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Distribution and dynamics of private forests across the United States

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1. Introduction

The 285 million ha of forestland in the U.S. (Butler et al., 2021) exist within a complex socio-political-economic environment that has fundamentally shaped the current state of the forests and has major implications for the future of the forests. A key element of this social context is ownership; the owners of the land – working within bio-physical, social, political, and economic constraints – make decisions about land disposition. They decide whether the land remains forested, how it will be managed, and who will have access to the land and many of the benefits it provides.

There is a wide diversity of forest ownership patterns within and across the US. Nationally, families are the largest ownership type, holding 39% of the forestland, while federal forests reflect 29%, corporate ownerships 19% and state ownerships 7% of U.S. forestland (Butler et al., 2021). Tribal, local, and other private ownerships each own approximately 2% of U.S. forestland (Butler et al., 2021). Across the Northern and Southern regions of the U.S., private ownerships control an estimated 81% of the forestland, while across the Rocky Mountain and Pacific Coast regions, an estimated 70% of the forestland is publicly owned (Butler et al., 2021). But virtually everywhere across the U.S. there is a complex matrix of ownership types, be they the result of the railroad allotments in the west or rural economic drivers in the east.

Similar to the U.S., many countries of the world have private ownership as the dominant ownership type, as indicated by data collected by the Food and Agriculture Organization of the United Nations (FAO) (FAO, 2020). For example, 69% of Finland's 22 million hectares of forest are owned privately, comprising individuals (59%) and private business entities and institutions (9%). In Austria, 85% of the total forest acreage (3.9 million hectares) are owned by private ownerships, made up of individual ownerships (57%) and business entities and institutions (15%). While detailed private ownership types are not always available for some countries, FAO data indicate large private ownership percentages, for example, 77% of Chile's 17.6 million hectares of forest are privately owned, and 59% of Japan's 24.9 million hectares of forest are privately owned.

Historically, forest ownership across the U.S. has gone through substantial structural changes. The initial allotments and subsequent transfers established most land as private in the East and left vast areas of public lands, largely in the western and less populated areas of the country. Land abandonment by private owners especially during the Great Depression, spurred acquisition of federal land in the East. Changes over the past few decades have included shifts to institutional ownerships as a result of the large-scale divestiture of vertically integrated forestry companies through company restructuring and land sales (Binkley et al., 1996; Zhang, 2021). Specifically, there has been a rise of timber investment management organizations (TIMOs) and real estate investment trusts (REITs) (Zhang, 2021). TIMOs manage and purchase timberland for investors, while timberland REITs invest in forest-based real estate and distribute income to investors (Zhang, 2021).

Recent evidence using USDA Forest Inventory and Analysis (FIA) data show the ownership dynamics between 2007 and 2017 (Sass et al., 2021). Specifically, the FIA data indicate that family ownerships had the greatest losses over this period, losing approximately 4.6 million ha; and that corporate ownerships have increased their holdings during this period by 4.5 million ha, with a substantial area held by large corporate ownerships (i.e., those with >18,000 ha) including TIMOs and REITs.

Forest ownership has a critical role in influencing the current and future of U.S. forests. The historical shifts from industrial to institutional ownership in the Northern U.S. are significantly related to socioeconomic and forest-related characteristics (e.g., forest type) compared with shifts from industrial to family forest ownerships (Pandit et al.,

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2021). Reforestation behaviors of forest owners in the southern U.S. are more likely associated with institutional and industrial owners rather than nonindustrial private forest owners, and highest for TIMOs (Sun et al., 2015). In addition, TIMOs and REITs own and/or manage more forest plantations in the southern U.S. than other owners and harvest more hardwood than is grown (Zhang et al., 2012).

There is no evidence in the literature of a model that formally explains the dynamics of forestland ownership change. Tangential, but no less important, are studies of land use change models. While there are numerous studies of specific geographic areas and for specific land uses (see, for example, Claassen and Tegene (1999), Irwin and Bockstael (2002), and Irwin et al. (2009)), Lubowski et al. (2008) highlight the importance of understanding the factors influencing change across multiple categories of land use. Specifically, this national econometric model and subsequent simulation estimation indicates that land use decisions on non-federal land (including those associated with forestland) have depended on anticipated economic returns to alternative uses and land quality. This finding forges connections with land ownership characteristics and, ultimately, begs the question of what influences ownership change.

Recent research reinforces the assumption that corporate owners are more financially focused than family owners. Timber production and land investment were the top ownership objectives for large corporate owners (94% and 83% of respondents, respectively) (Sass et al., 2021), while these objectives ranked 11th and 7th for family forest owners (21% and 52% of owners of 4+ ha, respectively) (Butler et al., 2021). All surveyed corporate owners had recently cut timber for sale (Sass et al., 2021), while only 16% of family owners engaged in this activity in the previous 5 years (Butler et al., 2021). Given the rise of corporate ownerships, and that of TIMOs and REITs, considering factors that influence ownership change may assist in a better understanding of what influences land use change and future forest conditions.

This paper presents a theoretical model of the factors that explain private forest ownership change and an empirical application of this model using USDA Forest Inventory and Analysis (FIA) longitudinal data to better understand forest ownership change throughout the U.S. While these models are developed and tested specifically for the U.S., the implications are likely to hold for other countries relative to similarity of ownership patterns and the factors influencing the dynamics.

2. Theoretical model of ownership change

Forestland in the U.S. is categorized into numerous landownership types (LOTs). Specifically, forested land can be owned privately by corporations, families (e.g., individual and family, including trusts, estates, partnerships), and other private entities (e.g., non-governmental natural resources organizations, unincorporated partnerships, associations, or clubs); publicly by Federal, State or Local governments; or tribally (Burrill et al., 2021).

The objective of this paper is to describe the factors that explain shifts in private forest landownership in the US over a 10-year period. We examine a panel of LOT observations and test hypotheses regarding which factors influence the probability of LOT change or retention.

We focus specifically on private forest LOT shifts because the motivations for public LOTs are often completely different from that of private LOTs. Motivations of public LOTs are influenced by legal and institutional constraints and decisions to buy or sell land are not primarily controlled by market factors.

Private LOTs may be able to derive different value streams or benefits from a given forest tract, for example, based on differences in capital rates or ownership objectives for different LOTs. Assume that the value assigned to a forest tract by landowner type *i* at time *t* is V_{it} and the transaction costs for transferring the land is C_t. If:

$$V_{it} - V_{jt} - C_t > 0 \tag{1}$$

then the tract would transfer from landowner type *j* to landowner type *i* through arbitrage, resulting in a transaction price between $V_{it} - C_t$ and V_{jt}.

Observations of V and C are generally unavailable and might not even be useful for our purposes. Many transactions are not "arm's length", so resulting prices reflect an incomplete accounting of value. Transactions may bundle multiple tracts, so average price may be unrelated to the attributes of the specific tract (which we are interested in defining). Value terms therefore are latent values, and we posit a set of key variables that may relate to value differences among LOT valuations and related to the attributes of a site/location (Z, consistent with a hedonic valuation framework), potential for various revenue streams (R, consistent with land rent/real options analysis), and a set of LOT attributes that may indicate alternative cost structures (A). Some private owners in particular derive utility from non-monetized benefits from the land (Caputo and Butler, 2017); for our purposes, we are drawing a distinction between those benefits and revenue, and implicitly assume they are part of the site/location attributes, Z. Some private owners may derive most of the utility of the land from site/location attributes (Z), others from revenue streams (R), and others from a more even split between both (Z and R).

We posit the following discrete choice model:

$$P_{ij} = Pr(s_{ij} = 1) = Pr(V_{it} - V_{jt} - C_t > 0) = f(Z, R, A) \tag{2}$$

We evaluate changes using aggregates of plots so that the left-hand side of the equation is defined as the frequency of the choice$(\widehat{s_{ij}})$ in a share model.

$$\widehat{s_{ij}} = f(Z, R, A) \tag{3}$$

At the plot level, many key variables are associated with each of the three categories. Site/location attributes (Z) include characteristics such as stand age, species diversity, average diameter. Revenue stream attributes (R) include items such as distance to road, distance to developed land, population density, population change, neighborhood income. Alternative cost structure variables (A) include measures of the opportunity cost of capital, mill proximity, effective tax rate. At the region level, where plots are aggregated into shares, the specific measures depend on the scale of the region, how LOT change is modeled, and the measurement period associated with the data. As such, additional variables in a share model would also include some measure to describe the region and measurement period length.

