Piedmont region. At the same time, large portions of the rural South have experienced steady depopulation with attendant implications for land use changes (Wear, 2011; U.S. Department of Agriculture, 2015; U.S. Census Bureau, 2016).

3. Methods

3.1. Theory

We estimate a land use change probability model to gauge how the probability of observing a land use change is influenced by a variety of variables. The modeling approach is generally consistent with a Ricardian land rent approach where we assume that land use observed at the beginning and end of the period is consistent with a risk-neutral landowner seeking to maximize returns. We estimate the discrete choice of transitions for each beginning period land use — i.e., separate models for initial forest, initial cropland, etc. We assume that landowners choose from a restricted set of land uses so that their use of land maximizes rent accruing to productive activity:

$$y_{ijt} = 1 \; if \; R_{ijt}{}^{*} = \max(R_{1jt}, R_{2jt},\ldots, R_{Kjt}) \tag{1}$$

where y_{ijt} is equal to one when land at location j is dedicated to land use i at time t. $R_{ijt}{}^{*}$ is the quasi-rent that accrues to land use i at location j which is a function of the marginal return to land in a multiple input profit framework for the selected land use (see Hardie et al. 2000).

A land use change implies a consequential reordering of quasi-rents across the land use options so that quasi-rent for a different use comes to dominate and land use switches accordingly. More precisely, a change from land use i to land use k implies that:

$$dR_{ik,t+1} = R_{k,t+1} - R_{i,t+1} - CC_{ik,t+1}(z) - A_{ik,t+1}(x) > 0 \tag{2}$$

That is, the difference between land rents accruing to land uses k and i, net of conversion costs (CC) which depend on site attributes (z), and a set of additional value changes in the vector A (e.g., related to biophysical, climate, or other factors (x) not accounted for in the rent calculations) as well as considerations that are outside the expected rent framework and may be essentially unobservable. Most clearly this includes option values forgone by executing the land use change when reversal costs are high. In general we expect that high option values would retard the adoption of land use switching otherwise indicated by the comparison of rents and net of conversion costs.

Translating Eq. (2) into an empirical model involves defining a discrete choice model that includes variables that proxy for the site specific rents, conversion costs, and other factors in Eq. (2):

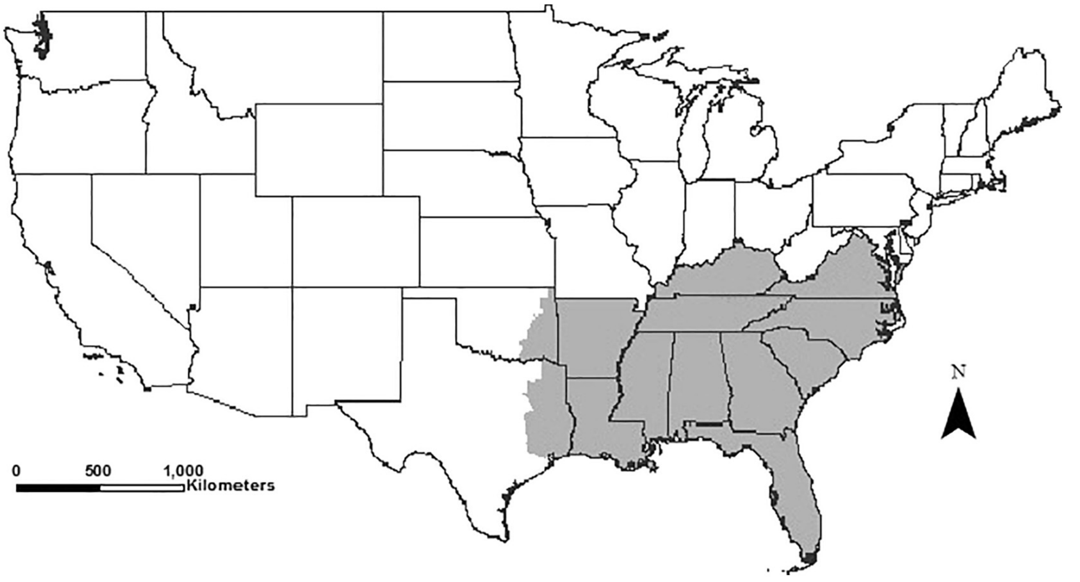

Fig. 1. Map of the study area.

