

ARTICLE

Family forest landowner preferences for managing invasive species: Control methods, ecosystem services, and neighborhood effects

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Abstract

Family forest landowners own and manage much of the world's forests, but we know little about their willingness to control biological invasions on their properties. Using a choice experiment, we find that landowners prefer mechanical methods and strongly oppose chemical methods when controlling the spread of an invasive shrub. Their choices are heterogeneously affected by ecosystem service outcomes resulting from control, namely timber production, trail recreation, and wildlife viewing. Landowners view their decision to control the invasive species on their land as a complement to the control by neighbors, offering further support for the areawide management of forest invasive species.

KEYWORDS

ecosystem services, forests, invasive species control, neighborhood effect

JEL CLASSIFICATION

C35, Q23, Q57

1 | INTRODUCTION

Invasive species, diseases, pests, fires, and other disturbances threaten ecosystem services provided by public and private forests worldwide (Boyd et al., 2013). While forest ecosystems and forest disturbances span landscapes, or large spatial scales, many private management actions, such as invasive species control on private forests are typically made in an uncoordinated manner, at smaller

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scales due to land ownership patterns or jurisdiction. Such mismatch in ecological and management spatial scales can limit the landscape-level success of private disturbance control. In the United States (US), more than half the woods and forests (441 million acres) are owned and managed by private ownerships, the large majority (95%) of which are families and individual ownerships (USFS, 2015). However, we know little about family forest landowner willingness to pay for invasive species control on their properties. The landscape-level success of controlling cross-boundary disturbances such as invasive species can be compromised if the willingness to control by private landowners is lower than socially optimal. One of the reasons for such divergence between private and socially optimal control is that landowners might have different willingness to pay for control methods and different preferences for ecosystem service benefits of control.

According to the National Woodland Owner Survey, 35% of family forest landowners report ownership motivations that are exclusively related to ecosystem services such as aesthetics, recreation, and wildlife, while 12% report ownership motivations exclusively related to supplemental income from timber, and 37% report owning their land for both ecosystem services and timber income (USFS, 2015). This diversity in ownership motivation can lead to differences in whether and how landowners control disturbances on their forestlands, thus causing a divergence between privately and socially optimal control. Consequently, public policies and policy instruments aimed at incentivizing private control of forest disturbances might be re-designed based on how landowner willingness to pay compares with the subsidized cost of control for each subsidized method. Invasive species control is currently one of the conservation practices eligible for financial assistance through cost-sharing and covers both chemical and mechanical methods at the same cost-share (i.e., reimbursement) rate of 75% (USDA, 2017; T. Jenkins, personal communication, February 22, 2023). Moreover, although we know most family forest landowners own their land for both nonmarket ecosystem services and timber, we do not know which ecosystem service improvements are the most important for their willingness to pay for control. Finally, despite the importance of spatial connectivity, strategic behavior, peer effects, and collective action in cross-boundary invasive species management, we do not know whether landowners would be more likely to control given information on the level of control by neighbors. Neighborhood effects could inform the prospects of landowner participation in areawide management programs similar to the ones that have emerged for managing crop pests (Garcia Figuera et al., 2022). In turn, such landowner participation would complement existing are-wide management programs managed by federal and state government agencies (Liebhold et al., 2021).

Our goal in this paper is to provide empirical estimates of private landowner willingness to pay for different invasive species control methods and related ecosystem service improvements, accounting for neighbor's control actions. These estimates are needed to assess the compatibility of existing policy instruments, such as conservation cost-share programs with landowner preferences and to assess the potential for collective action. Specifically, we investigate how private forest landowners' decision to control an invasive shrub on their forestlands depends on their preferences for control methods (chemical vs. mechanical), the ecosystem service benefits of control (timber, recreation on trails, wildlife viewing), and the control adoption rate in their neighborhood. Our analysis shows that landowners clearly prefer mechanical over chemical methods, partially because of environmental attitudes, and indicates a significant preference heterogeneity in chemical use. Respondents prefer control options that increase timber regeneration and wildlife viewing. We also see preference heterogeneity associated with timber benefits and trail recreation benefits of invasive species control. The ecosystem service benefit of improving trail recreation is only relevant for the control decisions of larger landowners. The estimated neighborhood effects are positive for landowners owning less than 26 acres, 80% of all landowners in our sample (and the population). Using our welfare estimates related to the control methods, ecosystem service improvement, and neighborhood effects, along with control cost estimates, we find that a landowner would only find it cost-effective to control using the mechanical method and only in the presence of existing cost-share payments. We note that, although this preference has the advantage of avoiding the negative

environmental and health consequences of chemical control, it can hinder the landscape-level control of invasive plants spread because mechanical control is less effective. On the other hand, willingness to pay is increasing with the rate of adoption in a forestland's neighborhood, which can inform the design of landowner areawide management programs for forest invasive species.