3. Empirical application of ownership change

3.1. Forest landownership data

We construct an empirical application of private forestland ownership change using FIA program plot data (Westfall et al., 2022) as well as U.S. Census and GIS-derived data. The FIA data reflect a historical record of national-level plot-level data describing ownership and stand characteristics over time. FIA data are derived from a national grid of permanent inventory plots, approximately 1 per 2500 ha (6000 ac), across all land use and ownership types. Every 5–10 years, depending on the region, plots are revisited to assess forest conditions, including forest mensuration attributes (e.g., tree species and diameters) and contextual information (e.g., ownership type).

The FIA database keeps track of forest plot data using several identifiers, two of which are pertinent to our application: *survey unit* and *evalid*. *Survey unit* is a geographical identifier, assigned to each plot, that consists of one or more counties in a state (Burrill et al., 2021). We focus on survey units instead of individual plots as our units of analysis to develop an aggregate, share-based model rather than an individual plot-based model. Changes in ownership type are rare events so aggregate models are more appropriate. Further, we do not focus on county because the underlying FIA data do not provide sufficient plot numbers at the county level. *Evalid* identifies a set of independent plots that can be analyzed to generate population-level estimates and aids in following plots longitudinally. In our application we analyze ownership change by *survey unit* using the last two measurement periods identified from *evalids*.

Thus, for each measurement period, we can track plot-level LOTs and determine if ownership change has occurred within a survey unit. The most recent measurement period (t_1) reflects data with a nominal/end year 2018 or 2019 (depending on state); the underlying data were collected during a measurement period length of between 4 and 9 years which varies by state. The prior measurement period (t_0) reflects data with nominal years between 2008 and 2014; the underlying data were collected during a measurement period of between 4 and 10 years, depending on the state. We focus on states that undertook efforts to remeasure their plots over time and, within those states, only on plots that have remeasurement data, i.e., plots that have data at times *t0* and *t1*. Even though these states undertook remeasurement of their plots, we found that 13.2% of the plots were not remeasured and thus not incorporated into our analysis. Some states have not undertaken remeasurement of plots and this limits the states we analyzed; specifically, at the time of analysis, remeasurement data were unavailable for the five Pacific states (Alaska, California, Hawaii, Oregon or Washington), three western states (Nevada, New Mexico or Wyoming) and one southern state (Oklahoma). The lack of remeasurement may also be due, in part, to land changing to non-forest.

Using plot-level LOT data where we have remeasurement, we characterize each survey unit based on its LOT composition. That is, we calculate the percentage of land associated with each LOT within each survey unit for each measurement period: *t0* and *t1*. The LOT composition across all survey units shows that both the corporate and family LOTs reflect not only the largest percentages of ownerships, but they also have the greatest variation (See Fig. 1). Public and tribal LOTs, overall, make up smaller shares of survey units, have little variation over time, and likely have different underlying motivations associated with ownership.

3.2. Methods

We analyze the FIA data to better understand what influences forest LOT change over time; however, the extent to which we can do this for every LOT is constrained by the FIA data. We focus on family and corporate LOTs and the transitions between them. This analysis focuses on the family-corporate transition and excludes other LOTs because they experience little plot-level change. For both family and corporate LOTs, <1% of plots transfer to any other LOT besides family or corporate. Further, if we were to analyze changes to public LOTs, we would find minimal change with 97% of these plots remaining in public ownership. See Table S.1 in the Supplement for details.

For each survey unit, we determined which plots started in either the family or corporate LOT at *t0* and ended up in either the family or corporate LOT at *t1*. We subset these data based on their starting LOT (family or corporate) and analyze the subsets separately. The family LOT subset reflects plots that are in the family LOT in *t0* and either remain in the family LOT or change to corporate LOT at *t1*. The corporate LOT subset reflects plots that are in the corporate LOT in *t0* and either remain in the corporate LOT or change to family LOT at *t1*. The total number of plots in each survey unit (u) for these subsets (family and corporate, respectively) are given by: N_u^{fam} and N_u^{corp}.

For each subset, we want to understand what factors are associated

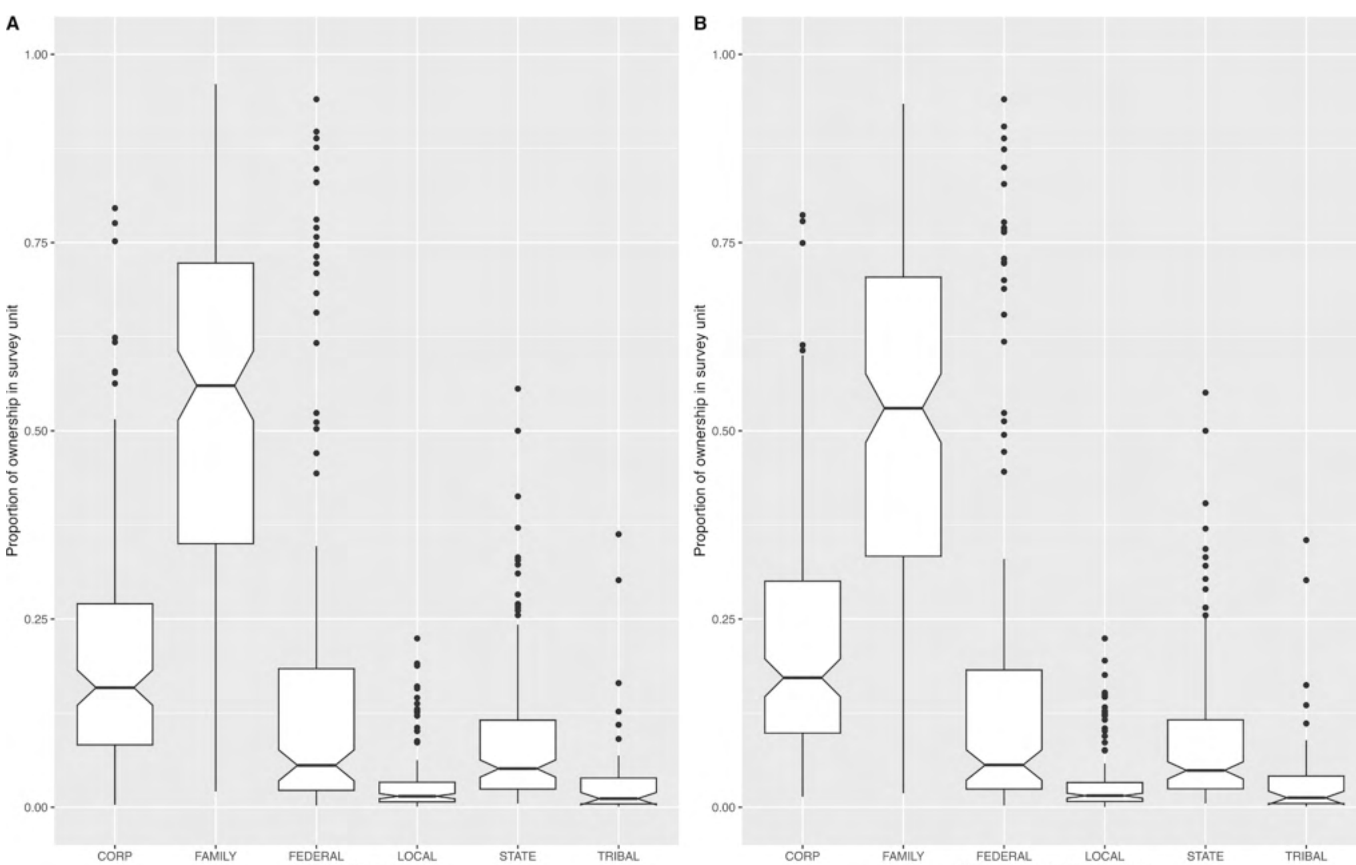

Fig. 1. FIA plot-level data indicating percentage of ownership in survey unit by ownership type for two measurement periods. Boxplot shows median, hinges (25th and 75th percentiles), and whiskers (1.5 multiple of interquartile range). Note: These data exclude Alaska, California, Hawaii, Nevada, New Mexico, Oklahoma, Oregon, Washington, and Wyoming.