$$P_{ik,t} = pr(dy_{ik,t} = 1) = pr(dR_{ik,t+1} > 0) = G(R, z, x) \tag{3}$$

Our study focuses on understanding the potential interaction between timber market returns and land use changes in the region. In particular we test whether the probability of conversion of forests (F) to other uses (k) is influenced by timber rents:

$$H_0\text{: } \partial G_{Fk} \big/ \partial R_{Fk} = 0$$

$$H_1\text{: } \partial G_{Fk} \big/ \partial R_{Fk} < 0$$

The alternative hypothesis would imply that strong timber markets — i.e., higher timber prices and forest rents — would reduce the propensity of forest land to be converted to other uses. One unique feature of examining land use change within the FIA inventory system is that each observation of forest land use includes detailed measures of forest type, age, and other conditions which can be used to identify site and period-specific land rents. We use a two period formulation of the stock adjustment forestry problem to estimate rents following Provencher (1997) and Polyakov et al. (2010). For each forest plot we calculate an implied annual return to timber management over the measurement period n by comparing three alternatives: no harvest, a partial harvest, and a full harvest using the following equation:

$$R_{F,t}^{m} = E\left\{p_t h^m e^{-r\left(t+\frac{n}{2}\right)} + p_{t+n} I_{t+n}^{m} e^{-r(t+n)} - p_t V_t\right\} / n \tag{4}$$

where m indexes the three alternatives, p is a vector of forest product (stumpage) prices, h is a vector of harvest outputs, r is a discount rate which we set to 4%, V is the beginning inventory, and I is the ending inventory distributed across product classes. For this case, we consider four product classes, defined by two size classes — sawtimber and nonsawtimber — and two broad species groupings — hardwood and softwood. We assign the largest rent from the set of three management options as the quasi-rent for each plot. Calculations involve size rules to "merchandize" standing volumes and regression equations to estimate the distribution of standing volumes at the end of the period and harvest volumes based on observed plot measurements (see Polyakov et al. 2010 for details). We assume that the landowner considers only the observed prices as relevant and makes decisions based on the time t data. Use of stumpage values defines returns to the in situ resources and is consistent with a quasi-rent. At early ages, forest rents are dominated by the growth component so "no harvest" rents are the maximum while at later ages, options with harvest returns are likely to dominate.

3.2. Empirical model

We implement the discrete choice model described by Eq. (3) for a set of remeasured plots as a multinomial logit model. We estimated a separate model for each initial land use category (see Table 1), for a total of five models. The model for the forest initial land use has more explanatory variables than the other four models because forest measurements are only collected on the subset of plot that are classified as a forest land use. These data allow us to calculate the implied forest rents for each forest plot and to assign other variables such as forest ownership type to the observation. We exclude forest rents from other land use models because this would require constructing a hypothetical bareland value (i.e., a Faustmann based infinite rotation formulation based on observed prices and average productivity) that would vary little across time in our dataset. Each observation was weighted by the weighting variable for the observation (i.e., percent area change between previous to current land use represented by the subplot within the survey) and the estimation of model parameters is based on an iterative maximum likelihood algorithm with the weighting variable incorporated. The multinomial logit models were estimated using PROC LOGISTIC in the SAS software, Version 9.4 of the SAS System for Windows (Copyright © 2002–2012, SAS Institute Inc., Cary, NC, USA).

Table 1
Definition of aggregate land use types for FIA phase I plots/subplots. Detailed land use categories are defined in O'Connell et al. (2016).