2 | LITERATURE REVIEW

The resource economics literature on the control of biological invasions has analyzed the centralized management for a single manager, landowner, or household (Horie et al., 2013; MacPherson et al., 2018; Sims et al., 2010) and the decentralized management by multiple farmers or landowners (e.g., Atallah et al., 2017; Costello et al., 2017; Epanchin-Niell & Wilen, 2015). The latter literature has analyzed issues that might arise from uncoordinated control such as the underprovision of control and has characterized the problem as a weaker-link public good problem (Burnett, 2006). Related work suggests that landowner control decisions might depend on the actions of neighbors when control actions are complements or substitutes. Control actions are complements when control by one landowner increases the returns to control for a neighboring landowner (Atallah et al., 2017; Fenichel et al., 2014). In contrast, free riding might lead control actions to be substitutes if a neighbor's control reduces the marginal value of control on a landowner's property (Fuller et al., 2017; Siriwardena et al., 2018). However, we have limited empirical research that tests predictions from such models such as family forest landowners controlling invasive species and making strategic decisions that consider the control by neighbors. While we know from survey work that landowners can be concerned or very concerned about invasive plants on neighboring or nearby lands (Clarke et al., 2019), we have little evidence on whether their decision to control is affected by their neighbors' control decisions. In addition, if such neighborhood effects exist, we do not know their importance relative to other factors, such as landowner preference heterogeneity over control methods, ecosystem service benefits of control, or whether these effects exist for all or a subset of landowners. Nor do we know if neighborhood welfare effects are large enough to incentivize adoption by neighbors.

Finally, while the nonmarket valuation literature includes elicitations of the public's preferences and willingness to pay for invasive species and disease control, we have limited similar work focused on private, family forest landowners. Meldrum et al. (2013) find that public support for white pine blister rust control is more motivated by the long-term protection of forests than by recreation. Moore et al. (2011) find that the public supports the protection of hemlock stands from the woolly adelgid if they primarily provide nonuse values. Sheremet et al. (2017) find significant support for part-financing disease control policies among the public, and this support depends on forest ownership type and the control measure used: the public supported control programs in publicly owned more than in privately-owned forests and had an opposition to control strategies involving tree felling, chemical sprays, and biocide sprays. Fleischer et al. (2013) also find a negative public attitude toward using toxic pesticides in invasive species control. Other results from this literature include a higher public willingness to pay for eradication than prevention, and the importance of invasive species knowledge, income, and the frequency of recreational visits for willingness to pay (Nunes & van den Bergh, 2004; Sheremet et al., 2017). The literature on private forest landowner preferences over disturbance control is more limited. Sheremet et al. (2018) assess the willingness of woodland owners to cooperate with neighbors within the framework of a payments for ecosystem service (PES) scheme to control forest diseases. The authors find mixed evidence for the acceptance of a PES scheme that included an agglomeration bonus rewarding landowners for the participation of neighbors. Woodland owners showed the highest levels of support for shorter contracts that allow tree removal and the use of chemicals.

3 | APPLICATION

We consider the case of glossy buckthorn (*Frangula alnus* P. Mill.), hereafter GB, in eastern white pine (*Pinus strobus*) forests. GB is a shrub that is exotic and invasive in North America. It is representative of around 20 nonnative woody plants that have invaded eastern US forests, including Japanese barberry and Amur honeysuckle. Because they are shade tolerant, this group of invasive shrubs efficiently colonize forest understories, affecting recreation and wildlife habitat (Cunard & Lee, 2009; Fagan & Peart, 2004; Frappier et al., 2003; Koning & Singleton, 2013; Lee & Thompson, 2012). Through competition, they inhibit the regeneration of economically important forest trees such as the eastern white pine (Fagan & Peart, 2004; Frappier et al., 2004; Koning & Singleton, 2013). The dispersal of these shrubs occurs across short distances by mammals and long distances by birds (Catling & Porebski, 1994; Godwin, 1943), creating spatial linkages across neighboring landowners beyond the immediate neighborhood. GB aggressively colonizes wooded and unwooded wetlands, eastern white pine forests, primarily through forest cover gaps created through logging, wind, or natural tree death.

The invasive shrub causes the following market and nonmarket ecosystem service damages. It inhibits or delays natural timber regeneration, potentially causing lower or delayed timber yields and revenues, reduces the population of native plants and wildlife, including the potential loss of songbird abundance, and lowers the recreational value of woods by affecting the ability to hike. Conversely, invasive species control generates market and nonmarket ecosystem service benefits that consist of mitigating the abovementioned damages. The invasive shrub control methods include chemical (herbicide) applications and the more expensive and less effective mechanical removal of invasive shrubs (Ward et al., 2013). In the case of GB, mechanical control costs between \$1500 and \$3000/acre and is 68% effective, while chemical control costs \$900/acre and is 90% effective (T. Lee, personal communication, May 23, 2019).