with the share of plots in each survey unit (u) that changed (and by corollary did not change) LOT. For the family LOT subset, we calculate how many family plots transitioned to corporate plots by survey unit: $n_u^{fam \rightarrow corp}$. The share changing from family to corporate by survey unit u is given by:

$$share_u^{fam\ loss} = \frac{n_u^{fam \rightarrow corp}}{N_u^{fam}} \tag{4}$$

For the corporate LOT subset, we calculate how many corporate plots changed to family plots by survey unit: $n_u^{corp \rightarrow fam}$. The share changing from corporate to family by survey unit u is given by:

$$share_u^{corp\ loss} = \frac{n_u^{corp \rightarrow fam}}{N_u^{corp}} \tag{5}$$

3.3. Model

Our analyses explore what is influencing: 1.) the share of family LOTs to change to corporate LOTs; and 2.) the share of corporate LOTs to change to family LOTs. The share data reflect the proportion of land changing ownership type for each survey unit. While there are several approaches to model share, our approach needed one that also accounted for the fact that each survey unit observation could derive from a different sized sample (i.e., N_u^{fam} or N_u^{corp}). Modeling a loss of family to corporate LOT without providing a normalizing constant (i.e., the size of the sample that the loss is based on) misses important information, especially if the survey units have different number of plots. For example, the share of family LOTs changing to corporate LOTs in two survey units may both be 0.25, but that 0.25 may derive from 100 observations in one survey unit and 10 observations in another survey unit.

In order to account for the underlying number of plots in each survey unit while also considering the share changing LOT, we estimate a negative binomial model (Cameron and Trivedi, 2013; Long and Freese, 2014). With the negative binomial model, the dependent variable is a non-negative count variable distributed as a Poisson and the normalizing constant is accounted for in an "exposure" (or "offset") variable. In our application, the non-negative count dependent variable is the number of plots changing by survey unit (i.e., $n_u^{fam \rightarrow corp}$ or $n_u^{corp \rightarrow fam}$) and the "exposure" variable is the total number of plots in a given survey unit (i.e., N_u^{fam} or N_u^{corp}). The model includes the natural logarithm of the "exposure" variable in the specification (Eqs. 6 & 7) such that the expected count can easily be transformed into an expected rate, or share.

$$n_u^{fam \rightarrow corp} = exp\left(\beta' X_u + ln\left(N_u^{fam}\right)\right) = N_u^{fam} \bullet exp(\beta' X_u) \tag{6}$$

$$share_u^{fam\ loss} = \frac{n_u^{fam \rightarrow corp}}{N_u^{fam}} = exp(\beta' X_u) \tag{7}$$

The impact of an individual exogenous variable on the share is determined by the incidence rate ratio (IRR), or the exponential of the coefficient. Incidence rate ratios indicate whether the exogenous factors increase or decrease the share of land transforming from one ownership to the other. An IRR that results in an increase in share is one that is >1, while an IRR that results in a decrease in share is <1. To estimate the extent of the impact for each additional unit of any given explanatory variable, the share of land changing ownership is multiplied by that variable's IRR. To estimate x units of change, the IRR is exponentiated by that amount of change (i.e., IRR^x).

With the negative binomial specification, we indicate the number of plots associated with ownership loss by survey unit for each model (the dependent variable), the size of the sample associated with each share (specified with the "exposure" syntax), and the associated exogenous variables. We estimate the two distinct models, one for each subset of data, using the Stata18 "nbreg" syntax. The dependent variable that provides the basis for the family LOT model is the number of plots changing from family to corporate LOT for each survey unit. The dependent variable that provides the basis for the corporate LOT model is the number of plots changing from corporate to family LOT for each survey unit (Table 1).

We associate the ownership in each remeasured FIA survey unit with exogenous data from FIA, U.S. Census, and other GIS-derived data. The exogenous data reflect attributes described in the theoretical section above (e.g., site/location, revenue stream, and alternative cost structure attributes). Specifically, we gather information on stand age (source: FIA program plot data), population density at the census tract level (source: 2010 U.S. Census), assessed land value per acre (excluding buildings or other improvements) (source: ParcelPoint) standardized to 2018 dollars using the consumer price index from the Bureau of Labor Statistics, and distance to nearest mill in kilometers (source: GIS-derived using coordinates from the USDA Timber Products Output Survey). We summarize these by survey unit as the median values across all plots in the relevant model dataset due to their non-normal distributions. We account for the percent of land associated with non-private ownership for each survey unit, hypothesizing that increasing amounts of non-private LOTs may influence land values and the subsequent likelihood of LOT change. We include two variables to account for differences in space and time. Each survey unit is associated with a region defined by the USDA Forest Service Resource Planning Act (source: Oswalt et al., 2019), either North, South or West with a factor variable; we exclude the Pacific coast region because of lack of remeasurement data for those states. In addition, we include a continuous variable that indicates the amount of time between measurement periods. The longer the remeasurement time, the greater the likelihood of ownership change. All exogenous data are associated with the initial measurement period, t_0.

We tested for multicollinearity among explanatory variables using Variance Inflation Factor diagnostics (VIF). Our intention was to also include distance to nearest road as a revenue stream attribute, but this

Table 1
Variable definitions and summary statistics at first measurement period for family (n = 163 survey units) and corporate (n = 159 survey units) model datasets.

Variable	Definition	**Family sample** Mean (Std. Dev.) Range	**Corporate sample** Mean (Std. Dev.) Range
Share	Share leaving forest landownership type in survey unit	0.10 (0.11) 0.0–0.5	0.11 (0.09) 0.0–0.5
Stand age	Stand age in years[a]	56.5 (17.5) 20.0–112.0	53.8 (21.1) 14.0–115.0
Population density	2010 US Census tract population density (people per km^2)[a]	16.4 (16.5) 0.4–92.1	16.8 (20.5) 0.1–104.7
Assessed value	Assessed land value/ha, excluding buildings & improvements (2018 $)[a]	2581.4 (4444.7) 11.8–3.4e+4	1.3e+5[b] (1.6e+6) 3.9–1.9e+7
Nearest mill	Distance to nearest mill (km)[a]	25.9 (42.7) 5.5–358.4	27.1 (45.6) 5.9–380.8
Remeasurement period length	Number of years between measurement periods	6.5 (1.8) 5–10	6.4 (1.8) 5–10
Percent non-private landowner type	Percent of public land in survey unit at initial time ($t0$)	27.0 (24.9) 1.3–95.0	26.9 (25.1) 1.3–95.0
Region	RPA region of survey unit (1/0):	Share of sample	Share of sample
	North	0.45	0.47
	South	0.37	0.38
	West	0.17	0.15

[a] Within each FIA survey unit, the value of the variable is the median across plots.
[b] This value is disproportionately inflated by a single observation that is implausibly high; without that observation the resulting values would be: mean = 2274.6, standard deviation = 4530.6, range = 3.9–4.6e+4.

variable was highly multicollinear with other variables (i.e., high VIF) in both the family and corporate models; thus, it was excluded from the analyses. In the family model, the largest changes in VIF by excluding it from the analysis occurred with region, stand age, distance to nearest mill and population density and in the corporate model the largest changes in VIF occurred with population density, assessed value and remeasurement time.

4. Results

The FIA plot data indicate that there are 163 survey units with data remeasurement available for our analysis. All these survey units contain some amount of family forest landownership at the initial time period. For corporate landownership, 159 survey units contain some amount of corporate forest landownership at the initial time period.

