

Article

Forest Owner Willingness to Accept Payment for Forest Carbon in the United States: A Meta-Analysis

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Abstract: Forests in the United States provide important carbon sequestration services that could be leveraged for climate change mitigation. There is increased interest among decision makers and investors to extend forest carbon payment programs to family forest owners (FFOs), the largest category of private forest owners. Since FFOs manage forests for multiple objectives, it is unclear which contract requirements and payment levels will appeal to early adopters and perhaps establish the direction of innovation. To answer this question, we conducted a comprehensive review of the research literature assessing forest owner preferences for carbon payment programs. Out of 22 papers reviewed, a total of 13 stated preference studies were included in the meta-analysis. Robust regression modeling and benefit transfer techniques were used to generate estimates for carbon payment contracts for different categories of FFOs. Results show significant variation in forest owner willingness to accept (WTA) as a function of management objectives, contract length, number of forest acres, management plan requirement, and management restrictions. Average annual per acre payment values were lowest for conservation-oriented forest owners, followed by passive and production-oriented forest owners. Overall, findings suggest the need for diverse types of contracts and payment levels in order to have widespread participation in carbon programs by forest owners.

Keywords: carbon sequestration; family forest owners; meta-analysis; contract design; willingness-to-accept



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1. Introduction

Among the portfolio of options available, managing forest carbon can be a low-cost, low-tech, and relatively simple approach to addressing climatic change [1]. Over half of forests in the United States (U.S.) are privately owned and may include individuals or family estates and trusts holding at least 1 acre of forest and at least 10% stocking density [2]. To work with these groups, carbon-offset project developers need to design strategies that engage diverse categories of forest owners, including family forest owners (FFOs) [3]. Innovations in carbon accounting and aggregation have allowed for the emergence of boutique carbon-offset programs, such as the Natural Capital Exchange and the Family Forest Carbon Program, which generally focus on smaller landholders in the eastern U.S. The management practices incentivized in many of these programs is delay in harvest (i.e., lengthening harvest cycles, changing harvest strategies, and optimal rotation). However, forests in the U.S. already offset up to 11% of total U.S. greenhouse gas emissions due to longstanding slowdowns in harvesting [4]. Furthermore, up to 89% of the U.S. timber supply comes from private forest lands, which means delaying harvest for additional carbon storage could have important implications for domestic timber supply [5]. With only a small fraction of FFOs enrolled in a carbon program, there is a limited amount of real data describing what owners may prefer in a contract and level of payment [6,7]. Stated preference studies have been the approach so far for assessing the potential of new markets; however, these kinds of studies can be challenging to conduct when time and resources are

limited. Benefit transfer (BT) methods are a useful way of employing values from existing studies to estimate preferred types of programs for FFOs. Estimating willingness to accept (WTA) values across a variety of FFOs and contracts may also help identify potential early adopters and the direction of innovation.

1.1. Background

Studies examining landowners' willingness to participate in a forest carbon payment program found choices are often a function of economic, social, and environmental factors [1,8–10]. For example, economic barriers to participation include low carbon prices and high opportunity costs and entry costs (e.g., requirements of a management plan and certification). Social factors include compatibility with other forest management objectives (e.g., timber production, recreational uses). The risk of a natural disturbance impacting carbon sequestration potential may increase liability risk due to accidental release. Despite these challenges, many forest owners are still interested in preserving the environmental benefits associated with their forest, including carbon storage [11]. Carefully designed carbon incentive programs for FFOs could help promote climate-smart forestry, which is needed to help protect other forest ecosystem services, including wildlife habitat, soil quality, water storage, nutrient retention, filtration, and biodiversity conservation [12,13].

Because private forest owners maintain forests for multiple uses, many consider forest carbon storage an ancillary benefit [14]. This means that opportunities for carbon incentives need to be in line with other expectations for forest ownership. Identification of early adopters is important for understanding what categories of owners will likely establish the direction of forest carbon programs and climate change mitigation solutions [15]. Stated preference studies have consistently found that acceptable payment levels can vary depending on conservation goals, expected management activities, and program design [1,3,14,16–18]. Early adopters of new technology in agricultural fields tend to be more accepting of change and better-equipped to manage uncertainty and risk, among other qualities [19]. Illustrative of variation in forest owner response to risk is the finding that certain portions of FFOs refuse to take part in forest carbon programs at any price [20]. Since the diffusion of forest carbon incentives is still in the early stages, owners who have actually enrolled in a payments program offer a glimpse of who may be early adopters [21,22]. Case studies reveal that these early adopters tend to be larger landholders that are actively working to advance biological conservation [22]. What it may take to engage other types of FFOs in forest carbon incentives is still unclear.

Benefit transfer (BT) is a valuation method that uses econometric methods to transfer economic information from existing empirical research to a new policy or site where the value has not been assessed [23,24]. The BT method has been widely applied to the valuation of various ecological assets, including wetlands, forests, fishery resources, and biodiversity at various scales, including individual projects at micro level and a larger geographic scale at regional, country, or global levels [24,25]. It has also been used to inform a number of decisions, including private project cost–benefit analysis, green accounting for public decisions, and providing a technical/legal basis for compensation of environmental damage [26,27]. Regression analysis is a statistical method commonly used to transfer values from the data collected via a meta-analysis study. This approach allows for better understanding of interstudy variation in research outcomes by modeling the characteristics that are typically held constant within an individual study, such as valuation methodology, survey mode, time, and physical attributes of the study site [24]. To our knowledge, the meta-analysis and BT approach has never been employed to generate estimates of value for carbon contracts for different categories of FFOs.