We present a study of GB control options for New Hampshire (NH) and Maine (ME) landowners. Forests in this area are characteristic of the private land ownership pattern of the Northern US and have a high prevalence of invasive plants that negatively impacts both market (timber regeneration) and nonmarket ecosystem services (ability to recreate on one's own land and view wildlife) activities in forests.

4 | SURVEY DESIGN AND DATA SUMMARY

We developed and conducted a survey with forest landowners, which included a discrete choice experiment (CE) on GB control options that vary in control methods (two attributes: mechanical vs. chemical), ecosystem service benefits (three attributes: trail recreation, wildlife, timber), neighborhood adoption rate, and cost, for a total of seven attributes. The CE asks randomly selected landowners in NH and ME to make choices over sets of control strategies to address the presence of GB on their land. The key section of the survey was a CE in which we asked survey respondents to choose among a few hypothetical GB control options, each utilizing specific control methods to produce a set of ecosystem service outcomes at a given cost.

The survey design was informed by two focus group meetings, conducted in Epsom (NH) and Gorham (ME), respectively, in June 2018. Participants were randomly selected landowners with varying land sizes and familiarity with invasive plants. We asked them to describe their knowledge and prevalence of invasive plants on their land and the implementation of any control strategies. We also requested that they review a draft survey questionnaire aimed to understand landowners' preferences regarding the management of GB. From the focus group meetings, we confirmed the attributes of a GB control program that could impact the decision to select a control option. We finalized the survey questionnaire based on the focus group results. In the CE, each hypothetical GB control option (a choice alternative) is described by seven attributes: two control methods (chemical

TABLE 1 Seven attributes for the choice experiment.

Description of attribute	Variable name	Levels
Mechanical control—physical removal of glossy buckthorn (0 = No, 1 = Yes)	Mech	0, 1
Chemical control (0 = No, 1 = Yes)	Chem	0, 1
Timber harvest (0 = maintained, 5% higher, 20% higher)	Timber	0%, 5%, 20%
Usable trails for recreation (0 = maintained, 5% more, 20% more)	Trail	0%, 5%, 20%
Wildlife viewing (0 = maintained, 1 = increased)	Wildlife	0, 1
Neighborhood adoption rate	Nbd Control	0%, 50%, 100%
Out-of-pocket cost (USD per acre per treatment)	Cost	150, 350, 550, 750

and/or mechanical), three outcomes from control (improvement of timber production, length of recreation trails, and wildlife viewing), neighborhood control rate, and control cost (Table 1). Because seeds of invasive plants can be carried by birds and spread across properties, we hypothesize that the management decision will be affected by the degree of GB control effort in the neighborhood; hence neighborhood control rate is included as one of the attributes in the CE. The design of the seven choice attributes for our CE is summarized in Table 1. Three attributes, timber production, recreation trail, and neighborhood control rate, are designed to have three levels. As for the control method and wildlife viewing attributes, each is designed to have two levels (yes or no). The levels of the program cost were designed to be close to the actual out-of-pocket treatment cost of GB control, as provided by extension specialists experienced in real-life costs of GB control in NH and ME. Each CE question consists of two hypothetical GB control choice alternatives and an opt-out option to stay in the current situation if neither hypothetical control option is desirable. The opt-out option is commonly referred to as the status quo choice. To promote consequentiality, we stated how the results will be disseminated, that those might help formulate policies supporting landowner's ability to maintain the health of their forestland and acknowledged the funding agency. To reduce hypothetical bias that might be due to the respondents' lack of experience or knowledge with the species, we included a brochure with pictures in color that describes the species, its natural habitat, how to identify it, its potential damage, and the options to manage it. We instructed respondents to read the brochure before completing the survey sections on their experience with the species and the choices section. We also added a budget reminder (see survey instrument and brochure in the Supporting Information).

Given the fairly large number of attributes and levels, it is not feasible to present all possible combinations of the attributes to survey respondents. Instead, a partial experimental design is employed. The runs of our CE were selected based on the D-optimal approach, which is a computer-aided design that selects the best subset of all possible runs by maximizing the determinant of the information matrix $|X'X|$ of our chosen model. In our study, we decided in advance to examine only the main effects of the attributes, which significantly simplified the model to be fit. Then, we used SAS to help choose the optimal treatment runs from all possible treatment runs. Four versions of the survey questionnaire are developed to be randomly assigned to survey respondents. Each survey respondent is asked to answer three CE questions, each consisting of choosing between two alternative control options and a status quo.