The average percent of forestland in a survey unit associated with the family LOT in the initial period across the U.S. is 51.9% (minimum 2.1%, maximum 96.1%). Family ownership decreased in the most recent measurement period to 50.1% (minimum 1.9%, maximum 93.4%). The average percent of forestland in a survey unit associated with the corporate LOT across the U.S. is 20.2% (minimum 0.3%, maximum 79.6%). Corporate ownership increased in the most recent measurement period to 21.7% (minimum 1.4%, maximum 78.6%). Figs. 2 and 3 show the distribution of family LOTs and corporate LOTs across the U.S. for the states in the analysis in the recent measurement period.

4.1. Sample description

Comparing the mean of the survey unit shares changing from family to corporate LOT with those changing from corporate to the family LOT shows little difference (0.10 for the family model vs 0.11 for the corporate model), including little difference for the standard deviation and range (Table 1). However, comparing the frequency distribution using histograms shows that the changing family shares leans further towards the left than the changing corporate shares (Fig. 4). While the means are similar, a comparison of medians shows smaller shares changing from family to corporate (0.057) than from corporate to family (0.093).

The summary statistics of the explanatory variables between the two model samples show similarities, for the most part (Table 1). Comparing average median values across the family and corporate samples indicates stand age is roughly 54 to 57 years, population density is roughly 16–17 people per km^2, the straight-line distance to the nearest mill is approximately 26–27 km, and the time between measurement period is approximately 6 years. The family LOT sample average median assessed value is roughly $2600/ha while the corporate LOT sample average median assessed value is over $130,000/ha. This corporate assessed value, however, is driven by a single survey unit which had a small number of parcels with a single exceedingly large value that we believe is incorrect (>400 times the next highest value). With the removal of that one implausibly large value, the average median values between the family LOT sample and the corporate LOT sample are more comparable (i.e., roughly $2600 for the family sample and $2300 for the corporate sample). The average median share of survey units owned by a non-private landowner type is 27%. While an artifact of how survey unit regions were defined, most survey units fall in the North (roughly 45% - 47%), followed by the South (37%–38%) and then the West (15%–17%).

4.2. Model results

The family model had full exogenous variable information for 157 observations. The corporate model had full exogenous variable information for 152 observations, and we drop one additional observation – the one including the exceedingly high assessed value per hectare – for a resulting sample of 151 observations. Log likelihood statistics for both fitted models indicate that it is highly unlikely that all the regression coefficients are simultaneously equal to zero. The */lnalpha* statistics is an estimate of the log of the dispersion parameter, *alpha*. The dispersion parameters are both significantly different from 0, indicating that the negative binomial regression is more appropriate than the more restrictive Poisson model.

The family LOT model shows significant coefficients for remeasurement length, percent of survey unit land in non-private ownership, and the region variables, where the North region is the reference category

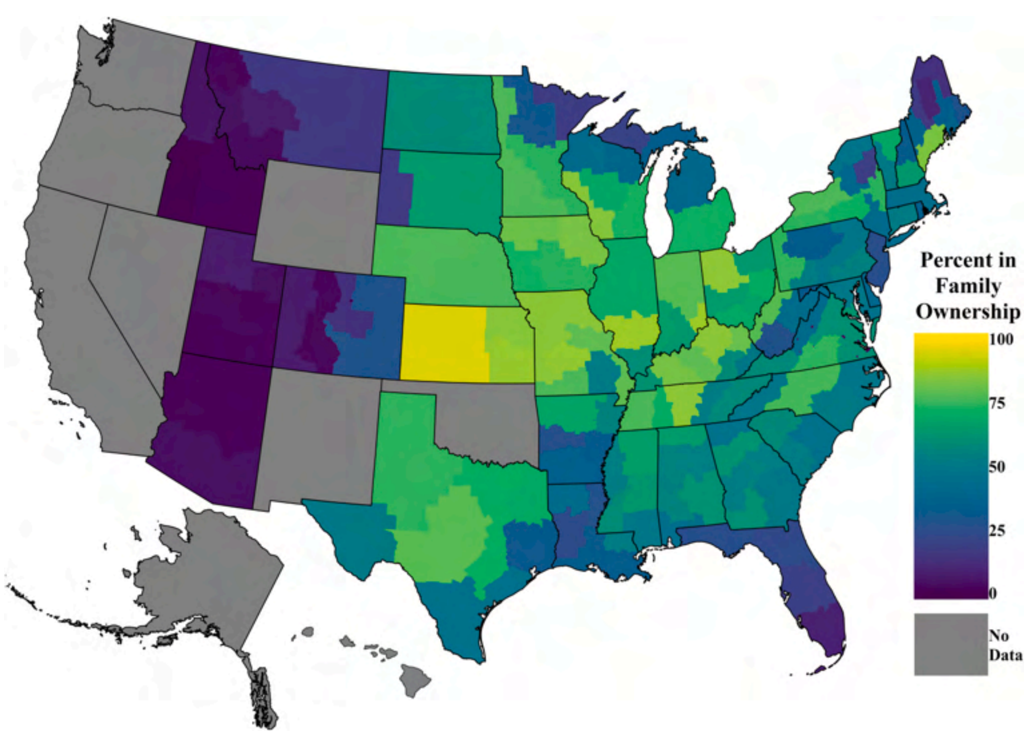

Fig. 2. Percent forest land in family ownership by survey unit in recent measurement period. States in gray are excluded from the analysis.

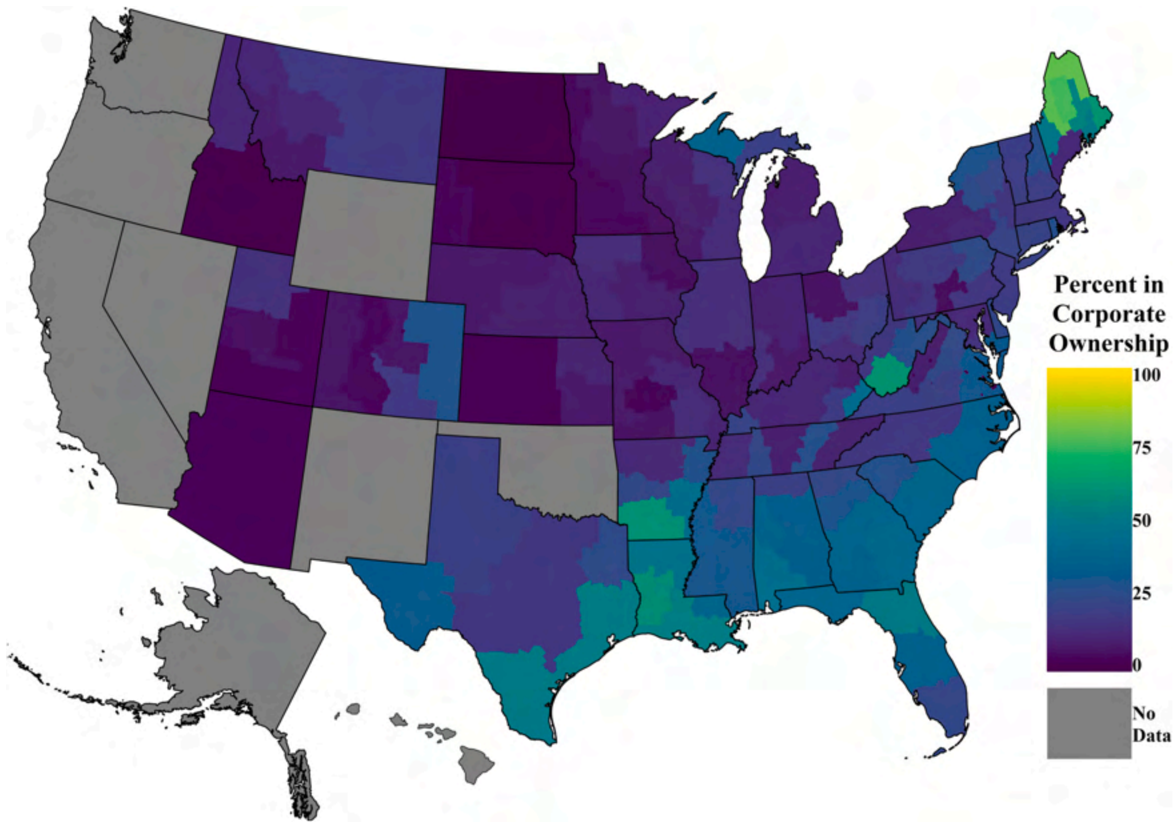

Fig. 3. Percent forest land in corporate ownership by survey unit in recent measurement period. States in gray are excluded from the analysis.