Category	Land use classification of the U.S. Forest Service SRS
Forest	Timber land, other forest land
Cropland	Agricultural land, cropland, idle farmland, orchard, Christmas tree plantation, maintained wildlife openings
Pasture	Pasture, rangeland
Developed land	Developed land, cultural land (business, residential, and lands with intense human activity), rights-of-way (roads, railway, power lines, maintained canal), recreation (parks, skiing, golf courses), mining
Others	Marsh, wetland, beach, water, unclassifed land

4. Data

The U.S. Department of Agriculture Forest Service Forest Inventory and Analysis program (FIA) collects data on forest and land use conditions using a global sampling grid (White et al., 1992; Bechtold and Patterson, 2005). The FIA survey grid is triangular, isotropic, and systematically covers the conterminous United States. The survey grid is decomposed into panels. In the study area 5 or 7 panel designs were used (depending on State). Each panel also systematically covers all land and water. Actual plot locations were randomly offset from the original grid locations. Data were collected using the above consistent sampling design with a consistent plot design and measurement protocols. The spatial sampling intensity is one 1/6 acre inventory plot per approximately 6000 acres. Under a 5 panel design the 20% of the plots are measured each year and the remeasurement period is ~5 years. Likewise a 7 panel design has 14.3% measure each year with a ~7 year remeasurement period. While earlier inventories focused on sorting plots between forest and nonforest conditions, the FIA now classifies nonforest plots among 23 detailed land use condition categories. For forested plots, FIA measures several variables including ecological (e.g. tree species, diameter, and height), physiographical (e.g. elevation, and slope), and socio-economic (e.g. forest ownership) while additional values (e.g., biomass volumes, carbon density) are derived from the measured values (Bechtold and Patterson, 2005; O'Connell et al., 2016).

For this study, we used FIA data from thirteen states: Alabama (AL), Arkansas (AR), Florida (FL), Georgia (GA), Kentucky (KY), Louisiana (LA), Mississippi (MS), North Carolina (NC), Oklahoma (OK), South Carolina (SC), Tennessee (TN), Texas (TX), and Virginia (VA); only the forested eastern parts of OK and TX. We used the data from the two most recent inventory cycles for each plot, where the inventory cycles fall between 1998 and 2015.

The dependent variables are categorical land use changes based on the remeasured plots. We reclassified the land use category by aggregating the 23 detailed land use classes into five aggregate classes. The reclassified categories of land use are: forest, cropland, pasture, developed land, and others (Table 1). In our subregion, rangeland occurs only in a small portion of southern Florida so is combined with pastureland. Measures of land use at the beginning and end of the survey cycle describe land use changes. For forested plots, we draw several explanatory variables from the FIA dataset including, remeasurement period, growing stock inventory, sawtimber inventory, diameters, elevation, slope, road distance, and ownership. For these plots, timber rents were calculated based on Eq. (4) and using the inventory data described above. In addition, we record the proportional change of land uses within a plot between previous and current measurements and use this as the weighting variable in model estimation. There are approximately 60,000 FIA plots within the study area, and we use the sub-plot level observations of the FIA dataset which consisted of 238,053 observations of land use measures at the beginning and end of the survey cycle, with additional data items recorded for all 137,172 observations of initial forest conditions. Additional data, including soil

Table 2
Descriptions of explanatory variables (O'Connell et al., 2016).

Source	Variable	Description	Level
FIA	Remeasurement period	Time taken to remeasure each plot in years	Plot
	Elevation	Height of location above sea level in feet	Plot
	Slope	Degree of inclination of a slope in percentage	Plot
	Road distance	A discrete variable of nine categories of linear distance to improved road from the plot center: 1 (100 ft. or less)/2 (101–300 ft)/3 (301–500 ft)/4 (501–1000 ft)/5 (1001 ft–1/2 mile)/6 (1/2–1 mile)/7 (1–3 miles)/8 (3–5 miles)/9 (> 5 miles). Considered as a numerical variable in the analysis to ease interpretation of results.	Plot
	Ownership	An ownership classification: private 1 or public 0	Plot
	Timber rent	Maximum implicit rent among three harvest choices within a FIA plot ($/ton): No, partial, or full harvests. Harvest choice was defined as a full harvest if removal rate $>$ 75% at time $t + n$, a partial harvest if 5% $<$ removal rate $<$ 75% at time $t + n$, and a no harvest if removal rate $<$ 5% at time $t + n$ (Polyakov et al., 2010). Refer to Eq. (4).	Plot
Others	Soil Productivity Index (PI)	An ordinal based index of soil productivity. The index is ranked from 0 (low productivity) to 19 (high productivity). Considered as a numerical variable in the analysis to ease interpretation of results. Source: Schaetzl et al. (2012)	Plot
	Population density	Population density of the initial measurement year defined as population per acre. Source: United States Census Bureau < http://www.census.gov/popest/data/ >	County
	Population change rate	Population change rate defined as (Population_{t+n} − Population_t)/Population_t. Source: United States Census Bureau < http://www.census.gov/popest/data/ >	County
	Agricultural cash rent	An average rent cash for non-irrigated croplands by county across measured years between 2008 and 2014 ($/acre). The measured years vary from four to seven years. All cash rents are adjusted to 2009 dollars using the implicit price deflator. Source: United States Department of Agriculture National Agricultural Statistics Service < https://quickstats.nass.usda.gov/results/E0F5EB36-3313-3D7B-9E7F-E56A3365CF2B#9A9F55D7-E267-38C6-ACB9-DF106291B5A7 >	County

