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Conservation easement adoption among forest landowners in the United States

Changyou Sun [a,*], Jeffry D. Kline [b], Xiaofei Li [c]

[a] Department of Forestry, Mississippi State University, MS 39762, USA
[b] Pacific Northwest Research Station, Forest Service, Corvallis, OR 97331, USA
[c] Department of Agricultural Economics, Mississippi State University, MS 39762, USA

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ABSTRACT

Conservation easements have become a prevalent method for conserving forestland in the United States in the face of housing and other development. In this study, we used data from the National Woodland Owner Survey conducted by the USDA Forest Service in 2017–2018 to examine patterns and determinants of conservation easement adoption on individual forestland parcels. A total of 9349 landowners are included in the analysis, covering all 50 states. We used a spatial binary probit model to consider potential spatial dependence in conservation decisions among adjacent landowners. Our results reveal that significant spatial dependence exists, suggesting that about 30 % of the total effect of an explanatory variable on easement adoption comes from an indirect spatial effect. Landowners' degree of awareness of conservation easements has the most significant positive effect. Easement adoption is also higher among landowners possessing non-commodity ownership objectives, such as wildlife protection, while adoption is lower among landowners with primarily timber and investment objectives. Demand for conserving forestland has increased in areas experiencing more remarkable population growth or household income. States adopting statutory conservation easement laws earlier tend to have higher rates of easement adoption. Policy implications of these findings are discussed for conservation entities and government agencies to promote conservation easements in the future.

1. Introduction

A conservation easement is a voluntary agreement that allows a landowner to donate or sell a portion of their property rights to a qualified third party for a certain period or in perpetuity in return for a tax benefit, a direct payment, or both (Gustanski and Squires, 2000). For conservation easements on forestland, typical constraints on landowners associated with their loss of particular property rights include restrictions on later property development for residential, commercial, or industrial purposes. Additional conditions may also be put on timber harvesting, parcel subdivision, or other conversion options. The National Conservation Easement Database (NCED, 2023) has collected and recorded basic information about individual easement contracts and makes this data available to the public. As of December 2023, the database reported 221,256 conservation easements in the US, conserving 37.9 million acres or 1.6 % of all land in the US.

Several studies have examined general patterns in the growing reliance on conservation easements in both government and nonprofit conservation efforts. Wiebe et al. (1997) elaborated with both theories and empirical evidence that conservation easements have been increasingly used to manage public and private land through partial interests and property rights sharing among stakeholders. Bick et al. (1997) summarized the contents of 79 easement contracts in New York as of 1995. In general, these contracts contain four categories of information that affect the use and management of encumbered properties: affirmative rights for grantees (e.g., entry for compliance inspection by a land trust), restrictions on grantors (i.e., no mobile home or limited timber harvesting by a landowner), reserved rights by grantors (e.g., a landowner's right to cut firewood for on-site use), and other provisions (e.g., a liability clause). Among many survey studies, Mortimer et al. (2007) collected information from 355 conservation organizations and 16 state agencies and summarized 3598 conservation easements identified in the US as of 2003. Finally, Owley (2015) analyzed several concerns about using easements for conservation from the perspective of law and policy. Conservation easements are usually between private parties and are subject to minimal public oversight. Therefore, private

* Corresponding author.
E-mail address: cs258@msstate.edu (C. Sun).

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and perpetual restrictions may invoke tensions in balancing a current landowner's responsibilities relative to intergenerational rights. Moreover, conservation easements might also be implemented to protect sites not in imminent danger of development.

A few studies have examined the economics behind the growth in using conservation easements. In particular, enrolling in a conservation easement is a critical decision by landowners, as many easement contracts are in perpetuity. LeVert et al. (2009) conducted a contingent valuation survey of forest landowners in Vermont and Massachusetts and examined their willingness to sell conservation easements. With the National Woodland Owner Survey data of 2006, Ma et al. (2012) used principal component analysis and a logit model to examine the factors associated with landowners' involvement in cost-share programs, forest certification, and conservation easements. Brenner et al. (2013) surveyed 513 private landowners in New York and used a logit model to analyze the determinants of their willingness to grant a conservation easement. Song et al. (2014) applied the propensity score matching approach to the National Woodland Owner Survey data of 2006 in the northern region to investigate how conservation easement participation is associated with forest management practices. Finally, Lamichhane et al. (2021) used a spatial panel data model to examine state-level adoption of conservation easements in the United States from 1990 to 2015. In summary, these studies have used aggregate and national data or survey data in small geographical regions. As a result, there has been a lack of analyses on the behavior of individual landowners at the national scale and inadequate consideration of the role that spatial dependence might play in enrollment decisions across landscapes.

We sought to identify patterns in conservation easement adoption by private forest landowners in the US and examine potential underlying determinants of their adoption decisions. Our data came from a unique landowner survey conducted by the USDA Forest Service in 2017–2018 (Bulter et al., 2021). The data included in this study comprised 9349 usable observations. The focal variable is a binary value representing easement adoption status on individual forestland parcels throughout the US. We used a spatial probit model to address potential spatial dependence in landowners' decisions. We constructed several explanatory variables related to individual landowners' forestland ownership objectives, land attributes and use, individual owners' characteristics, and potential demand for forestland conservation within the states where landowners were located. We also estimated our regression model separately for the North, South, and West regions to evaluate possible regional heterogeneity. To our knowledge, this is the first study using detailed landowner data at a national scale to examine easement adoption in the US. The findings have implications for government agencies and nonprofit conservation organizations to promote conservation easements while pursuing conservation goals on forestland.

2. Methodology

Our study focused on the status of conservation easement adoption by individual forest landowners in the United States and the potential determinants of their decisions. Our data were based on observations of individual forestland parcels. Because each forestland parcel is a spatial unit, using spatial econometrics methods is necessary to explicitly address the potential dependence inherent in these spatial data (LeSage and Pace, 2009; Loonis and de Bellefon, 2018). Spatial dependence typically results from unobservable processes associated with adjacent spatial units. In the case of conservation easement adoption on private forestland, spatial dependence might result from the influence of one neighboring forest landowner's decision on another or from two neighboring parcels subject to similar socioeconomic forces, to name a few possibilities. While the specific processes are often unobservable, we can account for spatial dependence by testing its presence and, if yes, ensuring that the coefficient estimates remain consistent and unbiased through including spatially lagged terms in the modeling. Using spatial methods has grown in analyzing natural resources and environmental issues when spatial dependence is deemed likely. Applications include analysis of landowner decisions on tree planting (Li and Zhang, 2007), land conversion (Upton et al., 2014), and timber harvesting (Aguilar et al., 2017), to name a few.