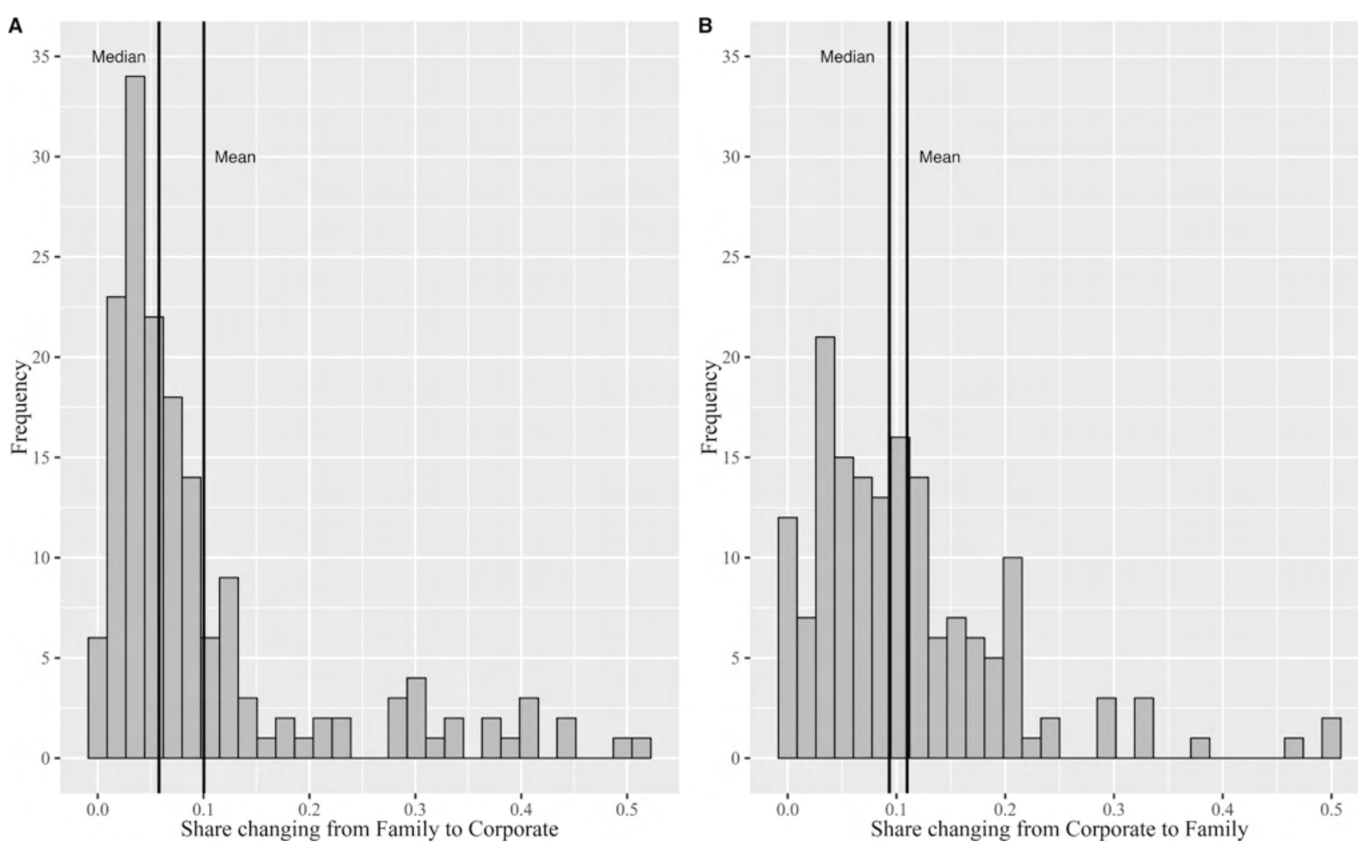

Fig. 4. Distribution of share changing landownership types by survey unit. A. Family landowner type changing to corporate landowner type. B. Corporate landowner type changing to family landowner type.

Table 2
Negative binomial model results, by forest landowner type (LOT).

	Family LOT model[a]		Corporate LOT model[b]	
Independent variable	Coefficient (SE)	Incidence Rate Ratio	Coefficient (SE)	Incidence Rate Ratio
Stand age	−0.0023 (0.004)	0.9977	0.0110** (0.004)	1.0111
Population density	−1.56e-06 (0.004)	1.0000	0.0063* (0.003)	1.0064
Assessed value per hectare	−2.92e-06 (1.58e-05)	1.0000	−3.41e-05** (1.38e-05)	0.9999[c]
Nearest mill (km)	−0.0015 (0.001)	1.0000	0.0014 (0.001)	1.0014
Remeasurement length	0.2377*** (0.034)	1.2684	0.0911* (0.043)	1.0954
Non-private percent	0.0081*** (0.003)	1.0082	−0.0102** (0.384)	0.9898
South region	0.9364*** (0.126)	2.5508	0.4380** (0.159)	1.5497
West region	0.7485*** (0.295)	2.1138	0.6178* (0.293)	1.8549
Intercept	−4.7822*** (0.295)	0.0084	−3.6160*** (0.360)	0.0269
/lnalpha	−1.9283 (0.183)		−1.6736 (0.230)	
alpha	0.1454 (0.027)		0.1876 (0.043)	

p-value: ≤0.001 = ***, ≤0.01 = **, ≤0.05 = *.
[a] $n = 157$; LR $chi^2(8) = 202.17$, Prob>$chi^2 = 0.000$; LR test of alpha = 0: $chibar^2(01) = 202.05$, Prob≥ $chibar^2 = 0.000$.
[b] $n = 151$; LR $chi^2(8) = 40.27$, Prob>$chi^2 = 0.000$; LR test of alpha = 0: $chibar^2(01) = 77.37$, Prob≥ $chibar^2 = 0.000$.
[c] The untruncated incidence rate ratio for the assessed value per hectare is 0.9999659.

(Table 2). The model indicates increasing shares transforming from family to corporate LOT with greater amounts of time between measurement periods and greater amounts of land in non-private ownership. The South and the West also see increasing shares transforming from the family to the corporate LOT than the North.

The corporate LOT model indicates increasing shares transforming from corporate to family LOT with older stands, greater population density, and greater amounts of time between measurement periods. The South and the West also see increasing shares from the corporate to the family LOT than the North. Decreasing shares transforming from corporate to family are associated with greater per-hectare assessed values and greater amounts of land in non-private ownership. (Table 2).

4.2.1. Incidence rate ratio results

The incidence rate ratio (IRR) results estimate the extent of impact on share changing LOT by exogenous variable (Table 2). For the Family LOT model, each additional year between measurement periods increases the share of land transforming from family to corporate ownership by a factor of 1.2684; equivalently, every additional year between measurement periods results in roughly a 27% increase in the share. With each 1 percentage point increase in the amount of non-private land in a survey unit, the share of land transforming from family to corporate ownership increases by 0.8%. Because a 1 percentage point change is very small, we consider larger changes. When the amount of non-private land in a survey unit increases by 20 percentage points, the share of land transforming to corporate ownership increases by roughly 17.7% $(100\times(1.0082^{20}-1))$, or as the amount of non-private land in a survey unit increases by 40 percentage points, the share of land transforming to corporate ownership increases by roughly 38.6% $(100\times(1.0082^{40}-1))$. IRRs indicate that the share of land transforming from family to corporate ownership is 155% greater in the South than the North and 111% greater in the West than the North. While this percentage change is large, the magnitude of the change is relatively small due to the small shares: the family share changing to corporate in the North is 0.05, while it is 0.13 in the South and 0.11 in the West. Fig. 5 shows the marginal effects of family share changing to corporate for the statistically significant variables.