productivity, population density, rate of population change, and cash rent for unirrigated cropland are also linked to each of these plot/subplot observations. See Table 2 for detailed descriptions of all data.

5. Results

All twenty five possible land use transitions were observed over the set of measurements (Table 3) which ended between 2014 and 2015 for all states except for OK (which ended in 2013). Forest defines the dominant land use in the South with 210 million acres or about 55% at the end of the cycle. Agricultural uses comprise about 23% (13% cropland and 10% pasture), while developed land represents 12% and all other land uses represent 10%.

Across remeasurements, forest and developed uses grew while all other uses declined. Developed area expanded overall by 2.2 million acres (4.9%). The source of new developed land was 46% forest, 25% cropland, 23% pasture and 6% others. Forest area increased by 1.1 million acres (0.5%) with the largest share of new forests coming from cropland. Cropland declined by 1.2 million acres (2.4%), while pasture area declined by 1.8 million acres (4.6%). Overall, the most common transitions were between pasture and cropland (4.1 million acres from pasture to cropland; 3.5 million acres from cropland to pasture).

Forest is the most stable land use across the survey cycle (97% of forest remains forest), while pasture is the least stable (81% of pasture remained pasture). Perhaps counterintuitively, developed land use is not strictly a sink – only 91% of initial developed land remains as developed at the end of the cycle. The remaining 9% of developed land transitioned to another use at the end of the survey period, about 50% of this area transitioned to forest.

Results for the five multinomial logit models (Table 4) indicate that models are significant for all initial land uses based on log-likelihood ratios. For all models we estimate five equations for all possible transitions and set the null case as no transition so coefficients need to be interpreted relative to this benchmark. The intercepts of all transition equations are large and negative indicating that the probability of observing a transition is much smaller than not observing a transition (null case). This is consistent with the calculated transition matrix (Table 3) and the relative magnitude of the intercepts is generally

Table 3
Estimated area change for each land use category between 1998 and 2015 from the FIA data (acres).

Initial land use		Current land use					
		Forest	Cropland	Pasture	Developed	Others	Total
Forest	Area	204,053,392	1,001,016	1,253,538	2,789,922	543,665	209,641,532
	Row %	97.33%	0.48%	0.60%	1.33%	0.26%	100.00%
	Column %	96.83%	2.02%	3.40%	5.98%	1.46%	55.02%
Cropland	Area	2,165,671	43,429,919	3,498,263	1,492,067	193,839	50,779,759
	Row %	4.26%	85.53%	6.89%	2.94%	0.38%	100.00%
	Column %	1.03%	87.62%	9.48%	3.20%	0.52%	13.33%
Pasture	Area	1,850,883	4,068,382	31,147,717	1,415,023	186,586	38,668,591
	Row %	4.79%	10.52%	80.55%	3.66%	0.48%	100.00%
	Column %	0.88%	8.21%	84.44%	3.03%	0.50%	10.15%
Developed	Area	1,858,455	887,421	834,600	40,648,823	274,312	44,503,611
	Row %	4.18%	1.99%	1.88%	91.34%	0.62%	100.00%
	Column %	0.88%	1.79%	2.26%	87.07%	0.74%	11.68%
Others	Area	795,462	180,923	151,200	338,518	35,970,784	37,436,886
	Row %	2.12%	0.48%	0.40%	0.90%	96.08%	100.00%
	Column %	0.38%	0.37%	0.41%	0.73%	96.78%	9.83%
Total	Area	210,723,863	49,567,660	36,885,317	46,684,353	37,169,185	381,030,378
	Row %	55.30%	13.01%	9.68%	12.25%	9.75%	100.00%
	Column %	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Total change		1,082,332	−1,212,099	−1,783,274	2,180,742	−267,701	0
% Change		0.52%	−2.39%	−4.61%	4.90%	−0.72%	