2.1. The theoretical framework

From a theoretical perspective, whether an individual landowner adopts a conservation easement on their land can be perceived as the result of a constrained optimization decision. This framework considers the supply and demand factors in a market and has been used in explaining similar conservation decisions or voting behavior of legislators (e.g., Kline, 2006; Sun, 2006). Specifically, in considering the adoption of a conservation easement on the land, we assumed that the utility of a risk-neutral landowner ($i \in [1, \ldots, N]$) can be measured as $U_i(G; M; L; O)$, where G represents the preference of easement adoption or non-adoption, M is the motivation behind the ownership, L is land attributes and use, and O is other characteristics of individual landowners. A landowner's utility maximization is subject to the constraints from the demand side of a conservation market. We assumed the implicit constraint function can be defined as $H(D) = 0$, where D measures the demand of conservation easements within a landowner's geographic region (e.g., funding, population density, or supporting legal environment). Maximizing utility subject to the constraint function yields an indirect utility function that depends on all the above factors, i.e., $U_i^*(G; M; L; O; D)$.

A landowner's choice of adoption or non-adoption of a conservation easement is binary and depends on the difference in two utility values: $y_i^* = U_{1i}^* - U_{0i}^*$, where U_{1i}^* represents the utility for landowner i associated with adoption (1), and U_{0i}^* is with non-adoption (0). The difference in utility (y_i^*) is not observable and is usually assumed to follow a normal distribution. The decision rule is

$$y_i = 1, \text{ if } y_i^* \geq 0$$

$$y_i = 0, \text{ if } y_i^* < 0 \tag{1}$$

where y_i is the observed adoption choice by landowner i.

As theorized, the landowner's adoption decision is a function of several potential factors related to the supply and demand of easements within the conservation market. Landowners' choices generally reflect the profit or benefit derived from timber management, private amenities, public interest values, or altruism (Miller et al., 2010; L'Roe and Rissman, 2017). Several studies, for example, have examined public preferences for environmental protection, such as the public's willingness to pay for conservation easements (Cho et al., 2008; Johnston and Duke, 2009) and tendencies of land trust agents (Cropper et al., 2012). Furthermore, a landowner's decision to adopt a conservation easement can influence a neighbor's decision through spatial dependence. The spatial influence may come from imitating a neighbor's conservation practices, information spillover, or peer pressure of conservation. All these factors can potentially influence forest landowners' decisions to adopt conservation easements. Ultimately, whether any of these factors significantly impact is an empirical question.

In this study, the dependent variable is defined as whether a conservation easement has been adopted on a land parcel included in the National Woodland Owner Survey. Our independent variables are classified into several groups, representing the characteristics of individual parcels, landowners, land use, and demand for conservation easements. Our selection of independent variables follows previous research literature, including the analysis of easement adoption in California (Yuan-Farrell et al., 2005), changes in conservation investment (Fishburn et al., 2009), and state-level variation in easement adoption (Lamichhane et al., 2021). These conceptual classifications were then translated into specific variable definitions using available data (e.g., the land size or median household income per capita). We incorporated the potential influence of spatial dependence into the model using a spatially weighted variable of neighbor's adoption decisions.

2.2. Spatial autocorrelation and the weight matrix

The focus of spatial econometrics is on the phenomenon of spatial autocorrelation (also known as spatial correlation or dependence) and the definition of spatially lagged variables to account for such dependence (Loonis and de Bellefon, 2018). Autocorrelation measures the correlation of a variable (e.g., z) with itself. When there is autocorrelation over time t, a lagged value in one period can be defined as z_{t-1} for z_t. When autocorrelation occurs across space, a spatial lag of observation z_i can be defined as the average of neighboring observations, Wz_i, where i indexes the spatial location of an observed value, and W is the weight matrix. Spatial autocorrelation is the positive or negative correlation of a variable due to its spatial location.

In a cross-sectional setting with N spatial locations, the spatial lag of variable z_i can be defined as $Wz_i = \sum_{j=1}^{N} w_{ij} z_{ij}$, where i is the spatial location of interest and j indexes all other spatial sites in the sample (LeSage and Pace, 2009). The weight matrix (W) has the dimension of $N \times N$ and can be defined in many ways. Among the most common definitions, the first one is a neighborhood matrix based on contiguity. An element of the weight matrix will equal one only if two observations share a common border; otherwise, it has zero value. Second, it can be defined as a neighborhood matrix based on distance. The geographical location of each spatial unit can be used to calculate the distance between two observations. After the distances among all the spatial units are calculated, the m closest neighbors for each observation are selected, and the corresponding values in the matrix are set to one. The other elements of the matrix have the value of zero. The number of neighbors, m, is usually set to be the same for all the observations. Third, the weight matrix can be defined as an inverse-distance weight matrix, which is a modification of the second definition. The value of each element in the matrix will depend on an inverse function of the distance $d(i,j)$ between two spatial units, usually the reciprocal, i.e., $w_{ij} = \frac{1}{d(i,j)}$. Then a cutoff value is set at some distance $\overline{d}$ beyond which the influence from a neighboring unit is assumed to be zero, i.e., $w_{ij} = 0$ if $d(i,j) \geq \overline{d}$.

For this study, we adopted the second definition. The first definition is appropriate when each spatial observation is based on an administrative unit (e.g., a county or state). However, the land parcels covered in the survey data of this study do not share any border. The third definition is also hard to apply here because the data are generated from a random survey, and the distances among neighboring observations vary widely. A fixed cutoff value (e.g., $\overline{d} = 150$ miles) may cover many neighboring observations in some northern states but few or even none in some western states. Thus, we felt it better to manually set the number of neighbors (m) as in the second definition. In addition, it is customary to standardize the weight matrix (i.e., the sum of each row being one), so the impacts of all neighbors together equal 100 %. We set the number of neighbors (m) to seven (as justified later), such that each observation has seven neighbors with an equal weight of 1/7 after standardizing. In the end, for each z_i, Wz_i will contain the average of values in the chosen neighboring locations for which $w_{ij} \neq 0$.

2.3. Assessment of spatial autocorrelation in the adoption decision

For this study, our focal variable, y_i, is the adoption status of conservation easements on individual forestland parcels, which has a binary value. Three ways are used to identify and measure the potential spatial autocorrelation in a variable, i.e., by a map informally, testing on the variable per se, and modeling the whole dataset. First, a map can show the location of each land parcel and the easement adoption status. It can demonstrate the spatial clustering of observed adoption decisions vividly. Thus, whether the observations are randomly distributed or clustered on the map can reveal the potential of spatial autocorrelation informally to some degree.

Second, the weight matrix and spatially lagged value of a variable can be used to test the existence of spatial autocorrelation in the variable more rigorously. Among various indicators, the Moran index is the most widely used (Loonis and de Bellefon, 2018), but it is generally used for a continuous variable. The adoption of conservation easements on forestland is measured with a binary value, and the join-count test has been developed for this type of categorical data (Bivand et al., 2008). The test can compare the spatial distribution of land parcels with easement adoption and non-adoption.