A sample of 4000 landowners in NH and Southern ME with at least one acre of land was drawn to participate in the survey.¹ The survey was conducted in the first quarter of 2019. A combination

¹Over 50% of landowners have a land size of less than 3 acres in NH and Southern ME. To collect sufficient information from landowners with larger land for analysis, a stratified sampling (20% 1–2 acres, 20% 2–3 acres, 60% 3 acres or more) was employed to slightly over sample those with 3 acres or more.

of web and mail surveys was employed. Survey respondents first received a letter with a link to complete the survey online. The questionnaire, along with a brochure describing GB and its prevalence and control methods, was presented online to the survey respondents. The survey elicited information in four areas: (1) property characteristics, (2) GB prevalence and treatments on property, (3) CE of GB control options, and (4) individual socioeconomic information. To provide incentives, a drawing of 20 USD 50 gift cards was promised to those who complete the survey. Nine hundred and thirty-nine respondents took the survey (75% online and 25% mail), yielding a response rate of 24%.² With each survey respondent responding to three CE questions and subtracting the missing values, there was an unbalanced panel with a total of 2507 GB control program choice responses. The socioeconomic characteristics of those who responded and that we included in data analysis are summarized in Table 2. About 60% of the respondents are male. Over one-third of the respondents are retired. The vast majority have at least a college degree. The median land size is 4 acres. About 27% of them have walking trails on their properties and 18% have harvested timber in the past 10 years. Approximately 12% are aware of GB present on their properties, 9% have controlled it, and less than 1% have participated in a governmental financial assistance or cost-sharing program in the past 10 years.

5 | EMPIRICAL MODELS

To analyze survey respondents' stated GB control program choices, we first employ the multinomial logit (MNL) model. Then, the mixed logit model is employed to enable and incorporate preference heterogeneity across individuals in the choice analysis. The general log-likelihood function that represents a set of choice decisions can be written as follows.

$$L = \sum_{i=1}^n (y_{i1} \log(\pi_{i1}) + y_{i2} \log(\pi_{i2}) + \dots + y_{ij} \log(\pi_{ij})), \quad (1)$$

where $y_{ij} = 1$ if good j is chosen by individual i , and $y_{ij} = 0$ otherwise; π_{ij} is the probability that individual i chooses good j . J equals the total number of choice alternatives, in our case $J = 3$, including two GB control options plus the "neither" option. The MNL model is to assume a logistic function for π_{ij} as a function of the utility level:

$$\pi_{ij} = \frac{e^{V_{ij}}}{\sum_{k=1}^J e^{V_{ik}}} = \frac{e^{\gamma_j' w_i + \beta' x_{ij} + \beta_p P_{ij}}}{\sum_{k=1}^J e^{\gamma_j' w_i + \beta' x_{ik} + \beta_p P_{ik}}}. \quad (2)$$

The indirect utility function, V_{ij} , is commonly assumed to be linear in parameters such that $V_{ij} = \gamma_j' w_i + \beta' x_{ij} + \beta_p P_{ij}$, where x_{ij} is a vector of choice characteristics including the CE attributes, P_{ij} is the proposed cost associated with CE option j ; w_i is a set of household/individual characteristics (including the alternative specific constant); β is a vector of parameters that are usually assumed constant across individuals and product choices; and the vector of parameters γ_j vary across j to indicate that individual i , who has characteristics w_i , may have different preferences for the J choices. For example, when choosing an occupation, individual i who is female ($w_i = 1$ if female) may prefer to be a civil servant ($j = 1$) to a construction worker ($j = 2$) that $\gamma_1 > \gamma_2$. Individual characteristics w_i can also be interacted with the choice attributes to allow the impact of attributes on choice decisions to depend on individual characteristics. For example, a GB control option is more likely to be selected if it improves wildlife viewing (a choice attribute), and it is even more so for those landowners who have grandchildren (an individual characteristic). Let w_{im} be an individual i 's

²There were 97 undeliverable addresses. The response rate = $939/(4000-97) = 24\%$.

TABLE 2 Summary statistics of survey data.

Variable	Description	Mean	Std. Dev.
Female	=1 if female	0.40	-
Retired	=1 if currently retired	0.38	-
Age	Age of the respondent	61.41	11.25
High	=1 if go to high school or have a high school degree	0.09	-
College	=1 if go to college or have bachelor's degree	0.61	-
Post_Graduation	=1 if have a master's, doctoral or professional degree	0.29	-
ChildrenVisit	=1 if children live on or visit your property on a regular basis	0.50	-
LandProject	=1 if ever volunteered for a project to control invasive plants	0.07	-
ResJob	=1 if had a job related to natural resource management	0.10	-
DonateEnv	=1 if donated to or a member of environmental groups last year	0.28	-
Income	Household income (in thousand dollars)	95.29	41.88
Landsize	Land size (acres)	12.96 ^a	26.13
Harvest	=1 if commercially harvest timber in past 10 years	0.18	-
Trails	=1 if trails present on property	0.27	-
RecUse	=1 if recreational use of property is important	0.40	-
GBland	=1 if glossy buckthorn present on property	0.12	-
GBctrl	=1 if took action to control glossy buckthorn on property	0.09	-
nbdctrl	=1 if knew neighbors had glossy buckthorn and tried to control	0.02	-
GovtPgm	=1 if participated in government cost-sharing programs (e.g., EQIP) in past 10 years	0.01	-
Mail	=1 if mail survey; =0 if web survey	0.24	-
Number of observations		2507	