Incidence rate ratios for the Corporate LOT model indicate factors that both increase and decrease the share of land transforming from corporate to family ownership. Each additional stand year age results in roughly a 1.1% increase in the share of land transforming from corporate to family ownership, while a 20-year increase in stand age results in a 24.7% increase in shares transforming $(100\times(1.0111^{20}-1)$. Each additional person per km^2 results in a 0.64% increase in shares transforming to family ownership, while each additional 10 people per km^2 results in a 6.6% increase in shares transforming to family ownership $(100\times(1.0064^{10}-1)$. For each additional year between measurement periods, the share of land transforming from corporate to family ownership results in roughly a 9.5% increase. IRRs indicate that the share of land transforming from corporate to family ownership is 55% greater in the South than the North and 85% greater in the West than the North. Like with the family model, the magnitude of these changes is small relative to the percentage changes; the family share changing to corporate in the North is 0.07, while it is 0.12 in the South and 0.14 in the West.

Factors influencing a decrease in the share of land transforming from corporate to family include assessed value per hectare and percentage of land in non-private ownership. For these variables, it is more useful to look at a change greater than one unit. For each additional $5000 per hectare value increase, the share of land transforming from corporate to family ownership results in a 15.7% decrease $(100\times(0.9999659^{5000}-1)$ in the share. (Because the exponentiation is so high, we apply the untruncated coefficient for the calculation.) With each 1 percentage point increase in the amount of non-private land in a survey unit, the share of land transforming from corporate to family ownership decreases by 1.0%. When the amount of non-private land in a survey unit increases by 20 percentage points, the share of land transforming to family ownership decreases by 18.5% $(100\times(0.9898^{20}-1))$, or as the amount of non-private land in a survey unit increases by 40 percentage points, the share of land transforming to family ownership decreases by roughly 33.6% $(100\times(0.9898^{40}-1))$. Fig. 6 shows the marginal effects of corporate share changing to family for the statistically significant variables.

5. Discussion

This analysis of ownership dynamics between family and corporate ownerships highlights the different motivations associated with each LOT. For family ownerships, the most important variables are time between measurement periods and how much private land is in the survey unit than other factors. Regional analysis shows how these relationships are greater in the South and in the West than in the North. These relationships may, in part, be corresponding to the ongoing changes associated with the large-scale divestiture of vertically integrated forestry companies and rise of TIMOs and REITs as discussed in Zhang (2021). The shift from the family LOT to the corporate LOT with greater time may also reflect changes associated with ownership structure, not ownership itself. That is, it is quite possible that land is remaining with the same owners but changing to the corporate LOT because the families are shifting ownership into a limited liability company (LLC), limited liability partnership (LLP) or family corporation for estate planning purposes.

Graphical analysis of the IRRs for time between measurements and percentage of public land by region show that even though the IRRs apply to the entire sample, the overall impact of the IRRs is greater in magnitude with the South and with the West than the North because the share of land changing ownership is greater in the South and the West than in the North. (Fig. 7).

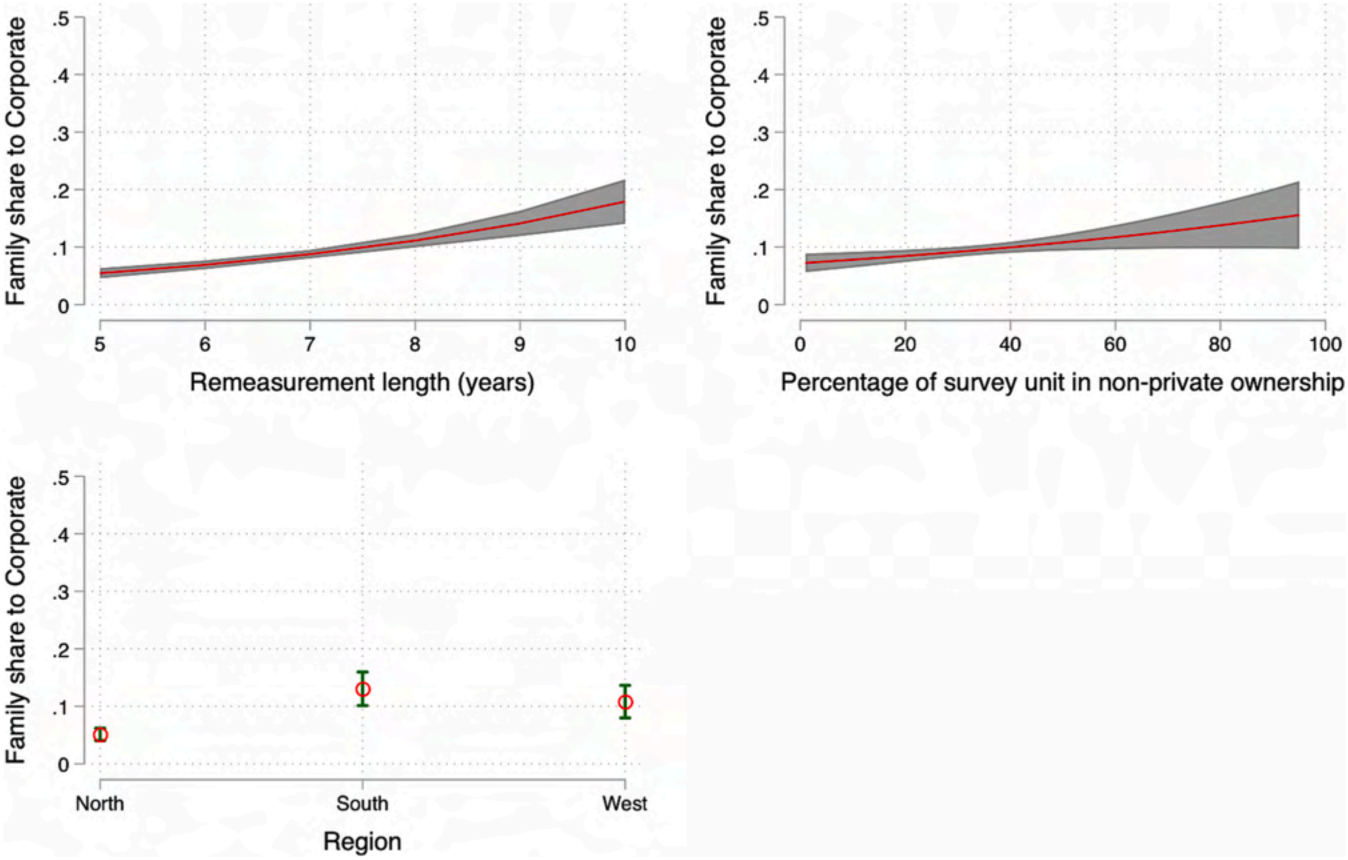

Fig. 5. Marginal effects for significant variables in family landowner model.