Finally, the estimate of the spatial dependence parameter from a spatial model and its significance can be used to measure the spatial autocorrelation directly. In this study, the dependent variable is binary, so a conventional probit model can be used to estimate the model. However, as the land parcels are spatial units, a spatial probit model, as developed below, can also be used to analyze the data. The spatial dependence estimate, if significant, can show the degree of spatial autocorrelation and justify the use of the spatial model.

2.4. Spatial binary probit model

Given the dependent variable has spatial characteristics and binary values, we elected to estimate the easement adoption model using a spatial binary probit model. An estimation challenge involved the attribute of potential spatial autocorrelation. Several types of spatial autocorrelation in the model can be observed: autocorrelation in the dependent variable, covariates, or the error term. In general, fitting a model while allowing for spatial dependence in all three types is not recommended because the model will usually become unidentifiable with so many parameters (Loonis and de Bellefon, 2018). Instead, model selection should be based on the economic rationale behind a research issue and the results from statistical tests. The three types of spatial lags have distinct economic meanings, and there must be clear justification before including any of them. Spatial dependence in the dependent variable occurs when one spatial unit's outcome is influenced by the outcomes of neighboring ones. Similarly, spatial dependence in the covariates assumes that the outcome in one spatial unit is influenced by the covariates in neighboring states. Spatial dependence in the error term can be used to capture unobserved or omitted factors that are spatially correlated. In this study, potential spatial dependence in both the dependent variable and the error term is intuitive, as conservation movements in neighboring states or regions generally affect each other. However, it is hard to justify the inclusion of spatially lagged covariates (e.g., the weighted average income of adjacent landowners). Preliminary data analysis also revealed that the estimate of spatial dependence in the error term is small and insignificant. Thus, we only considered spatial dependence in the dependent variable itself.

We defined an $N \times 1$ vector (y) to denote adoption decisions on individual land parcels by the N landowners in the sample. A conventional probit model would attempt to explain variation in the binary vector using an $N \times K$ covariate matrix of (X) and the associated $K \times 1$ vector of parameter (β). In considering the spatial dependence, LeSage and Pace (2009) developed a spatial autoregression variant of the conventional probit model as follows:

$$\boldsymbol{y}^* = \rho \boldsymbol{W}\boldsymbol{y}^* + \boldsymbol{X}\boldsymbol{\beta} + \boldsymbol{\epsilon},\ \boldsymbol{\epsilon} \sim \boldsymbol{N}(\boldsymbol{0},\ \boldsymbol{I_N}) \tag{2}$$

where y^* is the latent utility associated with the observed adoption decision. The spatial lag of the latent dependent variable (Wy^*) involves the $N \times N$ spatial weight matrix (W) that contains elements of either $\frac{1}{m}$ or 0, where m is the number of neighbors adjacent to landowner i. The scalar parameter (ρ) measures the strength of spatial dependence, with a value of 0 indicating independence. A conventional non-spatial probit model emerges when ρ equals 0. We used the R package of "spldv" by Piras and Sarrias (2023) to estimate the model in this study.

Interpreting the parameter estimates in a spatial probit model is more complicated if spatial dependence exists. In such a situation, the estimated coefficients associated with explanatory variables cannot be interpreted as in the usual framework of a linear model. Because of spatial interactions, the variation of an explanatory variable for a given spatial unit directly affects its own outcome (i.e., the direct effect) and indirectly the outcomes in neighboring spatial units (i.e., the indirect or spillover effect). The sum of these two effects is the total effect of the explanatory variable (Piras and Sarrias, 2023).

3. Data sources and variable construction

3.1. Data

The data used in this study came mainly from two sources. One was the National Woodland Owner Survey. The USDA Forest Service has conducted the Survey six times in 1958, 1982, 1996, 2002–2006, 2011–2013, and 2017–2018. Huff et al. (2019) summarized and compared the last three surveys. The final results from the latest survey cycle (2017–2018) were released and reported by Bulter et al. (2021). Each of these surveys is large, comprehensive, and independent, and they have been considered a census of private forest landowners in the United States.

We acquired data from the 2017–2018 Survey through an institutional agreement in 2022. The raw data has 10,398 observations and 259 variables. Parcel locations (i.e., the longitude and latitude values) were jittered slightly (about 0.5–2 miles) before the data were released to us. Location jittering is a technique used to protect respondent privacy by slightly altering geographic coordinates. A few variables relevant to the proposed analysis (e.g., parcel locations) had missing information. In particular, a few landowners did not answer the key question of whether there had been a conservation easement on their wooded land, leading us to exclude such observations from our analysis. After all the clearance, 9349 landowners were included in our study, covering all 50 states. Each landowner answered a set of questions related to their land, landownership, use, and personal attributes, and their responses were used to construct explanatory variables for regression analysis.

The other database we used was the American Community Survey (U.S. Census Bureau, 2023). It is conducted on a rolling basis by the U.S. Census Bureau and is updated annually with new demographic data for the entire country at various levels. We collected county-level data describing population, area, and median household income for 2016. There are more than 3000 counties in the United States. In addition, the geographical information of each landowner was used to identify each landowner's respective county location. Ultimately, the variables constructed from the American Community Survey are merged into the primary dataset abstracted from the National Woodland Owner Survey.

3.2. Dependent and independent variables

We defined our binary dependent variable indicating each forest landowner's adoption status of a conservation easement on their forestland based on landowners' responses to a question in the Survey that was worded as follows:

> "Development rights for land can be sold or voluntarily given away. This is usually in the form of a conservation easement. Have development rights been sold or voluntarily given away on any of your wooded land by either you or a previous owner? (a) Yes, (b) No, or (c) Don't know."

In constructing our dependent variable, its value equaled 1 if a conservation easement has been adopted on the wooded land and 0 if not. The few landowners who answered "Don't know" were excluded from the analysis.

We constructed 23 independent variables, which we organized into five groups (Table 1). Our first group includes four variables representing landowners' motivation and objectives concerning forestland ownership: wildlife protection, land investment, timber production, and concerns for heirs. Over ten reasons for forest landownership were listed in the National Woodland Ownership Survey, and the choices for each reason were arranged along a scale: not applicable, not important, of little importance, moderately important, important, and very important. Our preliminary analyses of these various motivations and objectives suggested that only those we included in Table 1 were pertinent to conservation easement adoption.

We constructed the second group of variables to represent attributes

Table 1
Definitions and summary statistics of the variables.