^aThe median land size is 4.0 acres.

characteristic that is expected to have interaction effects with the choice attributes. Then probability function in the MNL model in Equation (2) can be further expanded as follows.

$$\pi_{ij} = \frac{e^{V_{ij}}}{\sum_{k=1}^J e^{V_{ik}}} = \frac{e^{\gamma_j' w_i + \beta' x_{ij} + \delta' w_{im} x_{ij} + \beta_p P_{ij}}}{\sum_{k=1}^J e^{\gamma_j' w_i + \beta' x_{ik} + \delta' w_{im} x_{ik} + \beta_p P_{ik}}} \quad (3)$$

The mixed logit model adds additional flexibility to Equation (3) by allowing parameters in the indirect utility function, V_{ij} , to vary randomly across individuals and be correlated to each other (Revelt & Train, 1998). The random parameters can also be functions of variables such as individual characteristics. To conserve computational time, a common practice is to assume only some parameters in the β vector to be random and/or correlated with individual characteristics in a mixed logit model. For example, let β_{ik} be the coefficient associated with the k^{th} explanatory variable in V_{ij} , which depends on individual characteristics (w_i) and varies randomly across i :

$$\beta_{ik} = \beta_{ik}^* + u_{ik} = \alpha_k + \lambda_k' w_i + u_{ik} \quad i = 1, \dots, n. \quad (4)$$

The vector of parameters λ_k indicates the impact of individual characteristics on β_{ik} . The u 's are random errors with zero means. The u 's can be assumed to be independent of each other or follow a joint distribution with nonzero correlations. Since now the probability of choosing choice alternative j , π_{ij} , depends on the random parameter β_{ik} , the unconditional probability of π_{ij} in the log-likelihood function of the mixed logit model is to be derived by integrating over β_k (Haab & McConnell, 2002). When appropriate, mixed logit models can help further examine the impact of individual heterogeneity on choice decisions.

The welfare measure for a marginal change in a choice attribute is simply the ratio of the coefficient of the attribute variable to the negative coefficient of the cost variable (Champ et al., 2017).³

$$S_i = \frac{\beta}{-\beta_p}. \quad (5)$$

When there are interaction terms between choice attributes and individual characteristics, as shown in Equation (3), then the welfare measure formula is modified to be $S_i = \frac{\beta + \delta w_{im}}{-\beta_p}$.

6 | RESULTS AND DISCUSSION

To analyze the choice responses to the hypothetical GB control options in the CE, we estimate both the MNL and mixed logit models for comparison using NLOGIT. For the MNL model, we start with basic choice models that include only the option attributes of the GB control options and an alternative specific constant (ASC) for the status quo option as explanatory variables. Recall that the attributes to describe the GB control options include control methods (mechanical and chemical), control outcomes (timber production, trail recreation, and wildlife viewing), neighborhood control rate, and control cost. To examine in more detail why some respondents preferred status quo over the proposed GB control options, interaction terms of ASC and individual characteristics are added to the choice models. Additionally, from the focus group meetings and subsequent examination of the survey data, it becomes clear that the size of the property affects how a landowner values choice attributes when evaluating GB control options. We interact land size with option attributes to allow effects of the attributes on individual choices of GB control options to depend on land size. Three MNL models, models 1–3, are estimated and summarized in Table S1 in the SI.

Model 1 includes only the option attributes and an ASC for the status quo option. The estimation results indicate that mechanical removal of GB is preferred to chemical control. Improved timber production and wildlife viewing as a result of control significantly increase the probability of a GB control option being selected. Chemical use to control GB and high cost reduce the probability of a GB control option being chosen. An unexpected result is that increasing trail recreation on the property can negatively impact the choice of a GB control option in this basic MNL model. The neighborhood control rate does not appear to significantly impact the choice of GB control options in this basic model.

Individual characteristics are interacted with the ASC for the status quo option in Model 2. It is seen that all else equal, retirees are more likely to remain in the current situation, while higher-income individuals are more likely to choose a GB control option over the status quo. Those who

³In a mixed logit model with some of the β s are assumed random, the simple formula in (4) can still be employed and compute the welfare measure using the estimated mean of the β s. Alternatively, we may compute the mean welfare estimate by integrating the formula in (4) with respect to the random β s, $\int S_i(\beta) d\beta$. A simulation approach of random draws from the estimated distribution of β s can be employed to compute the multiple integrals (Train, 1998). In this paper, we compute all welfare measures using the simple formula in (4).