1.2. Goals and Objectives

The goal of this paper is to use existing studies to explore what kinds of forest carbon incentive levels and contracts may be preferred by a variety of forest owners. We used

meta-analysis and BT methods to generate estimates of value and applied these values to a variety of contracts that may be preferred by archetype categories of FFOs. Steps include:

1. Curate a collection of stated preference studies conducted in the U.S. and focused on forest carbon incentives;
2. Examine the statistical relationship between willingness to accept payment (WTA) for forest carbon and study program features, including contract design and respondent characteristics;
3. Apply estimated values to contractual arrangements that may appeal to different categories of FFOs based on their values and management objectives.

Findings are expected to provide valuable insights for forest carbon policies and project developers regarding the design of forest carbon incentive and assistance programs.

2. Methods

2.1. Review of Stated Preference Studies

The literature review and meta-analysis procedures were conducted following the recommendations of [28,29] (see Appendix A). *Google Scholar* and *Science Hub* were the primary databases, and the search was conducted using keywords such as “Private Forest landowners”, “Willingness to Accept (WTA)”, “carbon sequestration”, “carbon market programs”, “private forests in the USA”, “voluntary offset markets”, and “forest management for ecosystem services”. The criteria for inclusion in the study was: (1) used stated preference methods to generate WTA values for participating in a voluntary carbon-offset program, (2) conducted in the United States, and (3) the respondents are private forests landowners. Over 70 peer-reviewed articles, conference papers, book chapters, and gray literature were reviewed; however, 22 primary studies were found to be relevant to the subject, and 13 contained WTA data that could serve as a dependent variable for use in a regression analysis.

2.2. Data Sources

Most studies came from the southeastern U.S. (41.67%) followed by the Northeast (36.11%). The remainder came from Southwest, Midwest, and Northwest, respectively (Table 1). Implementation dates ranged from 1994 to 2019, and data were collected from landowners using survey methods. Most of the studies involved mail surveys (80.5%), followed by web and a telephone survey. Sample sizes ranged from 141 to 1032 complete responses (mean = 594), representing the opinions of 21,119 respondents in total. Response rates for the mail surveys averaged 39.3%.

Table 1. Summary of studies estimating forest owner willingness to accept (WTA) payment for managing forest carbon.

References	Obs.	Contract Design ¹	Services	Scale	Valuation	US State	WTA/Acre/Year (2020 USD)
[14]	5	YRS > 20–50+, PN	Carbon	Statewide	CE	Florida	USD 13.58–USD 88.14
[30]	1	-	Carbon	State region	CE	Massachusetts	USD 8.50
[31]	1	YRS50+, MR	Carbon	Statewide	CV	South Carolina	USD 67.83
[32]	5	YRS > 20–50+, PN	Carbon	Statewide	CE	Vermont	USD 11.68–USD 16.14
[9]	1	YRS <20, MR, MP	Carbon	Multistate	CV	Multiple states ²	USD 178.00
[33]	1	-	Carbon	State region	CV	New York	USD 65.55
[34]	2	YRS > 50, PN	Carbon	Statewide	CE	Massachusetts	USD 5.40–USD 7.19
[35]	3	YRS20–50+	Carbon	Multistate	CE	Multiple states ³	USD 20.44–USD 23.75
[36]	4	YRS20–50+, MR, MP, PN	Carbon	Statewide	CE	Massachusetts	USD 280.77–USD 356.92

Table 1. Cont.

References	Obs.	Contract Design ¹	Services	Scale	Valuation	US State	WTA/Acre/Year (2020 USD)
[37]	3	YRS > 20–50+,	Carbon	Statewide	CV	Texas	USD 10.86–USD 148.35
[18]	3	MR, MP	Multiple	Statewide	CV	Mississippi	USD 87.59–USD 194.90
[38]	2	MR, MP	Multiple	Statewide	CV	Mississippi	USD 87.48–USD 284.31
[39]	2	MR	Habitat	Northwest	CE	Oregon, Washington	USD 120.50–USD 151.93

¹ YRS, number of contract years; MR, management restrictions; MP, management plan is required; PN, penalty for early withdrawal. ² Alabama, Arkansas, east Oklahoma, east Texas, Georgia, Florida, Louisiana, Mississippi, North Carolina, South Carolina, and Virginia. ³ Michigan, Wisconsin, and Minnesota.

Methodologies used to generate estimates of WTA values included contingent valuation, dichotomous choice, best–worst choice modeling case, and attribute choice experiment. Nine studies produced multiple WTA observations, and four studies provided a single observation of WTA. Two studies described variation in WTA by constructing demand curves based on percent willing to enroll under different payment levels [35,36]. For these studies, a weighted means method was used to construct a single WTA value for use in the regression analysis.

The contract features described in the studies included options such as length of contract, whether there was a withdrawal option or not (penalty), type of ecosystem service (i.e., carbon sequestration or other ecosystem services), and requirement of management plan and management restrictions, such as delay in harvest (Table 2). Contract length was the most common contract attribute, and lengths ranged from one to 50+ years. All the studies reported socio-economic data about the respondents, including the respondent's ethnicity, gender, age, education, number of acres owned, and tenure length, but the format used varied across studies.

Table 2. Description of the variables tested in the regression analysis.

Variable Category	Name	Description	Mean	SD	Min	Max
Willingness to accept (dependent)	WTA2020_Ln	Natural log of mean WTA acre/year for carbon sequestration services (2020 USD)	USD 3.87	USD 1.25	USD 1.69	USD 5.88
Contract Attributes						
Other ecosystem services provided	MES	1 = manage for multiple forest ecosystem services, 0 for carbon only	0.36	0.48	0	1
Length of proposed contract	YRS	1 = less than 20 years, 2 = length is 20–50 years, 3 = over 50 years	0.23	0.42	1	50+
Penalty	PN	1 = penalty for early withdrawal, 0 otherwise	0.15	0.33	0	1
Management plan	MP	1 = contract requires a management plan, 0 otherwise	0.21	0.40	0	1
Management restriction	MR	1 = contract requires owner to delay or reduce harvest, 0 otherwise	0.42	0.50	0	1
Demographic Characteristics						
Gender of the respondent	Male	Percent male respondents reported in National Woodland Owners survey data	81.00	0.4	71.00	89.00
Age of the respondent	Age	Respondent's mean age category reported in National Woodland Owners survey data	55–64	0.34	>55	>75

Table 2. Cont.