Variable	Definition (data sources)	Mean	Std. Dev.
	Dependent variable		
Adoption	Binary, 1 if a conservation easement on the wooded land is adopted	0.08	—
	Motivation and concerns		
Wildlife	Binary, 1 if protecting wildlife habitats is (very) important	0.74	—
Investment	Binary, 1 if land investment is (very) important	0.51	—
Timber	Binary, 1 if producing timber (e.g., logs and pulpwood) is (very) important	0.32	—
Concern for heirs	Binary, 1 if keeping land intact for future generations is of (great) concern	0.76	—
	Land attributes and use		
Land size	Wooded land owned in total (100 acres)	10.04	35.04
Home nearby	Binary, 1 if a home is on or within a mile of the wooded land	0.52	—
Cabin nearby	Binary, 1 if a vacation home or cabin is on or within a mile of the land	0.24	—
Public recreation	Binary, 1 if the general public had recreation with a fee on the land	0.05	—
Management plan	Binary, 1 if there is a written management or stewardship plan	0.25	—
Forester in cutting	Binary, 1 if a professional forester was used in planning or cutting trees	0.34	—
	Owner characteristics		
Business owner	Binary, 1 if the ownership is in a partnership, trust, corporation, or business	0.27	—
Owner numbers	Number of owners under the ownership (persons)	3.40	8.78
Ownership tenure	2019 minus the date of land acquisition (years)	30.75	19.90
Knowledge	Binary, 1 if the owner knows a conservation easement well	0.27	—
Age	Age of the owner (years)	65.57	10.81
Male	Binary, 1 if the owner is male	0.69	—
Education	Binary, 1 if the owner has a bachelor's degree or higher	0.45	—
	Conservation demand		
Law duration	2019 minus the enactment date of a state easement law (years) (a)	37.28	6.70
Land trusts	Number of land trusts in a state as of 2017 (b)	6.53	7.02
Population density	Population density in the county (person/100 square miles) (c)	1.18	2.46
Household income	Median household income in the county ($1000) (c)	48.73	13.33
	Regions		
North	Binary, 1 if the land is located in the northern region (d)	0.41	—
South	Binary, 1 if the land is located in the southern region (d)	0.33	—

Notes: All the binary variables have the value of either 1 (as defined) or 0 otherwise. The data sources are (a) Gustanski and Squires (2000), (b) Land Trust Accreditation Commission (2023), (c) U.S. Census Bureau (2023), and (d) Bulter et al. (2021). The remaining variables are all collected from (d). The three regions defined in Bulter et al# (2021) are followed, and individual states in each region are listed in Table 2. The total number of observations is 9349 forest landowners.

and land use of each landowner's parcel. These included the size of the parcel, whether a residential home was located on or within a mile of the parcel, whether a vacation home or cabin was located on or within a mile of the parcel, whether the general public was allowed access to the parcel for recreation for a fee, whether there is a written management or stewardship plan for the parcel, and whether a professional forester was used in planning or cutting trees. The mean value of the land-size variable was 1004 acres. This value is mainly boosted by a few large parcels in the Survey, the largest being 92,000 acres. The median value of the land size variable is 120 acres.

The third group of explanatory variables characterize landowners themselves, including their legal structure of ownership (Business owner), ownership tenure, each landowner's self-described knowledge of conservation easements, age, gender, and level of educational attainment. Regarding landowners' knowledge of conservation easements, one of the National Woodland Owner Survey questions asked respondents:

> "How familiar are you with this concept (i.e., a conservation easement)? (a) Not at all familiar, (b) slightly familiar, (c) somewhat familiar, (d) moderately familiar, or (e) extremely familiar?"

Responses of moderately or extremely familiar were recorded as 1, and a zero otherwise.

The fourth group of explanatory variables was included to characterize the potential demand for conservation of forestland where these parcels were located. We assumed that conservation demand would be reflected in both the prevalence of institutional arrangements created to address the conservation of forestland, such as legislation enabling conservation easements, and the prevalence of conservation organizations, such as land trusts, as well as socioeconomic factors, such as population density and household income, which have long been shown to be correlated with conservation demand (e.g., Kline, 2006). Every state currently has a statutory law for adopting and managing conservation easements. States with the earliest enactments were Massachusetts and Montana in 1969. The latest enactments were in West Virginia in 1995 and Alabama in 1997 (Gustanski and Squires, 2000). We constructed a variable to represent how long such laws had been in effect in each state. Additionally, we defined a variable to describe the number of land trusts in each state. A land trust is an organization that conserves land by acquiring and stewarding land or conservation easements (Land Trust Alliance, 2015; Land Trust Accreditation Commission, 2023). In addition, the population density in a county where the wooded land is located is used to represent the pressure from conservation. The Survey did not collect the income information of landowners, and the median household income at the county level is included as a proxy.

Finally, our fifth group of explanatory variables was included to represent the northern and southern United States. All 50 states are divided into three regions (i.e., the North, South, and West), following the classification in Bulter et al. (2021). The northern region comprises 20 states, the southern region 13 states, and the western region 17 states.

4. Results

4.1. Spatial distribution and dependence of easement adoption

A total of 9349 observations were used for analysis, and their distributions by region and state are reported in Table 2. Among the three regions, the northern United States comprised 3824 forest landowners who responded to the National Woodland Owner Survey, and their adoption rate of conservation easements was 9.5 %. Similarly, the corresponding numbers were 3111 forest landowners and an adoption rate of 8.0 % for the South, and 2414 forest landowners and 7.5 % for the West. For all 50 states together, 792 out of the 9349 forest landowners had adopted a conservation easement on their land, resulting in an

Table 2
Numbers of observation and easement adoption by state and region.

Region/State	Total	CE	Share (%)
Total	9349	792	8.5
North (20 states)	3824	362	9.5
South (13 states)	3111	248	8.0
West (17 states)	2414	182	7.5
North (20 states)			
Connecticut	104	19	18.3
Delaware	168	38	22.6
Illinois	168	4	2.4
Indiana	250	13	5.2
Iowa	165	5	3.0
Maine	207	21	10.1
Maryland	197	41	20.8
Massachusetts	183	46	25.1
Michigan	273	13	4.8
Minnesota	252	8	3.2
Missouri	286	8	2.8
New Hampshire	134	25	18.7
New Jersey	172	25	14.5
New York	288	23	8.0
Ohio	237	18	7.6
Pennsylvania	206	18	8.7
Rhode Island	10	0	0.0
Vermont	120	17	14.2
West Virginia	177	5	2.8
Wisconsin	227	15	6.6
South (13 states)			
Alabama	199	10	5.0
Arkansas	264	14	5.3
Florida	115	16	13.9
Georgia	304	36	11.8
Kentucky	168	6	3.6
Louisiana	157	14	8.9
Mississippi	233	10	4.3
North Carolina	269	25	9.3
Oklahoma	254	15	5.9
South Carolina	273	44	16.1
Tennessee	192	10	5.2
Texas	456	23	5.0
Virginia	227	25	11.0
West (17 states)			
Alaska	39	4	10.3
Arizona	113	4	3.5
California	174	25	14.4
Colorado	260	37	14.2
Hawaii	48	2	4.2
Idaho	202	13	6.4
Kansas	127	2	1.6
Montana	186	28	15.1
Nebraska	183	2	1.1
Nevada	30	0	0.0
New Mexico	68	1	1.5
North Dakota	154	7	4.5
Oregon	180	6	3.3
South Dakota	39	2	5.1
Utah	136	17	12.5
Washington	162	12	7.4
Wyoming	313	20	6.4