Table 4
Parameter estimates for the weighted multinomial logit model for land use change.

Variable	Reference category	Forest			Agriculture			Pasture			Developed land			Others		
	Land use choice	Estimate	Standard error	Odds ratio	Estimate	Standard error	Odds ratio	Estimate	Standard error	Odds ratio	Estimate	Standard Error	Odds ratio	Estimate	Standard error	Odds ratio
Intercept	Forest	–	–	–	−2.2878[a]	0.1601	–	−2.6933[a]	0.1629	–	−2.7193[a]	0.1475	–	−2.7705[a]	0.2277	–
	Agricultural land	−4.5505[a]	0.6234	–	–	–	–	−2.3461[a]	0.1066	–	−4.0887[a]	0.1980	–	−5.1881[a]	0.5548	–
	Pasture	−2.7062[a]	0.4937	–	−1.4826[a]	0.1243	–	–	–	–	−4.0421[a]	0.2264	–	−4.2226[a]	0.5523	–
	Developed land	−2.4525[a]	0.3504	–	−2.5445[a]	0.1769	–	−3.3980[a]	0.1777	–	–	–	–	−3.4860[a]	0.3381	–
	Others	−5.7467[a]	0.7916	–	−6.5155[a]	0.5968	–	−5.7580[a]	0.4894	–	−5.4221[a]	0.3690	–	–	–	–
Remeasurement period	Forest	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Agricultural land	−0.0032	0.0597	0.997	–	–	–	–	–	–	–	–	–	–	–	–
	Pasture	−0.0720	0.0524	0.931	–	–	–	–	–	–	–	–	–	–	–	–
	Developed land	0.1244[a]	0.0360	1.132	–	–	–	–	–	–	–	–	–	–	–	–
	Others	0.1746[a]	0.0818	1.191	–	–	–	–	–	–	–	–	–	–	–	–
Ownership	Forest	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Agricultural land	0.9819[a]	0.4175	2.670	–	–	–	–	–	–	–	–	–	–	–	–
	Pasture	0.6508[a]	0.3074	1.917	–	–	–	–	–	–	–	–	–	–	–	–
	Developed land	0.5276[a]	0.2177	1.695	–	–	–	–	–	–	–	–	–	–	–	–
	Others	−0.2626	0.3952	0.769	–	–	–	–	–	–	–	–	–	–	–	–
Road distance	Forest	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Agricultural land	−0.4572[a]	0.0628	0.633	–	–	–	–	–	–	–	–	–	–	–	–
	Pasture	−0.6553[a]	0.0558	0.519	–	–	–	–	–	–	–	–	–	–	–	–
	Developed land	−0.9734[a]	0.0514	0.378	–	–	–	–	–	–	–	–	–	–	–	–
	Others	−0.3357[a]	0.0948	0.715	–	–	–	–	–	–	–	–	–	–	–	–
Elevation	Forest	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Agricultural land	0.0005[a]	0.0002	1.000	–	–	–	–	–	–	–	–	–	–	–	–
	Pasture	0.0003[a]	0.0001	1.000	–	–	–	–	–	–	–	–	–	–	–	–
	Developed land	0.0001	0.0001	1.000	–	–	–	–	–	–	–	–	–	–	–	–
	Others	−0.0002	0.0004	1.000	–	–	–	–	–	–	–	–	–	–	–	–
Slope	Forest	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Agricultural land	−0.0378[a]	0.0125	0.963	–	–	–	–	–	–	–	–	–	–	–	–
	Pasture	−0.0226[a]	0.0088	0.978	–	–	–	–	–	–	–	–	–	–	–	–
	Developed land	−0.0062	0.0058	0.994	–	–	–	–	–	–	–	–	–	–	–	–
	Others	−0.0130	0.0172	0.987	–	–	–	–	–	–	–	–	–	–	–	–
Soil PI	Forest	–	–	–	0.0023	0.0156	1.002	0.0092	0.0169	1.009	0.0194	0.0175	1.020	−0.0402	0.0267	0.961
	Agricultural land	0.0096	0.0270	1.010	–	–	–	−0.0315[a]	0.0121	0.969	0.0375	0.0244	1.038	0.0773	0.0550	1.080
	Pasture	0.0914[a]	0.0213	1.096	0.0052	0.0120	1.005	–	–	–	0.0810[a]	0.0244	1.084	0.0210	0.0568	1.021
	Developed land	0.0176	0.0174	1.018	−0.0844[a]	0.0189	0.919	−0.0173	0.0195	0.983	–	–	–	−0.0763	0.0406	0.926
	Others	0.0403	0.0396	1.041	0.1106[a]	0.0544	1.117	0.0004	0.0551	1.000	0.0604	0.0427	1.062	–	–	–
Timber rent	Forest	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Agricultural land	−0.0051[a]	0.0008	0.995	–	–	–	–	–	–	–	–	–	–	–	–
	Pasture	−0.0054[a]	0.0007	0.995	–	–	–	–	–	–	–	–	–	–	–	–
	Developed land	−0.0032[a]	0.0004	0.997	–	–	–	–	–	–	–	–	–	–	–	–
	Others	−0.0030[a]	0.0009	0.997	–	–	–	–	–	–	–	–	–	–	–	–