Variable Category	Name	Description	Mean	SD	Min	Max
Willingness to accept (dependent)	WTA2020_Ln	Natural log of mean WTA acre/year for carbon sequestration services (2020 USD)	USD 3.87	USD 1.25	USD 1.69	USD 5.88
Income from timber	IT	Percent income from timber in study state(s)	15.69	0.85	1.00	30.00
Number of acres owned	Acres_Ln	Natural log of mean number acres owned by respondents reported in study	4.98	1.04	2.89	7.51
Length of the tenure	TL	Mean number of years forest land owned in study state(s) from National Woodland Owners survey data	26.07	0.24	26.00	27.5
Respondent's education ¹	Edu	Percent woodland owners with bachelor's degree in study state(s) from National Woodland Owners survey data	44.30	1.01	14.00	57.00
Race of the woodland owners	White	Percent of white woodland owners in study state(s) from National Woodland Owners survey data	98.30	0.16	94.00	100.00
Study Characteristics						
Region of the study	Region	1 = Southwest, 0 = All other regions	2.08	1.22	0	1
Data collection method	Method	1 = Mail survey, 2 = Phone survey, 3 = Web survey	1.33	0.71	1	3
Type of question format	Questform	1 = choice experiment was used, 0 otherwise	0.94	0.23	0	1
Weighting variable	Weight	Ratio of natural log of sample bias and natural log of response bias	2.16	0.41	1.30	2.83
Study year	Year	Years since 1994 (first study year)	2010 is the most frequent study year			

¹ Respondent education was classified into six categories. The mean education level reported lies in fifth category (bachelor's degree).

2.3. Description of Variables Tested in the Regression Analysis

Willingness to accept observations were understood to be the minimum monetary amount that an owner is willing to accept as a compensation to change their forest management activities to enhance carbon sequestration services. The summary statistic for WTA reported in each study served as the dependent variable in the meta-analysis. To make them comparable, all mean WTA values were converted into an annual payment per acre in 2020 USD and transformed by taking the natural log. A total of 17 independent variables were developed for testing to help explain important variation in WTA. These variables represented different contract attributes, respondent characteristics, and study characteristics. Contract attributes included length of contract, withdrawal penalty, management plan, and management restrictions. Data describing forest owners in each study were arranged into categories representing relevant distributions of age, gender, race, educational status, income from the timber, acres owned, and length of tenure. When data from studies describing owner characteristics were incompatible or incomplete, state level data from the National Woodland Owners survey 2006, 2013, and 2018 were used as a substitute. Information on the study region, data collection methods, sample size, survey questions, and respondent's rate were coded using percent or category codes. Study response rate metrics were used to create a weighting variable to control for differences in study quality. A fractional weight was used to control the influence of multiple observations from a single study.

2.4. Meta-Analysis and Benefit Transfer Methods

Due to the small number of observations, a robust regression model was employed using STATA 15.1. Robust regression is an alternative to least squares regression when using small data sets with large variation in data distributions [40]. Final models include only significant variables, and model selection was based on R-squared and root mean square error [41]. The relationship between the dependent and independent variables are described in the equation below:

$$Y_i = \beta_0 + \beta_1 x_{1i} + \dots + \beta_k x_{ki} + \mathcal{E}_i \quad (1)$$

where Y_i is the WTA value estimate from study i ; β_0 is an intercept term; $\beta_j = 1 \dots k$ is estimated coefficients; $x_j = 1 \dots k$ specifies study attributes, such as respondent characteristics and valuation approach; and $\mathcal{E}_i$ specifies between study variation [42]. Study attributes can be adjusted to arrange new contracts and scenarios using the equation below:

$$(WTA) = \beta_0 + \sum (\beta_j) (L_{jl}) \quad (2)$$

where WTA is the value of a new hypothetical contract, β_0 is the estimated equation intercept, β_j is the estimated coefficient for attribute j , and L_{jl} is the multiplier assigned to variable j to adjust attribute levels [43]. The multiplier code for most variables ranged from 1 to 8 and included category of acres owned and number of contract years, etc.

To generate a discount rule for early adopters, we used the studies that reported WTA metrics using demand curves [35,36]. Percent enrollment at different price points indicated that at least half of forest owners were willing to accept up to 75% less compared to the other half of forest owners. To account for this variation in the benefit transfer, we calculated a second estimate for early adopters by applying a 75% discount rule to mean WTA values using the following equation:

$$\text{Mean WTA}_{\text{early adopters}} = \text{Mean WTA}_{\text{all owners}} - (\text{Mean WTA}_{\text{all owners}} * 0.75) \quad (3)$$

The following benefit transfer procedure was used to assign values to carbon contracts expected to appeal to three categories of forest owners. These categories are intended to represent different forest owner archetypes and include the passive forest owner, the conservation-oriented forest owner, and the timber production-oriented forest owner. These categories were based on the findings of a related study that linked willingness to pay/accept behaviors with different motivations and management objectives [44]. Those with conservation or social responsibility motives were less sensitive to potential financial losses compared to those with timber-production motives. Other differences among these groups may also be related to how land use and expected benefits are prioritized.