Notes: The 50 states are divided into three regions (Bulter et al., 2021). For each region or state, the three numbers reported are the total number of landowners in the survey (Total), the number of landowners with a conservation easement (CE), and the percentage (i.e., Share = CE/Total × 100).

overall adoption rate of 8.5 %. That is consistent with the aggregate statistics reported in other sources, e.g., the National Conservation Easement Database (NCED, 2023) and the summary statistics in Lamichhane et al. (2021).

The number of forest landowners included in the National Woodland Owner Survey for each state is highly correlated with state land area totals and the acreage of private forestland. For example, the 13 southern states are heavily forested, and private forest ownership is around 90 % in the South. Thus, the Survey included many forest landowners in the southern states (Fig. 1), with Texas having the largest number (i.e., 456 landowners). In contrast, some states are small or have limited private forestland, so they had fewer observations (e.g., ten landowners in Rhode Island). The states with the highest easement adoption rates were in the northern region, including Massachusetts (25.1 %), Delaware (22.6 %), Maryland (20.8 %), New Hampshire (18.7 %), and Connecticut (18.3 %). In comparison, the highest adoption rate in the South and West was in South Carolina (16.1 %) and Montana (15.1 %), respectively. At the lower end, a few states had no adoption (i.e., Rhode Island and Nevada) or low rates (e.g., Nebraska and New Mexico).

Visual inspection of the spatial distribution of conservation easement adoption among National Woodland Owner Survey respondents suggests the possibility of spatial autocorrelation in easement adoption (Fig. 2). To measure the spatial dependence more formally, we used a join-count test applied to the binary variable of adoption decisions. The choice of spatial weight matrix is critical, so the number of neighboring landowners (i.e., m) was allowed to vary from one to ten in the test (Table 3). The results confirmed a positive and significant pattern of spatial dependence in the adoption. All the statistics are highly significant, and when $m = 7$, the value of non-adoption is the largest. Thus, the number of neighbors was set to 7 in the spatial weight matrix.

4.2. Probit model coefficient estimates

We estimated the conventional and spatial probit models for the entire sample and then separately for individual regions. The spatial probit model was also fitted with different numbers of neighbors in defining the spatial weight matrix. We found that the spatial dependence parameter (ρ) was highly significant in each estimation, which justified using the spatial probit model. Furthermore, the magnitude of ρ became slightly larger when the number of neighbors (m) was increased, as shown in Table 3. Nevertheless, the results of coefficient estimates were all fairly similar, and there were no qualitative differences in the main results. Thus, we elected to continue our analysis using seven neighbors to define the spatial weight matrix.

Among all the 23 covariates, the t-ratios and the number of statistically significant variables are similar between the conventional and spatial models (Table 4). For the spatial model, the spatial dependence parameter is 0.309, suggesting small or moderate spatial autocorrelation, which aligns with the similarity of the estimated coefficients between the conventional and spatial models. However, the estimates for some covariates from the two models do differ. The absolute values of the estimates from the spatial model are larger for five covariates, smaller for 11 covariates, and comparable for the remaining ones. Given the significance of the spatial dependence parameter, we deemed the spatial model results more credible.

4.3. Marginal effects

Marginal effects from the spatial model are divided into direct, indirect, and total effects (Table 5). The magnitude of the total effect from the spatial model is larger than the marginal effect from the conventional model, suggesting that including a spatial dependence component in the modeling has allowed for a more comprehensive assessment of the impacts of the explanatory variables on conservation easement adoption. Given the presence of spatial dependence, we focus on the results from the spatial probit model.

Let us examine the signs of the marginal impacts first. Among the 23 covariates, 15 have statistically significant marginal effects. The eight statistically insignificant variables are Home nearby, Public recreation, Business owner, Ownership tenure, Age, Male, Law duration, and Land trusts. Among the significant variables, 12 have positive impacts, and three have negative impacts (i.e., Investment, Timber, and Education). The likelihood of easement adoption tends to be higher for forest landowners with the intention of protecting wildlife habitats or with concern for heirs among the reasons they own forestland, landowners owning larger forestland parcels, and those with a home nearby their parcels. Easement adoption is also positively correlated with proxy

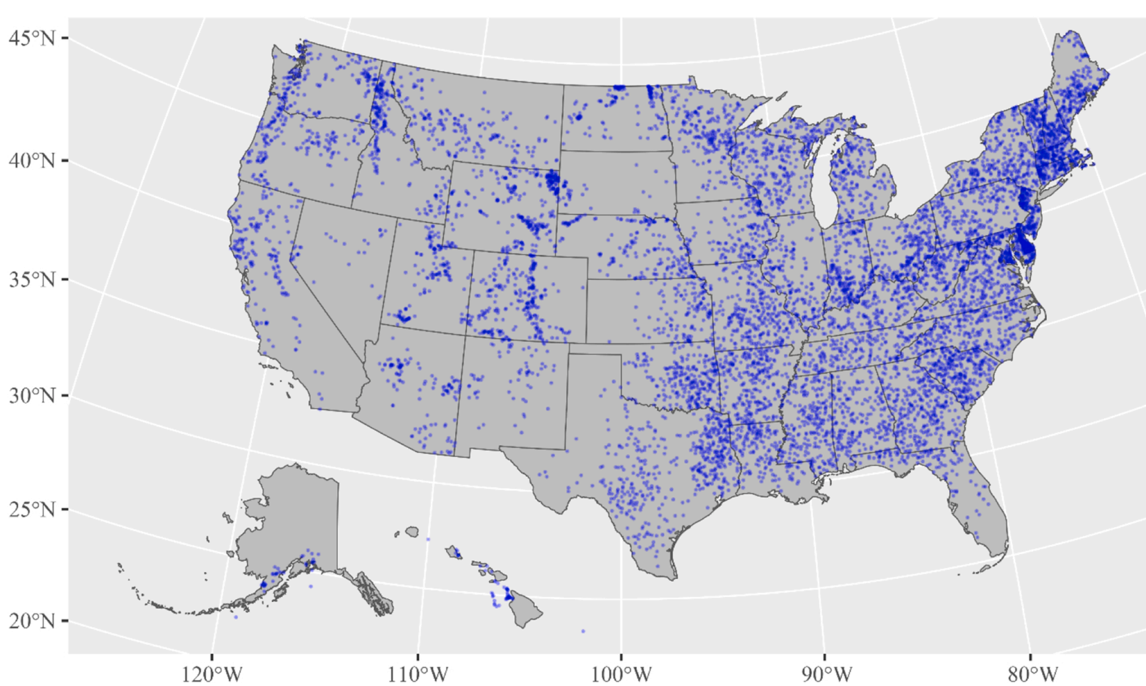

Fig. 1. Spatial distribution and location of all the 9349 landowners in the survey.