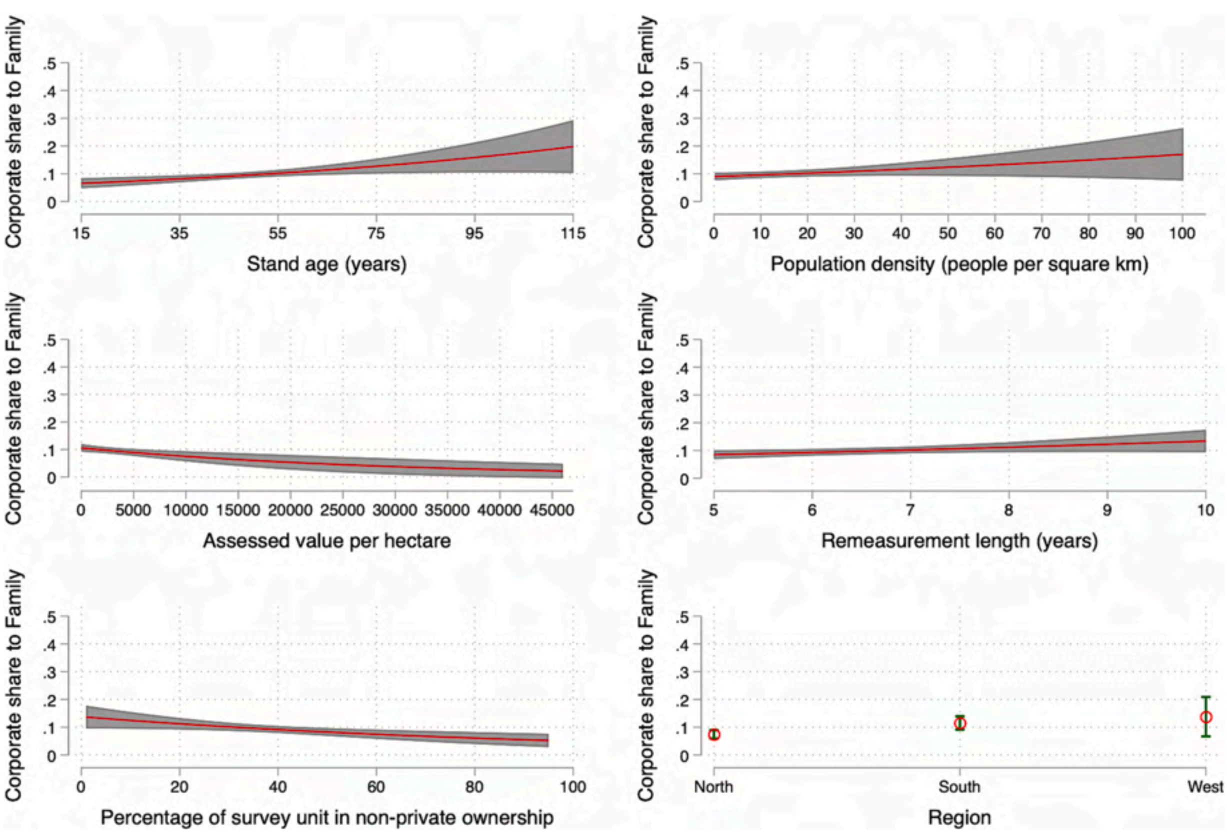

Fig. 6. Marginal effects for significant variables in corporate landowner model.

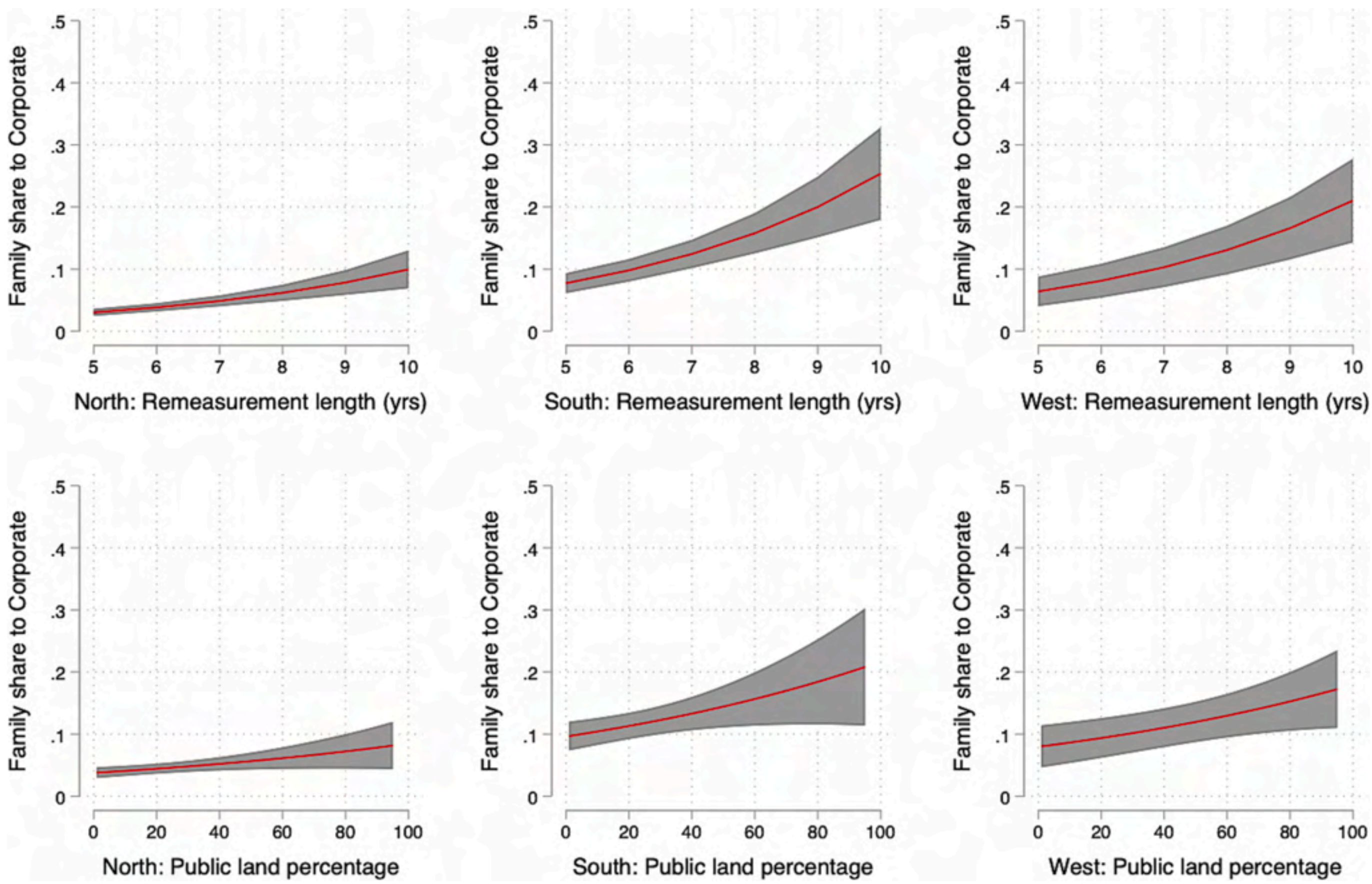

Fig. 7. Marginal effects for significant variables in family landowner model by region.

For corporate ownerships, all exogenous variables influenced ownership transition except for the distance to the nearest mill. That is, factors reflecting site/location attributes, the potential for various revenue streams, the region (i.e., the percentage of non-private land), and measurement period length all weighed in on transitioning to family ownership. The factor that did not appear to play a role in corporate ownership change is related to alternative cost structures (i.e., mill proximity). Additional analysis should include more or different measures of this to explore the influence of this factor. Transition from corporate to family is associated with several factors. Older stands appear to be associated with greater transition to family LOT. It is possible that the diameter at breast height (DBH) may be too high to be merchantable and exceeds maximum sawmill specifications; alternatively, it may indicate that the corporate ownership had not been able to sell the timber at younger stand ages. Further research needs to be done to determine the reason behind this finding. More densely populated areas may not hold the characteristics that corporations want for their land holdings – perhaps these areas pose issues to corporations because of regulations such as zoning, or perhaps corporations seek more private areas and prefer to hold land in more remote areas where public comment on their activities (e.g., harvesting) is less likely. As with the family model, time appears to be a factor in transitioning from corporate to family ownership.

The negative relationship between non-private land use share and transition from corporate LOT to family LOT may indicate that these areas may not be preferable to family ownerships who may need more amenities nearby (e.g., roads, supermarkets, schools). Alternatively, it may reflect corporate ownerships' unwillingness to part from forested land that is near protected, non-developed parcels; like the result with population density, corporations may seek areas of greater privacy farther away from private individuals. The negative relationship between assessed value and transition from corporate to family may indicate that corporate ownerships are retaining more economically valuable forestland. This could mean that in areas of high assessed values, corporate ownerships do not sell to retain the ability to subdivide and convert the forestland. The liquidity of corporations, compared with that of families, may make them able to maintain ownership despite rising assessment values. Concurrently, family ownerships may be unable to gain ownership because of high land values.

Similar to that of the family model, graphical analysis of the corporate model IRRs for the significant exogenous variables shows that although the IRRs for these exogenous variables are the same by region, the overall impact of that variable is of greater magnitude with the South and with the West than the North because the share of land changing ownership is greater in the South and the West than in the North. (Fig. 8).