have had a job related to natural resource management are more likely to choose a GB control option. The presence of GB on a landowner's property and past GB control experience do not show any significant effect on the choice of a control option versus the status quo. Model 3 allows the impact of option attributes on choosing a GB control option to differ according to land size. The estimation results show an interesting heterogeneous, individual effect of option attributes on the choice of GB control options. The neighborhood control rate remains positive but insignificant, while the interaction of land size and neighborhood control rate is significant and negative, indicating that there is a significant effect of neighborhood control rate and it decreases with property size. Large landowners seem to be less concerned about whether or not neighboring landowners control GB. Model 3 also allows the impact of the mechanical and chemical option attributes on choosing a GB control option to differ according to environmental attributes, proxied by whether respondents donated to an environmental group in the previous year. The interaction of the environmental attitude variable with the mechanical removal attribute is significant and positive. In contrast, the interaction with the chemical treatment is significant and negative, indicating that the opposition to this method and the preference for the mechanical method is plausibly due to environmental attitudes and concerns.

To further examine the potential impact of individual heterogeneity, we employ the mixed logit models with similar specification treatments. In general, we can allow all coefficients in the mixed logit model to be random and depend on individual characteristics. However, a complete set of coefficients as a function of individual characteristics plus a random error term is difficult to estimate due to a flat likelihood function (Green et al., 2001; Ruud, 1996). Further, specifying the coefficient of the program cost variable to be random can be troublesome because of its essential role in converting a utility change into a monetary value, as seen in the welfare measure formula in Equation (5). Therefore, it is recommended by researchers to assume a fixed coefficient for the cost variable (e.g., Goett et al., 2000; Revelt & Train, 1998). Following the recommended practice, we allow the coefficients of all choice attributes, except for the cost attribute, to be random with a normal distribution. The three estimated mixed logit models, Models 4–6, are reported in Table 3.

The results of the impact of choice attributes on GB control choices from the mixed logit models are qualitatively similar to those from the MNL models with a few enhanced results. First, the neighborhood control rate is positive and significant in all the estimated mixed logit models. The positive sign suggests that landowners view their decision to control the invasive species on their land as a complement to the control by others. That is, control by others increases own probability of choosing a control option. We interact the neighborhood control attribute with a variable that indicates whether respondents reported having neighbors who control the invasive species. The estimate on this interacted term is significant and positive, indicating that the complementarity effect is larger for those who, at baseline, have a higher level of control in their neighborhood (Model 6, Table 3).

The impact of neighborhood control rate decreases with land size. Based on the coefficient estimates in Model 6, we calculate the threshold. The estimated effect of the neighborhood control rate is positive for a land size smaller than 29 acres, which accounts for over 80% of all landowners in our sample, and negative for the rest. The mean estimated effect of neighborhood control rate is positive. A result in the mixed logit Model 6 that differs from Model 3 is the significant and positive estimated coefficient for the interaction between trail recreation and land size. The estimated negative impact of trail recreation on the choice of GB management options diminishes as the size of a landowner's property increases, indicating that the invasive shrub's damage to trail recreation is more relevant for larger landowners. Based on the coefficient estimates, the effect of trail recreation on choosing a GB control option becomes positive for landowners with land 70 acres or larger. In this study, for a vast majority of landowners, improvement of trail recreation appears to negatively impact their choices of GB control options, but it has a positive effect on choosing GB control options for a small portion of the largest landowners. Finally, the estimated variance of the coefficients of three option attributes (chemical use, timber production, and trail recreation) are

TABLE 3 Estimated mixed logit models.

	Model 4		Model 5		Model 6	
	Coef (SE)	Std Dev (SE)	Coef (SE)	Std Dev (SE)	Coef (SE)	Std Dev (SE)
Mechanical	1.5462*** (0.3820)	0.7441 (0.6351)	1.5069*** (0.3605)	0.5196 (0.5643)	1.3743*** (0.3088)	0.4166 (0.5405)
Chemical	−1.8788*** (0.4752)	3.0382*** (0.8190)	−1.7725*** (0.4141)	2.9048*** (0.7389)	−1.5440*** (0.3379)	2.7088*** (0.6134)
Timber	0.0171* (0.0089)	0.0768* (0.0411)	0.0170** (0.0082)	0.0693* (0.0367)	0.0171** (0.0085)	0.0576* (0.0337)
Trail	−0.0287*** (0.0111)	0.0757** (0.0329)	−0.0260*** (0.0095)	0.0629** (0.0299)	−0.0295*** (0.0100)	0.0552* (0.0292)
Wildlife	0.4039*** (0.1153)	0.0301 (0.4021)	0.3932*** (0.1074)	0.0096 (0.3651)	0.4399*** (0.1102)	0.0036 (0.4262)
Nbd control	0.0024* (0.0014)	0.0007 (0.0045)	0.0023* (0.0013)	0.0011 (0.0042)	0.0032** (0.0014)	0.0014 (0.0042)
Cost	−0.0025*** (0.0005)		−0.0024*** (0.0004)		−0.0024*** (0.0003)	
Mech × Landsize					−0.0020 (0.0032)	
Chem × Landsize					0.0071 (0.0052)	
Timber × Landsize					−0.0000313 (0.00029)	
Trail × Landsize					0.0004* (0.0002)	
Wildlife × Landsize					−0.0045 (0.0033)	
Nbd × Landsize					−0.00011** (0.000048)	
Mech × DonateEnv					0.3600*** (0.1257)	
Chem × DonateEnv					−0.7296*** (0.2580)	
Timber × Harvest					−0.0029 (0.0150)	
Trail × Trails					0.0000285 (0.01206)	