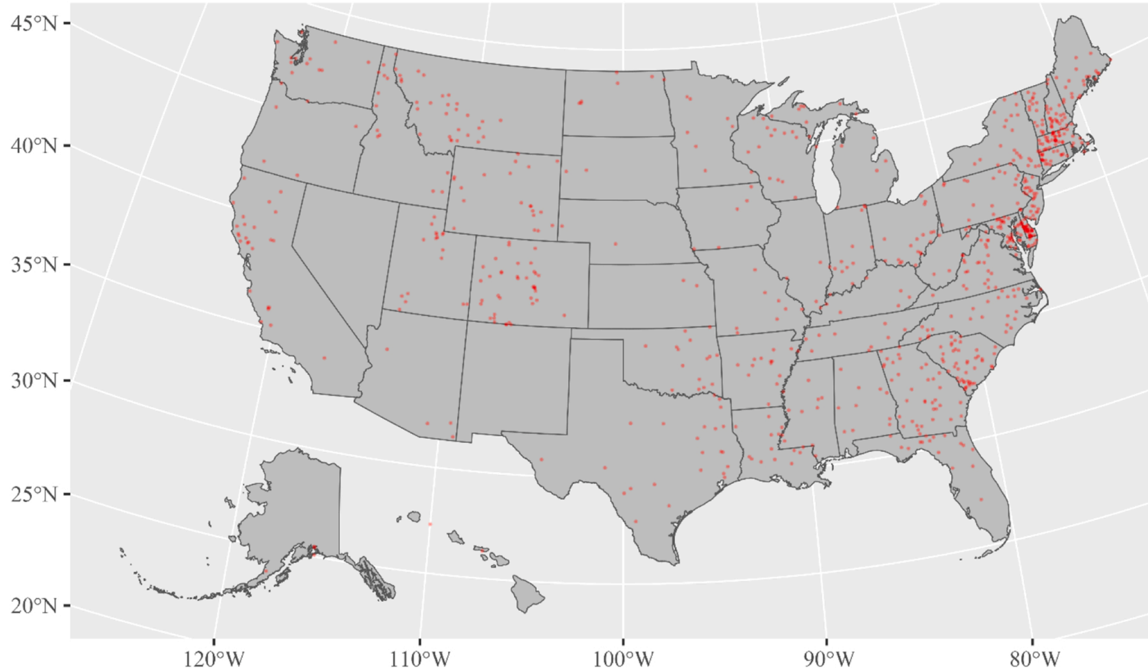

Fig. 2. Location of the 792 landowners with conservation easements on their wooded land.

Table 3
A comparison of the impact of different numbers of landowners in the spatial weight matrix.

m	Non-adoption		Adoption		Spatial effect (ρ)	
	Statistic	p-value	Statistic	p-value	Estimate	p-value
1	2.373	0.018	5.673	0.000	0.043	0.202
2	3.322	0.001	7.839	0.000	0.166	0.000
3	3.612	0.000	8.805	0.000	0.176	0.000
4	3.915	0.000	8.910	0.000	0.212	0.000
5	4.140	0.000	9.381	0.000	0.256	0.000
6	3.989	0.000	10.016	0.000	0.271	0.000
7	4.276	0.000	11.127	0.000	0.309	0.000
8	3.705	0.000	12.321	0.000	0.321	0.000
9	3.613	0.000	13.436	0.000	0.338	0.000
10	3.802	0.000	13.523	0.000	0.331	0.000

Notes: *m* is the number of nearby landowners included in the weight matrix. The first panel of results is the statistic and p-value from the join-count test on the spatial distribution of non-adoption versus non-adoption status. The second panel is for adoption versus adoption status. The final panel contains the estimate of the spatial effect parameter (ρ) from the spatial probit model.

variables representing conservation demand, with positive and statistically significant estimated coefficients for the variables Population density and Household income. Conversely, easement adoption tends to be lower among landowners whose reasons for owning forestland include land investment or timber production goals as major reasons for ownership.

The magnitudes of the marginal effects vary widely. The explanatory variable with the largest marginal effect on easement adoption is landowners' knowledge of conservation easements (i.e., Knowledge). In total, the knowledge could increase the adoption rate by 19.52 %. Similarly, a management plan on the wooded land seems to increase the adoption rate by a total of 4.92 %, wildlife protection as a reason of ownership would increase the rate by 3.84 %, and timber production would reduce the rate by 2.79 %. By region, landowners in the southern states tend to have higher adoption rates (i.e., a marginal effect of 3.8 %) than landowners in the northern states (i.e., a marginal effect of 1.9 %), followed by the west (i.e., the base case). These regional differences may

Table 4
Coefficient estimates from the conventional and spatial probit models.

Variable	Conventional model		Spatial model	
	Estimate	t-ratio	Estimate	t-ratio
Intercept	−3.439***	−14.43	−2.498***	−10.29
Motivation and concerns				
Wildlife	0.234***	4.24	0.230***	4.18
Investment	−0.140***	−3.04	−0.152***	−3.28
Timber	−0.152***	−2.84	−0.154***	−2.98
Concern for heirs	0.123**	2.26	0.121**	2.22
Land attributes and use				
Land size	0.001**	2.53	0.001**	2.37
Home nearby	0.065	1.42	0.066	1.47
Cabin nearby	0.158***	3.15	0.146***	2.96
Public recreation	0.042	0.47	0.020	0.22
Management plan	0.284***	5.73	0.276***	5.60
Forester in cutting	0.107**	2.15	0.089*	1.82
Owner characteristics				
Business owner	0.077	1.55	0.070	1.40
Owner numbers	0.004**	2.30	0.004**	1.99
Ownership tenure	0.000	0.23	0.001	0.45
Knowledge	1.139***	23.77	1.124***	23.28
Age	0.004*	1.72	0.003	1.43
Male	−0.058	−1.19	−0.065	−1.35
Education	−0.158***	−3.39	−0.162***	−3.47
Conservation demand				
Law duration	0.008**	2.16	0.004	1.27
Land trusts	0.004	1.14	0.001	0.30
Population density	0.016**	1.97	0.017**	2.30
Household income	0.008***	4.67	0.006***	3.63
Regions				
North	0.148**	2.52	0.114**	2.57
South	0.292***	4.31	0.218***	4.18
Spatial effect (ρ)			0.309***	6.57

Notes: ***, **, and * denote the significance at the 1 %, 5 %, and 10 % levels, respectively. See Table 1 for the definitions of variables.

have reflected the influence of factors not included in our analysis, as it is challenging to quantify them with reliable data (e.g., conservation traditions, limitations in access to conservation easements, cultural attitudes toward partial land ownership, and ecological variations on individual land parcels). In contrast, the total effects are significant but

Table 5
Marginal effects from the conventional and spatial probit models.