(*continued on next page*)

Table 4 (*continued*)

Variable	Reference category	Forest			Agriculture			Pasture			Developed land			Others		
	Land use choice	Estimate	Standard error	Odds ratio	Estimate	Standard error	Odds ratio	Estimate	Standard error	Odds ratio	Estimate	Standard Error	Odds ratio	Estimate	Standard error	Odds ratio
Agricultural cash rent	Forest	–	–	–	−0.0129[a]	0.0021	0.987	−0.0069[a]	0.0027	0.993	−0.0058[a]	0.0024	1.020	0.0051[a]	0.0017	1.005
	Agricultural land	0.0125[a]	0.0024	1.013	–	–	–	0.0130[a]	0.0014	1.013	0.0123[a]	0.0021	1.038	0.0159[a]	0.0053	1.016
	Pasture	−0.0056	0.0032	0.994	−0.0230[a]	0.0018	0.977	–	–	–	−0.0019	0.0032	1.084	−0.0126	0.0083	0.987
	Developed land	−0.0026	0.0025	0.997	−0.0085[a]	0.0025	0.992	0.0046	0.0025	1.005	–	–	–	0.0009	0.0021	1.001
	Others	0.0039	0.0045	1.004	−0.0018	0.0054	0.998	0.0118[a]	0.0050	1.012	0.0023	0.0044	1.062	–	–	–
Population density	Forest	–	–	–	−0.1614	0.2599	0.851	0.0719	0.1861	1.197	−0.5718[a]	0.1249	0.564	−0.5509[a]	0.2444	0.576
	Agricultural land	0.3644	0.2290	1.440	–	–	–	0.1801	0.1335	1.075	−0.9683[a]	0.2766	0.380	−2.7940[a]	0.9138	0.061
	Pasture	−0.1505	0.2738	0.860	0.2168	0.1260	1.242	–	–	–	−0.8967[a]	0.2499	0.408	−0.8848	0.6192	0.413
	Developed land	0.5263[a]	0.1097	1.693	0.5545[a]	0.1438	1.741	0.5057[a]	0.1338	1.658	–	–	–	0.1603	0.1959	1.174
	Others	0.6525[a]	0.2209	1.920	0.6582	0.3396	1.931	0.6977[a]	0.3272	2.009	0.1680	0.1470	1.183	–	–	–
Population rate change	Forest	–	–	–	−2.3298[a]	0.8402	0.097	−0.9964	0.9030	0.369	−1.1108	0.8092	0.329	2.3926[a]	0.9493	10.94
	Agricultural land	0.1771	1.2462	1.194	–	–	–	−0.6561	0.6389	0.519	−5.8322[a]	1.3030	0.003	−0.1271	1.7869	0.881
	Pasture	0.4238	1.0234	1.528	1.3708[a]	0.5799	3.938	–	–	–	0.3392	1.1428	1.404	3.7236[a]	1.8377	41.41
	Developed land	1.6929[a]	0.6929	5.435	2.7442[a]	0.7805	15.552	2.6067[a]	0.7929	13.56	–	–	–	3.6968[a]	1.3591	40.32
	Others	0.5992	1.7392	1.821	1.4597	2.4871	4.305	−2.8140	3.1352	0.060	−3.8940	2.1371	0.020	–	–	–