Owners with limited knowledge and skills in forest management can be expected to be more passive or less proactive in forest management. However, there is reason to expect that passive owners may still act as early adopters in a carbon payments program. Passive owners may see carbon payments as a new and easy source of supplemental income compared to arranging a timber harvest every 5 to 10 years. Because they are less invested in timber production as a primary goal, the opportunity cost of delaying harvest may be perceived as minimal. However, passive owners may also see longer contracts as increasing other types of opportunity costs and would want greater compensation for longer contracts. Passive owners are also less likely to have a forest management plan and may want financial compensation in order to adopt a management plan. The contract conditions that may be acceptable to a passive forest owner are

$$\text{Mean WTA}_P = (\beta_0 + \beta_1 \text{YRS} + \beta_2 \text{MP} + \beta_3 \text{Acres}_{Ln}) \quad (4)$$

where WTA is the expected utility of a program for passive forest owners; β_0 refers to the constant term; β_1 and β_2 are coefficients for variables describing a shorter contract length

(<20 years) and the inclusion of a management plan; β_3 represents coefficient for acres owned, which was adjusted for three categories of property sizes. The 75% discount rule was then applied to the total WTA_P estimate to represent the value of an early adopter.

Some conservation-oriented forest owners could also be early adopters if climate stewardship is perceived as being part of forest stewardship. These owners may have some knowledge and skills in forest management and already have a forest management plan, so modifying the plan could be relatively easy and not require large compensation. They may also see carbon incentives as a better way to finance forest management activities compared to timber harvesting (because the payments may be more regular, or harvesting may not be compatible with their management objectives); therefore, a delay in harvest may not be associated with a large opportunity cost. Conservation-oriented owners may also be less resistant to longer contracts, especially if it is in line with their legacy planning objectives, but some compensation would still be needed to represent important land values. The contract conditions that may be acceptable to conservation-oriented forest owners are:

$$\text{Mean } WTA_C = (\beta_0 + \beta_{1YRS} + \beta_{Acres_In}) \quad (5)$$

where WTA is the expected utility of program, β_0 refers to the constant term, β_1 variable coefficient refers to a longer contract length (>20 years), and β_2 represents variable coefficient for acres owned, which was adjusted for three categories of property sizes. The 75% discount rule was then applied to the total WTA_C estimate to represent the value of an early adopter.

Timber production-oriented owners may also have some knowledge and skills in forest management but could still be later adopters of forest carbon payment programs. This is because the perceived or real opportunity costs associated with delaying harvest and managing for carbon may be more strongly felt. Longer contracts could also increase opportunity costs by delaying harvest to a rotation age that is beyond their lifetime. These owners may also have a management plan already in place, so modifying the plan may not be costly to do. The contract conditions that may be acceptable to production-oriented forest owners are:

$$\text{Mean } WTA_T = (\beta_0 + \beta_{1YRS} + \beta_{2MR} + \beta_{3Acres_In}) \quad (6)$$

where WTA_T is the expected utility of the program, β_0 refers to the constant term, β_1 variable coefficient refers to a shorter contract length (<20 years), β_2 is the variable coefficient for management restriction or delay in harvest, and β_3 represents variable coefficient for acres owned, which was adjusted for three categories of property sizes. No discount rule was applied.

3. Results

3.1. Regression Analysis

Five out of the seventeen variables tested were significant ($p < 0.05$) in predicting variation in WTA and revealed the important influence of contract design on forest owner choices. Significant variables included YRS, Acres_Ln, MP, MR, and region (Table 3). The final regression model performed moderately well with an R-squared value of 0.63. All variables with the exception of number of acres were positive, indicating that WTA increased when a management plan or harvesting restrictions were required, and number of contract years increased. Number of acres, however, had a negative coefficient, indicating that WTA decreased as the size of landownership increased. Regarding the magnitude of significant coefficients, MR had the greatest influence on the model, indicating that delaying harvest underpinned much of the opportunity costs associated with a carbon program. The region in which the study occurred and the requirement of a management plan also had a large impact on acceptable prices. Comparatively, size of ownership (acres) and number of contract years had a more modest impact on price.

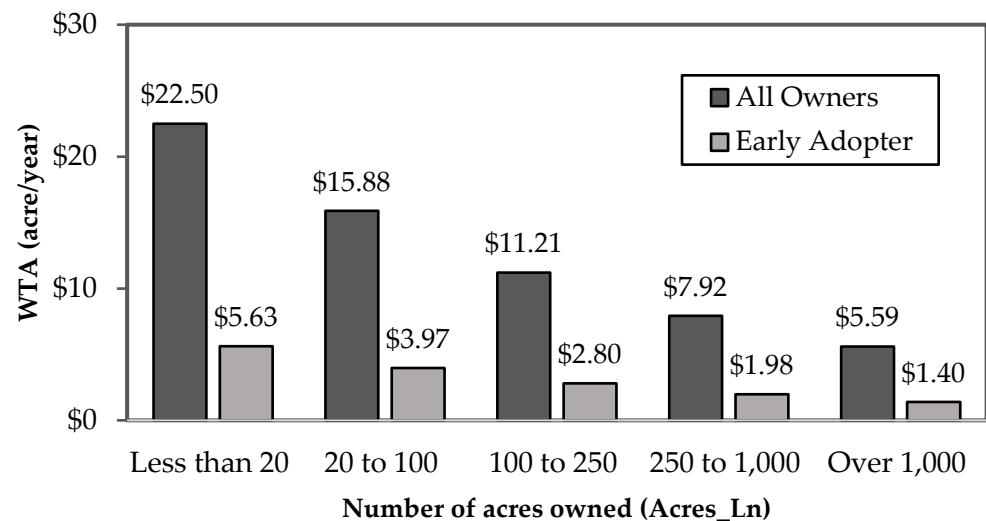
Table 3. Robust regression of forest owner WTA for carbon sequestration in private forests.