Variable	Conventional model		Spatial model					
	Effect	t-ratio	Total	t-ratio	Direct	t-ratio	Indirect	t-ratio
Motivation and concerns								
Wildlife	0.0207***	4.65	0.0384***	4.11	0.0267***	4.35	0.0117***	3.13
Investment	−0.0136***	−3.02	−0.0261***	−3.10	−0.0182***	−3.26	−0.0080**	−2.52
Timber	−0.0141***	−2.96	−0.0279***	−3.30	−0.0194***	−3.42	−0.0085***	−2.72
Concern for heirs	0.0113**	2.38	0.0203*	1.90	0.0142*	1.93	0.0061*	1.76
Land attributes and use								
Land size	0.0001**	2.51	0.0002**	2.47	0.0001**	2.44	0.0001**	2.33
Home nearby	0.0063	1.42	0.0113	1.32	0.0079	1.32	0.0034	1.27
Cabin nearby	0.0164***	2.94	0.0256***	2.93	0.0179***	2.90	0.0077***	2.61
Public recreation	0.0042	0.45	0.0051	0.34	0.0036	0.34	0.0015	0.34
Management plan	0.0311***	5.08	0.0492***	5.53	0.0343***	5.92	0.0149***	3.74
Forester in cutting	0.0107**	2.09	0.0146*	1.81	0.0102*	1.81	0.0044*	1.74
Owner characteristics								
Business owner	0.0077	1.51	0.0114	1.25	0.0079	1.25	0.0035	1.21
Owner numbers	0.0004**	2.29	0.0006**	2.00	0.0004**	2.00	0.0002*	1.87
Ownership tenure	0.0000	0.23	0.0001	0.72	0.0001	0.72	0.0000	0.69
Knowledge	0.1729***	18.55	0.1952***	14.78	0.1361***	23.32	0.0591***	5.12
Age	0.0004*	1.72	0.0005	1.33	0.0004	1.34	0.0002	1.27
Male	−0.0057	−1.17	−0.0126	−1.55	−0.0088	−1.54	−0.0037	−1.50
Education	−0.0152***	−3.42	−0.0279***	−2.98	−0.0194***	−3.10	−0.0085**	−2.47
Conservation demand								
Law duration	0.0008**	2.16	0.0006	1.20	0.0004	1.20	0.0002	1.18
Land trusts	0.0003	1.15	0.0001	0.36	0.0001	0.36	0.0000	0.34
Population density	0.0016*	1.96	0.0029**	2.44	0.0020**	2.50	0.0009**	2.14
Household income	0.0008***	4.66	0.0010***	3.86	0.0007***	3.70	0.0003***	3.40
Regions								
North	0.0147**	2.46	0.0199***	2.68	0.0140***	2.62	0.0059***	2.58
South	0.0309***	3.96	0.0379***	4.31	0.0264***	4.27	0.0114***	3.50

Notes: ***, **, and * denote the significance at the 1 %, 5 %, and 10 % levels, respectively. See Table 1 for the definitions of variables. The marginal effects from the spatial probit model are composed of three effects: direct, indirect, and total effects.

small for several variables, including Land size (0.02 %), Owner numbers (0.06 %), and Household income (0.10 %).

The above marginal effect from the spatial probit model is the total effect, which is composed of direct and indirect effects. For example, if landowners are knowledgeable about conservation easements, their adoption rate would increase by 13.6 % (i.e., the direct effect). If land-

Table 6
Estimates of the spatial probit model by region and total marginal effects of the covariates.

Variable	All	t-ratio	North	t-ratio	South	t-ratio	West	t-ratio
Motivation and concerns								
Wildlife	0.0384***	4.11	0.0657***	3.58	0.0317**	2.20	0.0194	1.16
Investment	−0.0261***	−3.10	−0.0490***	−3.48	−0.0143	−1.03	−0.0068	−0.49
Timber	−0.0279***	−3.30	−0.0073	−0.47	−0.0487***	−2.81	−0.0438***	−2.67
Concern for heirs	0.0203*	1.90	0.0301	1.63	0.0018	0.11	0.0286	1.48
Land attributes and use								
Land size	0.0002**	2.47	0.0009***	4.00	0.0001	0.99	0.0000	0.21
Home nearby	0.0113	1.32	−0.0052	−0.39	0.0225*	1.68	0.0208*	1.74
Cabin nearby	0.0256***	2.93	0.0114	0.70	0.0345**	2.06	0.0283**	2.19
Public recreation	0.0051	0.34	0.0353	0.94	0.0340	1.50	−0.0510*	−1.91
Management plan	0.0492***	5.53	0.0485***	3.35	0.0454**	2.55	0.0588***	3.66
Forester in cutting	0.0146*	1.81	−0.0067	−0.42	0.0338**	2.56	0.0141	0.93
Owner characteristics								
Business owner	0.0114	1.25	0.0161	0.99	−0.0137	−0.91	0.0393***	3.11
Owner numbers	0.0006**	2.00	0.0001	0.31	0.0005	0.66	0.0017**	2.46
Ownership tenure	0.0001	0.72	0.0001	0.17	−0.0002	−0.77	0.0005	1.35
Knowledge	0.1952***	14.78	0.2275***	8.92	0.1868***	6.15	0.1510***	6.02
Age	0.0005	1.33	0.0001	0.10	0.0010	1.47	0.0010	1.34
Male	−0.0126	−1.55	0.0108	0.68	−0.0215	−1.54	−0.0229	−1.54
Education	−0.0279***	−2.98	−0.0450***	−2.96	−0.0282*	−1.77	−0.0047	−0.32
Conservation demand								
Law duration	0.0006	1.20	0.0008	0.95	−0.0008	−0.78	0.0015	1.45
Land trusts	0.0001	0.36	−0.0005	−0.79	−0.0006	−0.34	0.0011*	1.67
Population density	0.0029**	2.44	0.0033**	2.23	0.0018	0.45	−0.0049	−1.19
Household income	0.0010***	3.86	0.0015***	3.91	−0.0001	−0.20	0.0014***	3.07
Regions								
North	0.0199***	2.68						
South	0.0379***	4.31						
Model								
Spatial effect(p)	0.309***	6.57	0.360***	5.35	0.282***	2.96	0.192*	1.83
Observations	9349		3824		3111		2414	

Notes: ***, **, and * denote the significance at the 1 %, 5 %, and 10 % levels, respectively.

owners' neighbors are knowledgeable about conservation easements, their adoption rates, through spatial dependence, would increase by an additional 5.9 % (i.e., the indirect effect). Thus, the total effect of the knowledge variable is 19.5 %. For each covariate in this application, the indirect effect is about 30 % of the total effect, or stated in another way, the direct effect is about 2.3 times of the indirect effect. The relationship largely corresponds to the estimate of the spatial dependence parameter ($\rho = 0.309$).