While the FIA data available allow us to analyze transitions between family and corporate ownerships, this analysis does not include these transitions from every state. As time goes on, more remeasurement data will become available, allowing analysis of transitions in other states – particularly those in the West. Until then, the results described herein, especially as they relate to the West region, must be taken with caution; not all states in the West are included and the findings may change as more remeasurement data become available. In addition, the analyses presented here are limited to transitions between family and corporate ownerships. The small shares of land in public and tribal ownerships at the survey unit level along with the lack of ownership variation with these ownership groups is currently not conducive to analysis. As more data become available, it will be important to include these in a model of ownership change.

Future tests of the theory presented in this manuscript should strive for a better match between the theoretical constructs and the measured

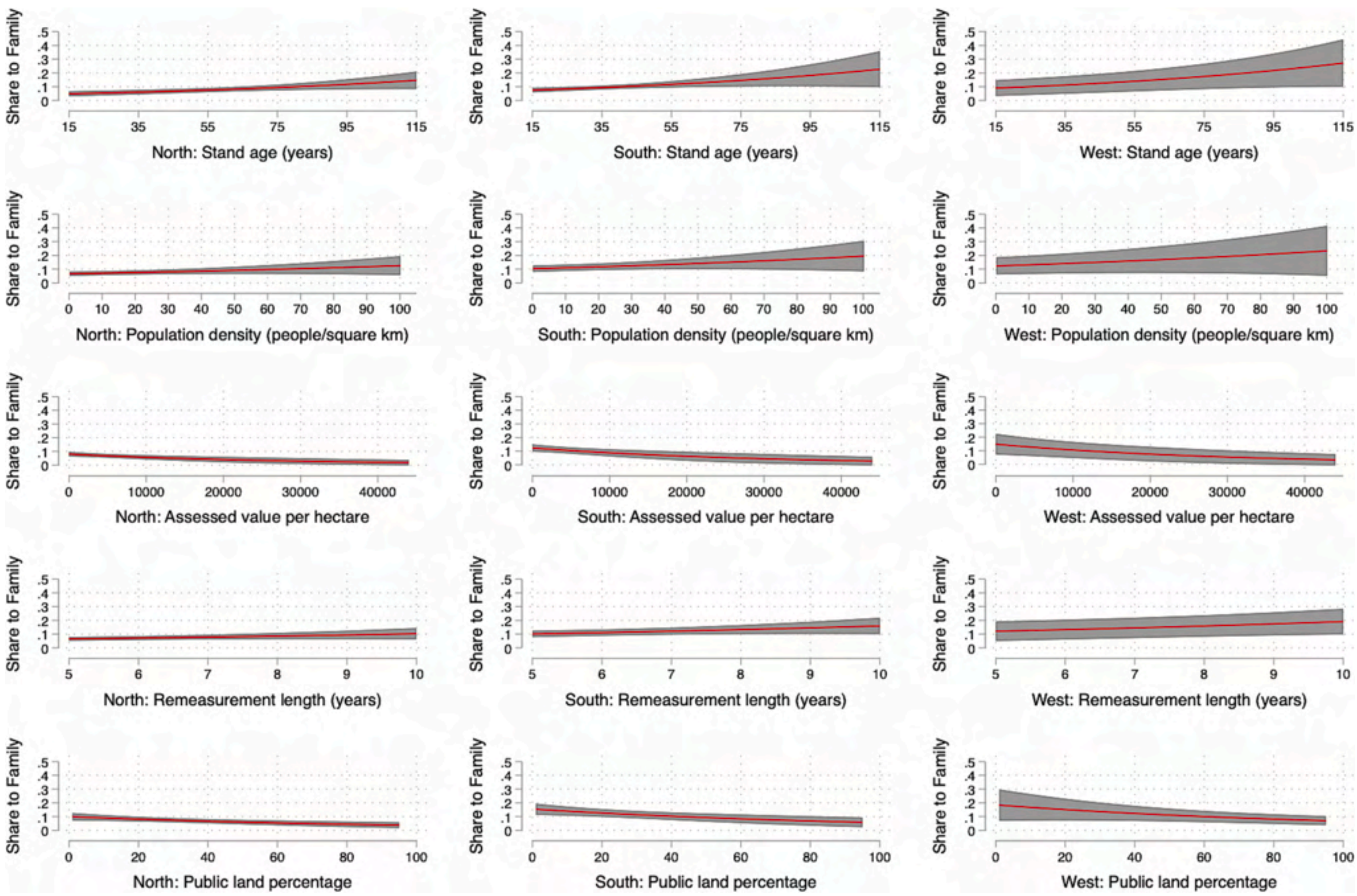

Fig. 8. Marginal effects for significant variables in corporate landowner model by region.

variables. For example, revenue stream attributes could describe markets better with measures such as local stumpage rates or demand/ conditions for non-timber revenue streams (e.g., hunting leases). Another important variable to include would be differences in effective tax rates between corporate and family ownerships at the survey unit level. There are many site/location attributes that could be relevant (e. g., stand density), and future research could test a wider array of these types of variables. Some of these attributes, however, have more of a regional focus (e.g., pine plantation versus hardwood acres in the South or species mix) and therefore could be more suitable for regional rather than national models.

6. Conclusion

Forest ownership across the U.S. has gone through significant historical changes, especially regarding private ownership. Our theoretical model for ownership change and subsequent empirical application exploring transitions of family and corporate ownerships is a first attempt at understanding the dynamics of land ownership type. These ownership dynamics have important implications for forest dynamics, including total forest acreage, timber supply, and other ecosystem services. We find differences across the models. Family ownerships changing to corporate ownerships are affected by regional characteristics (share of land in non-private ownership in the survey unit and region of the U.S.) and time between measurement periods. Corporate ownerships changing to family ownerships are affected by site attributes (stand age), revenue stream attributes (population density, assessed value of land), regional characteristics (share of land in non-private ownership in the survey unit, region of the U.S.), and time between measurement periods.

Ownership change motivations will continue to evolve and affect the whole U.S. as development and forest loss increases and as policy affects land ownership. Corporations with goals of maximizing profits and minimizing financial burden are affected by the economics of the forestry sector. When timber production is an element of corporate financial portfolios, the decision to harvest depends on stumpage values which depend on timber markets. Corporations will weigh their various decisions (e.g., to harvest, to sell) based on the profitability that the markets provide. While family ownerships decisions may not rely on profit maximization in the same way as with corporate ownerships, their decisions are still affected by the value they get from their land. They are also affected by legacy decisions as they age (Markowski-Lindsay et al., 2016, 2018), thereby influencing land disposition. Policies developed to stem forest loss, especially that affecting alternative cost structures and revenue streams, or devoted to storing carbon, thereby influencing site/ location attributes, are likely to influence decisions to keep or sell land. This first attempt at understanding forest landownership type dynamics will be enhanced in the future by including more remeasurement periods (including records from states without current remeasurement data), all landowner types, and TIMO/REIT designations directly into the analysis. Additionally, analysis of the effect of policy instruments on ownership change may be explored with longitudinal analysis at smaller spatial scales and as these policies become implemented. In addition, analyzing ownership change across states where certain policies have already been enacted, accounting and controlling for differences important to the underlying theoretical model would be useful additional research.

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CRediT authorship contribution statement

Marla Markowski-Lindsay: Conceptualization, Data curation, Formal analysis, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Brett J. Butler:** Conceptualization, Funding acquisition, Methodology, Supervision, Writing – review & editing. **Jesse Caputo:** Data curation, Formal analysis, Methodology, Software. **David Newman:** Conceptualization, Methodology. **Daowei Zhang:** Conceptualization, Methodology. **David Wear:** Conceptualization, Methodology, Writing – review & editing.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Marla Markowski-Lindsay reports financial support was provided by USDA Forest Service Renewable Resources Planning Act Assessment. Editor-in-Chief at Forest Policy and Economics (DZ). External manuscript reviewer for Forest Policy and Economics (BJB, JC, MML).

Data availability

The data that has been used is confidential.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.forpol.2023.103143.

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