Variable Name	Definition	Coef.	Std. Error	<i>p</i> > (t)
YRS	Number of contract years. 1 = less than 20 years, 2 = length is 20–50 years, 3 = over 50 years	0.3561	0.1789	0.05
Acres_Ln	Natural log of mean number acres owned by respondents reported in study	−0.3482	0.1237	0
MP	1 = contract requires a management plan, 0 otherwise	0.9954	0.3701	0.01
MR	1 = contract requires owner to delay or reduce harvest, 0 otherwise	1.2406	0.3496	0
Region	1 = Southwest, 0 = All other regions	1.0637	0.5074	0.04
Constant		4.1583	0.6484	0
F (5,30) = 16.92, R-Squared = 0.6270				

3.2. Benefit Transfer

When transferring values, variables with a negative coefficient decreased total WTA, whereas variables with a positive coefficient increased total WTA for a carbon contract. The constant in the model was positive and describes the amount of unexplained variation associated with WTA observations. As such, the constant term is useful for estimating the value (or opportunity cost) of any given forest carbon incentive program not explained using the contract variables or acres owned. The mean value of the constant term in the final regression model was USD 63.95 acre/year for all forest owners and USD 15.99 acre/year for early adopters. To help support interpretation of model variables, the following figures report a total value using the sum of the part-worth value for each variable and the constant value.

Total WTA for different categories of acres owned ranged from USD 22.50 acre/year for owners with less than 20 acres to USD 5.59 acre/year for owners with over 1000 acres (Figure 1). For early adopters, WTA values ranged from USD 5.63 acre/year for owners with less than 20 acres owned to USD 1.40 acre/year for owners with over 1000 acres.

**Figure 1.** Willingness to accept payment for forest carbon based on number of acres owned (acre/year).

The total value of number of contract years ranged from USD 63.94 acre/year for a one-year contract to USD 186.10 acre/year for a 50+-year contract (Figure 2). Estimates for early adopters ranged from USD 15.99 for a one-year contract to USD 46.53 for a 50+-year contract.

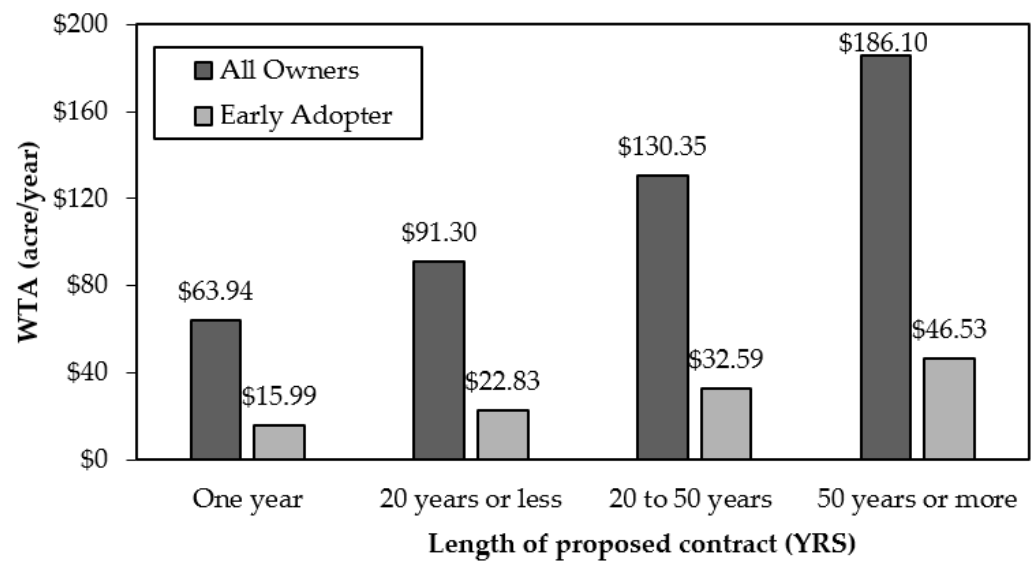


Figure 2. Willingness to accept payment for forest carbon based on contract length (acre/year).

For the management plan variable, the constant term served as the status quo alternative. The value of adopting a management plan was USD 173.02 acre/year compared to USD 63.94 when no management plan was required (Figure 3). For early adopters, the value of requiring a management plan was USD 43.26 acre/year compared to USD 15.99 when no management plan was required.

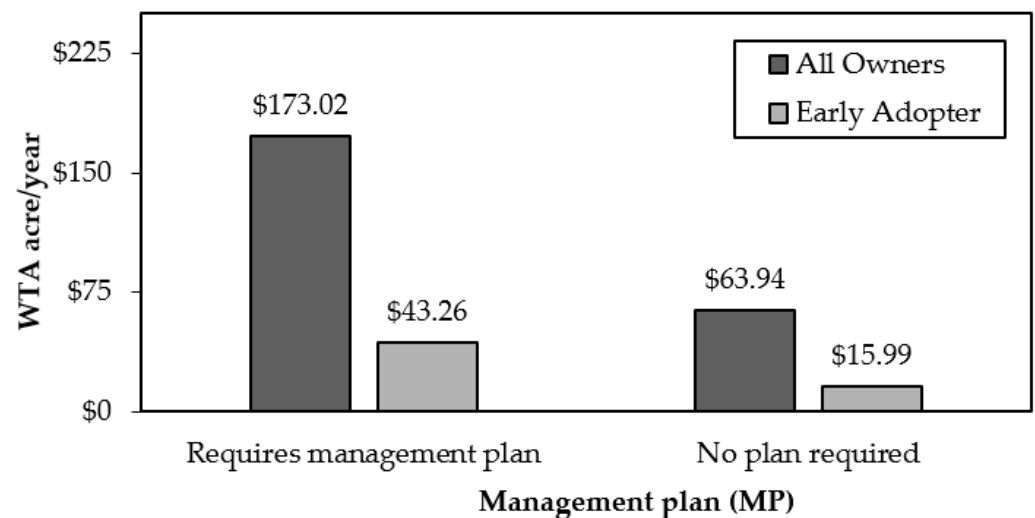


Figure 3. Willingness to accept payment for forest carbon if a management plan must be adopted (acre/year).