Finally, we estimated a group of models by region to examine potential heterogeneity in spatial dependence among the regions. We estimated four separate models—one for the entire sample and then each for the three regions (Table 6). Our analysis was motivated by the statistically significant estimates for the variables representing regional differences across the entire sample. Our region-specific spatial model results suggest variation in spatial dependence across the three regions. The spatial dependence parameters were all statistically significant in each estimation but varied in their values: 0.309 for the entire sample, 0.360 for the North, 0.282 for the South, and 0.192 for the West. Thus, the spatial dependence in the North was the strongest among the three regions.

Moreover, the number of statistically significant total effects was 13 out of 21 variables in the whole sample (i.e., excluding the two regional variables to make the results comparable), 8 in the North, 8 in the South, and 10 in the West. Only two variables—Management plan and Knowledge—had statistically significant marginal effects from the four separate fittings. The remaining variables were statistically significant in only one or two models. For example, Land size was statistically significant only in the models for the entire sample and the North. This result seems consistent with the fact that many conservation easement contracts in the North are large in acreage. The variables Timber, Home nearby, and Cabin nearby were statistically significant only in the South and West models. Finally, the variable Knowledge, having the largest marginal effect in the entire sample model, also had the largest total effect in the North model (22.8 %), followed by the South model (18.7 %), and then the West model (15.1 %).

5. Discussion and policy implications

With the expansion of wildland-urban interfaces, forestland conservation has become an increasingly important land-use and forest policy issue in recent decades, with conservation easements emerging as a major land-use mechanism to protect forestland from housing and other forms of development. Our study of conservation easement adoption among private forestland landowners in the US suggests that there can be considerable spatial dependence in easement adoption and correlation with landownership objectives, forestland parcel characteristics, and conservation demand. Findings from our analysis suggest several policy implications pertaining to the use of conservation easements in forestland conservation efforts.

Overall, 8.5 % of forest landowners in the National Woodland Owner Survey adopted conservation easements in the United States as of 2017–2018, with differences being present among the regions (i.e., 9.5 % in the North, 8.0 % in the South, and 7.5 % in the West). Although these statistics indicate that conservation easements appear to be reasonably well accepted and prevalent among private forestland owners, data from the National Conservation Easement Database indicate that conservation easements on private forestland represent just 1.6 % of the total land base in the US as of 2023 (NCED, 2023). While the above two data sources are not strictly comparable, conservation easements seem to have become a widely adopted conservation tool with substantial promise for future conservation efforts.

Our spatial statistical modeling suggests a robust spatial dependence in easement adoption among private forest landowners, implying that the likelihood of one landowner adopting a conservation easement is greater if that landowner has a neighbor who has adopted an easement. This result suggests that one way to motivate easement adoption might be through outreach and education among forest landowners about where other landowners have successfully adopted easements. Combining the spatial effects finding with those for individual covariates suggests additional policy implications. First, our results regarding the influence of objectives in forest landownership indicate that conservation easement adoption is more likely among those landowners possessing wildlife habitats and concern for heirs-type objectives, while those landowners with more timber or investment objectives are less likely inclined to adopt easements. These results generally align with the body of research literature suggesting that more conservation-minded private forest landowners are often more willing to participate in forestland conservation efforts (e.g., Kline et al., 2000; Fischer et al., 2013), suggesting that conservation efforts might be most successful by targeting landowners possessing such objectives.

Second, our results indicate that landowner knowledge about conservation easements is crucial in their adoption of easements. Thus, conservation efforts might best turn to additional education and outreach through extension services, workshops, and the like to inform landowners about the role that conservation easements can play in the overall state or regional conservation efforts, as well as what conservation easements might mean for individual landowners were they to adopt an easement. Third, our findings align with previous research (e.g., Kline, 2006) and demonstrate the influence of public demand for conservation in motivating conservation efforts. Specifically, states and regions experiencing higher population growth, and thus scarcity of undeveloped forestland, tend to experience increasing demand for land conservation. Such demand is also generally more prevalent in locations and regions with higher household income levels. The northern United States is usually more populated than other states and is shown to have a higher easement adoption rate. Part of this likely reflects the long legacy of population growth and increasing population densities in the northern region and the extended history of using conservation easements as a conservation tool relative to other areas. As population densities grow and more Americans migrate to the sun belt (e.g., Texas, Georgia, and Florida), we can similarly expect growing conservation demands in such locations, with expansion in the use of conservation easements to follow.

Finally, the duration of state conservation laws has shown their relevancy to overall easement adoption rates. States that have adopted statutory laws enabling the use of conservation easements earlier tend to have higher easement adoption on forestland. Such results demonstrate the fundamental role governments can play in conservation efforts by establishing the necessary legal environment, tax benefits, and other factors that enable and facilitate forestland conservation in places where the public demands it.

Forestlands provide significant timber and ecosystem benefits to society, including wildlife habitats, clean water and air, and carbon storage. With continuing growth in population and income, the demand for conservation likely will continue to grow in the US. Currently, private forest landownership accounts for about 58 % of all forestland in the US. While many such ownerships comprise extensive land holdings, much of the private forestland base has become fragmented by low-density development or the expansion of wildland-urban interfaces. Such fragmentation can influence options to manage existing forest landscapes in ways that address public concerns about wildfire risk, wildlife conservation, carbon sequestration, and climate change. Given that there are about 9.6 million family forest landowners in the US, each holding less than 100 acres (Bulter et al., 2021), it is apparent that the behavior and decisions of individual forest landowners are critical to conservation efforts. Therefore, there will be a constant need to monitor the progress of conservation easement adoption in the US while providing helpful and timely information and assistance to private forest landowners to meet the future conservation challenges associated with shifting forest landscapes.

CRediT authorship contribution statement

Sun Changyou: Writing – review & editing, Writing – original draft, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Li Xiaofei:** Writing – review & editing, Validation, Resources, Methodology, Investigation, Conceptualization. **Kline Jeffery D:** Writing – review & editing, Validation, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The data that has been used is confidential.

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