[a] Significant at an α level of 0.05.

consistent with frequency of transition occurrence.

For the forest model (n = 137,172), the overall model is significant (Pr > Chisq < 0.0001) and all variables except one are significant within the system of equations based on Wald Chi-squared tests at the 95% level (not shown). Only the rate of population growth within the county is nonsignificant at the system level (population density is significant). The set of biophysical variables (elevation, remeasurement period, distance to a road, and slope) are variously significant across transition equations and generally conform with expectations where significant (e.g., remeasurement period is positively associated with transition to developed and other land uses). Soil productivity is only significant in the equation for transitions to pasture from forest. Population variables (population and rate of population change), which we use to proxy for the developed land rent, are positively associated with the probability of forest conversion to developed uses but is not significantly associated with transitions to other rural land uses. Coefficients for land rent variables in the forest model generally conform with economic expectations: the cropland rent coefficient is significant and positive only in the equation explaining transitions from forest to agriculture. The timber rent coefficient is significant and negative for all transitions from forest land use. Coefficients for the ownership dummy variable (private = 1) are significant and positive for all land use transitions except to "others" indicating that transitions are more likely on private land versus public land as anticipated.

Estimates for the remaining models do not factor into our primary focus on the effect of forest returns on land use, but they do provide useful context for evaluating the consistency of all observed land use transitions with economic theory. A lack of conformity would raise concerns about the logic of the model, especially the classification protocol. The cropland model (n = 33,269) is significant based on a log likelihood test and all explanatory variables (crop rent, population variables and soil productivity) are significant based on Wald tests. Both coefficients for the population variables are significant and positive for the transition from cropland to developed uses but only for the rate of population change for the transition from cropland to pasture land use. Soil quality is negatively associated with transition from cropland to developed uses – i.e., higher quality cropland is less likely to transition to developed. The coefficient for cropland rent is significant and negative for transition from cropland to all land uses except "others." Higher cropland rents reduce the probability of transitioning from cropland to developed and other rural land uses.

The pastureland model (n = 25,454) has the same structure as the cropland model and is significant based on log likelihood tests. All variables except soil productivity are significant at the system level based on Wald tests. Population level and rate of change in population are significantly related to transitions to developed land uses but not significantly related to transitions to other rural land uses. The coefficient for the crop rent variable is significant and positive for transitions to crop land use.

The transition model for developed land uses (n = 32,639) contains the same explanatory variables as crop and pasture models and is significant based on log likelihood tests. All variables are significant at the system level based on Wald statistics. Coefficients for one or both of the population variables are significant and negative for transitions from developed to all other land uses indicating that reversion from developed to rural land uses is less likely in highly populated or populating areas. The crop rent variable is positively associated with transitions to cropland but negatively associated with transitions from developed to forests.