Likewise, delay in harvest had a value of USD 221.10 acre/year across all owners but was USD 55.28 acre/year for early adopters (Figure 4).

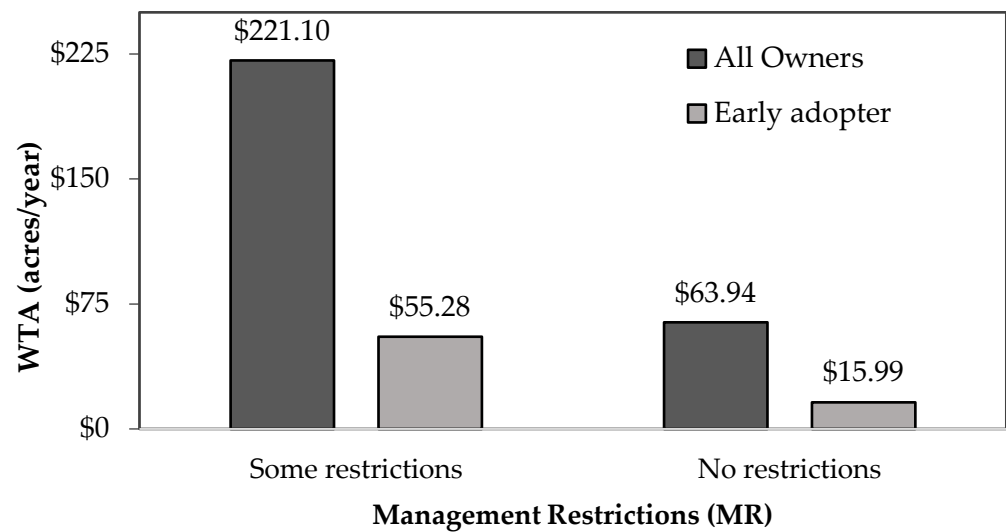


Figure 4. Willingness to accept payment for forest carbon if a delay in harvest is required (acre/year).

Total mean WTA also varied across the contracts developed for the three categories of forest owners (Table 4). The type of contracts that may be considered acceptable to timber production-oriented forest owners produced significantly larger WTA values compared to the WTA values of passive and conservation-oriented forest owners. The overall largest WTA value (USD 111.06 acre/year) was associated with the contract for production-oriented owners who have less than 20 acres of land. The lowest WTA value (USD 3.44 acre/year) was associated with the contract for conservation-oriented owners with more than 250 acres of land.

Table 4. Mean willingness to accept payment for carbon contracts across different forest owner types, estimated using benefit transfer techniques and 13 valuation studies.

Ownership Size	Passive Forest Owner ^a			Conservation-Oriented ^b			Timber Production-Oriented ^c		
	Mean	95% CI High	5% CI Low	Mean	95% CI High	5% CI Low	Mean	95% CI High	5% CI Low
Less than 20 acres (USD)	21.73	28.70	16.45	11.47	15.14	8.68	111.06	146.70	84.09
20 to 250 acres (USD)	13.08	17.28	14.64	6.90	9.12	5.23	66.88	88.34	50.63
More than 250 acres (USD)	6.52	8.61	4.94	3.44	4.54	2.60	33.33	44.02	25.23

^a Likely an early adopter, indifferent about changes in harvesting, will need to set up a management plan, and may be opposed to long contracts (more than 20 years). ^b Likely an early adopter, likely has a management plan, indifferent about changes in harvesting for production purposes, and open to longer contracts (more than 20 years). ^c Less likely an early adopter because of high opportunity cost from delay in harvest, likely has a management plan, and may be opposed to long contracts (more than 20 years).

4. Discussion

Trends in the model were in agreement with the findings of included studies. Variables describing contract features and number of acres owned explained over half of the variance in the model and are discussed in more detail below. Twelve of the variables tested were not significant in the model; however, study features such as survey design and socio-demographic characteristics may still be important. Moreover, early-withdrawal penalties and additional requirements, not significant in this analysis, have been found to influence choice in other studies [36]. Low sample size may have obscured evidence of systematic variation within some of the data and prevented the use of filtering techniques. Efforts to improve the model through the use of weighting variables was found to be ineffective,

as they did not have a significant influence on the model and were therefore removed. Findings are in agreement, however, with related carbon market feasibility studies not included in this meta-analysis, which found carbon market program attributes such as revenue and contract length to be important in understanding NIPF owner willingness to participate [9,14,32,45]. Evidence of external validation for our findings is provided in a recent study by [13], where it was reported that very few (9%) of FFOs were interested in program enrollment at USD 50 per acre annually (75% cost share) with no harvesting and a 30-year contract, whereas 26% of FFOs showed interest in joining the program at the same payment rate but with only a 20-year contract length and allowable harvest rate (5-year growth).

Unexplained variation, as described in the model constant, could be due to a number of latent factors that influence choice, including attitudes toward climate change, non-timber management objectives, risk tolerance, and financial motivations [13,32,35,45]. Likewise, absentee status and land tenure may also have an important influence on owner perspectives about how their forest may be used [35]. Accounting for unexplained variation in the BT is important for capturing unobserved forms of opportunity costs and was used in this study to generate scenarios with a baseline WTA after controlling for contract requirements.