6. Discussion and conclusions

The primary focus of this study was to look at the impact of forest returns on forest conversion in the southeastern United States, and we found a negative influence of timber rent on forest conversion, retarding conversion of forest to other land uses. This implies that at the margin higher timber prices reduce the probability of transition of forest to other land uses. Additional simulation results based on the estimated models further illustrate these implications. A 10% increase in timber rents increased the area of forest by 0.08%, while with a 10% decrease in timber rents reduced the area of forest by 0.09% indicating a forest land elasticity with respect to forest quasi-rent of about 0.8. The future of forest product markets in the southeastern United States is therefore likely to have important influence on the area of forest land use — i.e., increased prices result reduced forest conversions. This result is consistent with the findings of previous studies that find forests generally tend to remain as forests with higher forest returns (Lewis and Alig, 2014).

Our study differs from previous land use models in how forest quasi-rents are calculated. Our approach allows for incorporation of detailed measures of forest attributes to account for current inventory conditions integrated with market data and specific management options. Preceding studies have used average values for large areas (e.g., county or region) based on a hypothetical management regime (usually linked to the Faustmann formulation) or simply used average stumpage prices as rent proxies (Mauldin et al., 1999; Plantinga et al., 1999; Kline and Alig, 2001; Ahn et al., 2002; Plantinga and Ahn, 2002). Remeasured FIA data allow us to formulate a two period model from which returns to harvest and growth can be derived from observed timber market prices for the remeasurement period for each individual plot (Polyakov et al., 2010). The landowner's harvest choice (no, partial, or full harvests) is based on the maximum expected net present value of the management options for each forest plot over a relatively short period. In this sense, the timber rent is more comparable to the observed average annual agricultural cash rent than averages based on hypothetical management regimes.

Our study indicates a significant linkage between a number of factors and land use transitions in the southeastern United States. In particular, population and agricultural cash rent are influential factors driving land use change in the southeast. Land use changes in all land use categories except “others” were significantly and positively influenced by population change rate and/or population density consistent with previous studies (e.g., Alig 2007). Shifts from forest uses to developed uses mostly occurred adjacent to metropolitan areas where population growth has been increasing over the past decade (U.S. Census Bureau, 2016). Transitions from non-agriculture to agricultural land uses were significantly influenced by cropland prices indicating that lands with a high crop yield potential have a higher propensity to transition to and be retained in cropland use.

Other significant factors that influenced forest land use change were road distance, ownership, slope, and soil productivity. With the exception of soil productivity, the results were consistent with expectations. The probability of conversion of forest decreased as the distance to improved road from the FIA plot center increased. In other words, less accessible forests were less likely to be converted to other uses. Private owners tended to convert more forest for agricultural uses, development, and pasture compared to public ownerships, and slope did not have any effect on conversion of forest to other land uses. However, coefficients for the soil productivity variable were not consistent with expectations. We hypothesized that higher soil productivity would lead to higher probability of conversion to agricultural land, but higher soil productivity was only associated with transition of forest and developed land to pasture. Collinearity between soil productivity and cropland rents may explain the lack of significance for transitions to cropland.

While we estimated models for all other initial land uses, our interpretation of these results is limited due to model specification. The estimated coefficients are consistent with expectations regarding non-forest use rents but may be subject to missing variable bias, notably due to the omission of the forest use quasi-rent in these equations. Future work could estimate forest rent potential for nonforest uses based on a planted forest options linked to site productivity and ancillary data on potential growth and yield. Without developing this type of spatially explicit approach, regional return potential would lack variation across the region and forest rent effects would not be distinguishable from regional dummy variables. The advantage of this subsequent would allow for an evaluation of the total net change in forest area (both influx and exit) associated with future market scenarios.

We find the FIA land use data are especially useful and informative regarding understanding the potential transition of forests to other uses. The bridge between land use and detailed forest measurements is a unique source of information for studying these dynamics. Unlike previous studies we show that higher forest quasi-rents and timber prices may significantly reduce transitions to other land uses including developed land uses. This is an especially important insight for ongoing debates about the sustainability of timber production for bioenergy in the southeastern United States. While higher prices lead to more timber harvesting within a region, we show that they are also likely to expand the area of forest land as well. Both vectors of change would need to be accounted for in deducing, for example, the net effect of this market on standing forest carbon stocks or other relevant environmental effects.

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