The finding of a higher WTA for longer contracts is consistent with [13]. Likewise, increased rate of participation has also been found to be influenced by contract length [36]. Contract length, however, had the least impact on WTA compared to other significant variables, such as delay in harvest. This may be due to the abstract nature of future values and the uncertainty of how a carbon contract may impact those values. A general preference by FFOs for shorter contracts is also not well-suited for longstanding carbon programs, such as the projects supported by the California Air Resources Board, which require a 100+ years' commitment. This said, a few private forest owners could be the exception and prefer longer time commitments due to landowner expectations about stewardship and legacy (e.g., desire for a conservation easement) [30]. However, most owners may prefer more flexibility in order to modify their asset when the value of the alternative uses increase (e.g., investment in development) or pass the property to their children unrestricted [46,47]. Carbon programs that focus on storing carbon within the forest are compelled to require long commitments. Since preferences for contract length is not consistent across FFO categories, it may be important to consider other types of projects that provide additional carbon uptake through increased primary production but do not require that the carbon be stored in the forest (e.g., biochar, long-lived wood products) [48].

The size of the landholding also had a moderate influence on WTA estimates and generally decreased as property size increased. This is still a key finding, however, since the majority (89%) of FFOs have forest parcels of 1–50 acres, whereas a minority of FFOs (5%) own over 500 acres [49]. Most carbon project developers prefer to enroll larger landowners as a way of reducing transaction costs. Moreover, owners with larger properties may be more inclined to become early adopters in a carbon payments program since they can designate areas of their property for enrollment and distribute their risk across land-use investments [33,35,50]. Engaging smaller forest owners, however, may be an important opportunity for sustaining smaller forested properties, which is needed to prevent the conversion of these lands to other uses and becoming a carbon source [51]. Owners with smaller properties tend to suffer from economies of scale issues and have to risk enrolling most of their land in a program [52,53]. As such, owners with smaller properties may require higher compensation compared to larger owners [50,54]. An increase in the price of carbon or a government subsidy for smaller landholders will likely be important for encouraging programs that engage smaller property owners.

The requirement of having a forest management plan had a relatively larger impact on WTA forest carbon payments. Developing a forest management plan is important for attaining sustainability goals but can be time-consuming and accrue some costs since it is often done in conjunction with a professional forester. Unfortunately, only 5% of FFOs in the U.S. reported having a forest management plan, 15% have consulted a professional

forester in the past 5 years, and only 1% have a certified forest [49]. Programs that require owners to obtain a management plan and work with professional foresters will likely increase transaction costs for most forest owners [9,49,55]. Related studies have found landowners who already have management plans are sometimes less likely to enroll in a carbon program [2,9]. This may be because significant changes to the plan or, more specifically, changes to land use may also result in important opportunity costs [10,34–36]. Project developers that help FFOs find and acquire the services of a forester to help build a management plan could help reduce some of the friction in program enrollment, especially for owners who do not have a plan in place.

Delaying harvest is the primary silvicultural restriction considered in this study and was found to have the most impact on WTA estimates [56]. Harvesting trees is generally considered the largest economic benefit of owning forest land, so it is reasonable that delaying harvest be considered a tangible loss. Most FFOs (65%) have harvested trees in the past 5 years, for logs and woodchips, even though many claim that timber production is not the primary goal for owning forests [49]. Owners who do place a high priority on timber production as a preferred land use and are less willing to consider other options, such as carbon payments [18,38]. One explanation for preferring timber production as a land use (other than avoiding opportunity costs) may be due to concerns about government oversight of activities that promote the provision of public goods, such as climate regulation. Examples of these kinds of concerns can be found in landowner response to laws protecting endangered species and the perceived risk that restored landscapes may become designated as protected habitat in the future [57,58]. Programs that result in additional carbon sequestration as an ancillary benefit to another primary objective, such as managing for wildlife habitat, may be seen as more preferred way of participating [58]. Afforestation and preventing deforestation also offer climate change mitigation benefits; however, these strategies are still infrequently used by project developers when working with FFOs [59].

Region was not a significant predictor of WTA in this study, with the exception of the southwest region. It is reasonable to expect that opportunity costs could vary by region due to differences in forest ecosystems and timber markets [60,61]. However, a lack of significant variation across region may also be an indicator of the conditions in which most FFOs find themselves regarding the costs and opportunities associated with forest ownership. It is unclear why a higher WTA was associated with the southwest region; however, the inclusion of one observation from this region suggests caution in drawing any conclusions.

Examination of the types of contracts preferred by different categories of forest owners in the BT procedure showed wide variation in WTA. Importantly, the hypothetical contracts were designed to address only the opportunity costs important to that particular category of FFO. The National Woodland Owner survey reported that only 10% of FFOs assign timber production as a primary land use. Based on the BT estimates for production-oriented owners, the current price of carbon does not appear sufficient for offsetting opportunity costs of their delaying harvest, meaning these owners may prefer to be later adopters. Getting timber production-oriented owners into a carbon payments program could be important for ensuring additionality through delay in harvest. This is because changes to harvest rotations are more meaningful when the counterfactual condition can be more accurately predicted. However, the opportunity cost of forgoing timber harvest may be more strongly felt by production-oriented owners because it is the primary purpose for owning forests. Leaving valuable timber in the stand for an extended period can also come with higher risk of damage to the timber (e.g., disease, rot).

Almost all FFOs support conservation ideals, but this is not always represented by their actions. For example, over 70% of FFOs claim that nature and biological diversity are an important management objective, but less than 20% have actually managed for invasive plants or for pests and disease, and only 2% have a conservation easement [49]. Dedicated conservationists tend to be more engaged and proactive in their land management and will make plans for longer timeframes. While timber harvesting may occur, the purpose is

generally for reasons other than revenues (e.g., create early successional habitat, improve stand health by reducing tree density) [62]. However, these owners tend to respond well to economic assistance programs that helps them meet their goals, since biological conservation does not often pay for itself [44]. Opportunities for gaining additional revenues though carbon payments may be particularly attractive even if the contract requires a delay in harvest and longer time commitments [45]. The WTA estimates for these owners falls within the payment levels currently offered by project developers to smaller forest owners (about USD 6 to USD 12/acre/year) [22]. However, it is important to consider that the conditions for additional carbon storage may not always be met when working with conservation oriented forest owners if the payments support management activities that would have occurred anyway.

Most FFOs could be classified as passive owners. Passive forest owners tend to prioritize seclusion and recreational land uses, are more likely to have plans to sell their land in the next 5 to 10 years and may be less interested in learning or practicing forest management [2,63]. Passive owners may also be less familiar with forest carbon as a good, which may interfere with how they value that good in an exchange [63]. Even though timber production is not a top priority among most owners, up to 64% of FFOs have harvested trees in the last 5 years [49]. This suggests that most forest owners are reacting to opportunities to generate revenues, which may make them more willing to consider switching to carbon revenues (e.g., early adopters). The challenge in working with passive owners is that they more often prefer shorter contracts, which makes it difficult to employ strategies that help keep carbon in the forest. Moreover, the longstanding trend of reduced harvesting on private lands, even without incentives, makes it difficult to determine the counterfactual condition, which is needed to ensure additional carbon storage [4]. Some project developers make assumptions about the likelihood of harvest on FFO lands based on external factors such as stand age and property distance to mills. Ignoring variability in decision making among individual owners (e.g., passive or production oriented) may increase the margin of error in carbon accounting practices. The WTA estimates for passive owners are also within the range of payment levels currently offered to forest owners but appear to be a better fit for those with larger landholdings. Limitations in this study could come from our use of the National Woodland Owners Survey data to fill in missing data for forest owner characteristics, which may have an unexpected influence on the model. Most of the available data were also limited to the eastern half of the United States and may not be representative of the nation. The archetype categories of forest owners discussed in this study may be an oversimplification of the heterogeneity among forest owners. The limited number of related studies for use in the meta-analysis may also obscure important unobserved variation. To assist with these types of meta-analysis studies in the future, it would be helpful for researchers to use consistent formatting when describing socio-economic data and provide mean WTA estimates for 100% of the sample group. More research on landowners WTA for forest carbon is also needed in western states.

5. Conclusions

The meta-analysis presented here highlights the importance of contract features on forest owner choices, with a special focus on different categories of forest owners. A fair number of WTA estimates are within the range of current payment levels for forest carbon, but the values were more often associated with conservation-oriented and passive owners with larger landholdings. Timber-production-oriented owners' resistance towards carbon payment programs may help soften implications of delay in harvest on domestic timber supply, but this is uncertain since production-oriented owners are also a minority category of FFOs. Furthermore, assumptions about how delays in harvest can lead to additional carbon storage are difficult to justify for many FFOs since passive owners' intentions about harvesting are unknown even to them. Outreach and education programs for all types of owners will be important for helping cultivate more informed economic actors around forest carbon and encourage future investment in forest ownership. An increase in the price

of carbon may also help attract more participants by helping remove some of the barriers to participation (e.g., obtaining a forest management plan) and economies of scale issues. Incentives that encourage climate smart forestry while supporting other management objectives (e.g., wildlife habitat) could be structured as a cost-share arrangement rather than a direct payments approach, which tends to be more difficult to validate. There is also the need for investors to consider approaches that do not require storing carbon in the forest, since there may be limits to the capacity of private forests serving as a carbon sink while also providing other important ecosystems services. Encouraging the production of long-lived wood products could help store forest carbon offsite and offset the use of substitutes with a larger carbon footprint [64]. Future studies should examine how long-lived wood products could be wrapped into a carbon offset project and determine under what conditions (e.g., percent enrolled) carbon programs may start to interfere with domestic timber supplies. Research is also needed to understand a broader set of factors on choice, such as perceived legitimacy of the program on offer and the preferences of underserved forest owners and owners in countries outside the U.S.

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Appendix A

This meta-analysis comprises five sequential steps with specific principles as briefly discussed below.

Step 1: Developing the research question

Our meta-analysis began with a distinctly formulated research question (e.g., hypothesis) after identifying the research gap in the topic of interest. The research question was derived from a detailed assessment of relevant studies. The scope of our study was specified by defining the number of primary studies, review articles, and existing metanalysis in the related field. The study of important ideas and principles, conflicts, and controversies that need to be resolved and some prominent variables were conducted prior to the review.

Step 2: Literature search for review

The comprehensive review of all relevant research was performed following the common search strategy of keyword search in electronic database. Additional details are available in the method section. The relevant studies were manually screened by reading the abstract method and result sections. For instance, the studies reporting willingness to accept payment value for forest carbon in the USA were considered. Further, grey literatures were also reviewed to avoid the selection and publication bias that could underestimate the true effect size (correlation coefficients and standardized mean differences).

Step 3: Coding the important information from studies

A specific coding strategy was performed to track the attributes of selected studies. Considerable attention was paid to the variables and studies that were coded for program attributes, study features, and respondent's characteristics. The codes were formulated according to the type of data available (binary, categorical, and continuous) in the studies. Willingness to accept payment value served as dependent variable in our study. This value is a summary statistic from the primary literatures and was assessed using different

conversion procedures such as converting the value to same unit, changing to its inflated value for the year 2020, etc.

Step 4: Systematic data analysis

Once the dataset was formulated, a general analysis was conducted, resulting in a statistical summary. Further, we performed meta-analysis with regression to identify relationships between variables using STATA software. The latest version of STATA presents built-in functions to execute several meta-analytical assessments or to generate various plots. Outlier analysis and bias tests were conducted prior to the model selection. For example, a weighting variable was created to adjust the responses in order to eliminate the response and sample bias. We applied the results of our empirical model as a benefit transfer to represent WTA values of new contracts and scenarios in the USA.

Step 5: Directing future research with clear conclusion

At the end, results from the meta-analysis were used to serve as a useful guide to future research. Directions and research avenues are briefly discussed to address key weakness and to complement current knowledge within the research area.

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