(Continues)

TABLE 3 (Continued)

	Model 4		Model 5		Model 6	
	Coef (SE)	Std Dev (SE)	Coef (SE)	Std Dev (SE)	Coef (SE)	Std Dev (SE)
Nbd × nbdctrl					0.0119*	
					(0.0065)	
Neither	0.5093*		1.1261***		0.9939***	
	(0.2920)		(0.3732)		(0.3309)	
Neither × GBland			0.3479		0.3082	
			(0.3090)		(0.3025)	
Neither × GBctrl			−0.4908		−0.3508	
			(0.3731)		(0.3615)	
Neither × ResJob			−0.5391***		−0.5485***	
			(0.1979)		(0.1926)	
Neither × Female			−0.0226		0.0155	
			(0.1108)		(0.1083)	
Neither × Retired			0.2487**		0.2717**	
			(0.1180)		(0.1157)	
Neither × Income			−0.0067***		−0.0061***	
			(0.0016)		(0.0015)	
N	2507		2507		2507	
Pseudo R ²	0.1240		0.1339		0.1428	
Log-Likelihood	−2412.7759		−2385.2983		−2360.9685	

* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

significant in the mixed logit Model 6, indicating individual heterogeneous views on these choice attributes when choosing a GB control option.⁴

We compute the welfare measures of option attributes based on each of the six estimated models and use the delta method to calculate the standard errors (Table 4). Three attributes (Mechanical, Chemical, and Wildlife) have a qualitative definition (0 and 1), and each corresponding welfare measure indicates the value associated with the presence of the attribute. The other three attributes (Timber, Trail, and Neighborhood) are defined to be in percentage point increase, and each corresponding welfare measure shows the estimated value of a 1% increase in the attribute. Note that Models 3 and 6 enable attribute effects to be dependent on land size and individual characteristics. The welfare measures associated with Models 3 and 6 are computed at the median land size of 4.0 acres and the mean individual characteristics. By examining the welfare estimates, we see that landowners have strong objections toward using chemicals to control GB, while improving wildlife viewing incentivizes the control of GB. On average, improving timber production is valued

⁴We also interact individual characteristics, such as gender, recreational use of land, current presence of GB on property, with some relevant attributes. They were insignificant and did not change the general conclusions of the study.

TABLE 4 Welfare measures^a

	Conditional logit model			Mixed logit model		
	Model 1 (SE)	Model 2 (SE)	Model 3 (SE)	Model 4 (SE)	Model 5 (SE)	Model 6 (SE)
Mech	397.360*** (70.8170)	394.034*** (72.2693)	416.799*** (74.2296)	610.316*** (105.0248)	624.295*** (111.2299)	621.052*** (103.7803)
Chem	-481.572*** (68.4485)	-481.596*** (68.9204)	-499.851*** (71.1955)	-741.597*** (133.2030)	-734.358*** (132.1318)	-727.818*** (122.9457)
Timber	7.1140** (2.8206)	7.3695*** (2.8300)	7.3803** (2.9839)	6.7569* (3.6623)	7.0306** (3.5485)	7.0776** (3.5190)
Trail	-4.9328* (2.6074)	-5.1337** (2.6147)	-6.4738** (2.7700)	-11.3412*** (3.5951)	-10.7667*** (3.4005)	-11.7877*** (3.4292)
Wildlife	136.297*** (39.8397)	137.680*** (39.8371)	157.244*** (42.2363)	159.413*** (41.0676)	162.886*** (41.1430)	178.655*** (42.51174)
Nbd	0.4656 (0.4900)	0.5050 (0.4914)	0.7362 (0.5154)	0.9567* (0.5035)	0.9661* (0.4978)	1.23305** (0.5153)

Note: Standard errors in parentheses.

^aWelfare measures (in USD) from Models 3 and 6 are computed at median land size = 4 acres and the average values of the socioeconomic characteristics. Attributes Mech, Chem, and Wildlife are measured qualitatively (from 0 to 1), while attributes Timber, Trail, and Nbd are measured by 1% point increase. Standard errors are calculated using the delta method (NLOGIT's Wald command).

* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$

positively when choosing a GB control option, while increasing trail recreation has, on average, negative values.

As seen in the MNL regression results, “neighborhood control rate” is insignificant in Models 1 and 2 and marginally significant in Model 3. In contrast, this variable is significant in all three mixed logit models, indicating that the significant impact of neighborhood control on individual GB control decisions is detected when heterogeneous preferences are explicitly modeled. Although the welfare measure associated with a 1% point increase in neighborhood control rate may seem small compared to those for other option attributes, the welfare measure can be 10-fold if the neighborhood control rate is increased by 10 percentage points. It is also worth noting that the magnitude of welfare measures associated with GB control methods and trail recreation derived from the more flexible mixed logit models is significantly larger.

Chemical control is 90% effective while mechanical control is only 68% effective at controlling GB (T. Lee, personal communication, May 23, 2019). This difference in effectiveness is typical for other shrubs, such as the Japanese barberry (Ward et al., 2013). Because of the spatial dynamics of biological invasions, this difference in effectiveness can contribute to the persistence of the invasive shrubs and its ability to cause spatial-dynamic externalities depending on the spatial ecology of the long-distance dispersal and seed bank dynamics (Szewczyk et al., 2019). Existing conservation cost-share programs cover both types of control. However, if the program aims to control invasive species at the landscape level, chemical control might be necessary to achieve that goal.

Assuming a 20% increase of timber yields and an improvement in wildlife viewing as a result of control, and a 50% neighborhood control rate, we find that the cost-share payments cannot offset the negative welfare associated with chemical control and that is partially due landowners' environmental attitudes. In fact, the sum of ecosystem benefits and the neighborhood welfare effect does not justify the negative welfare estimate associated with chemical control, even before

TABLE 5 Landowner cost-benefit analysis (\$/acre) for mechanical versus chemical invasive shrub control.

	Mechanical	Chemical
Welfare measures ^a		
Method used	628	−736
Timber yield increased by 20%	142	142
Wildlife viewing improved	179	179
Neighborhood adoption of 50%	61	61
Status quo	202	202
Total benefits ^b	808	−556
Total benefits minus control cost ^c	−1442	−1456
Total benefits minus out-of-pocket cost ^d	245	−781

^aEstimates are from Model 6, Table 3.
^bTotal benefits are computed as the difference between the sum of welfare estimates associated with attributes and the welfare estimate associated with the status quo.
^cAssumes a control cost of \$2250/acre for mechanical (obtained as the midpoint of the range from \$1500 to \$3000/acre) and \$900/acre for chemical control (T. Lee, personal communication, May 23, 2019).
^dBased on a USDA Environmental Quality Incentives Program (EQIP) 75% cost-share payment (USDA, 2017).

accounting for chemical control costs (total benefits of \$-556/acre; Table 5). Absent any government incentive, the sum of ecosystem benefits and the neighborhood welfare effect does not justify the cost of mechanical control either (total net benefits of −\$1442/acre; Table 5). However, in the presence of a 75% cost-share payment, the net benefits become positive, at \$245/acre. Thus, the welfare estimates from this CE relative to the costs of mechanical control justify the existence of these cost-share payments (USDA, 2017). It remains to be seen what the landscape-level bioinvasion consequences are when the most preferred method is the least effective and the only one existing government programs can incentivize according to the welfare estimates. A change in the design of incentives from a cost-share to a lumpsum subsidy could incentivize landowners to adopt the more effective method if this is desired to reduce bioinvasion externalities. A lumpsum conservation payment of more than \$1456/acre (the sum of \$556 and \$900; Table 5) would incentivize landowners to prefer chemical control over no control. Similarly, a payment of more than \$1701/acre (the sum of \$1456 and \$245; Table 4) would be needed to incentivize landowners to choose chemical control over mechanical control under the current 75% cost-share programs.

7 | CONCLUDING REMARKS

We designed a CE to evaluate options to control GB, an invasive plant that is exotic and invasive in North America. We employed mixed logit models to examine the effects of option attributes on choosing a GB control option and derived welfare estimates associated with the option attributes. We find that to a typical landowner, choices of GB control options are affected by control methods, control outcomes (including timber production, trail recreation, and wildlife viewing), neighborhood control rate, and the cost. We find a strong preference for mechanical methods that is partially environmentally driven, and significant individual heterogeneity regarding chemical use, timber production, and trail recreation improvements resulting from control. We also find that smaller landowners are more concerned about the adoption rate of control in the neighborhood, while larger landowners care more about improving the ability to recreate on their trails in choosing a control option. If the goal of cost-share payments is to reduce invasive species spread at the

landscape level, then landowners' strong preference for the less effective method might be a hindrance to achieving this goal. In fact, these landowners could act as the weaker link in the landscape-level control of invasive species in forests. On the other hand, landowners' willingness to pay is increasing with the rate of adoption of control in their neighborhood, which offers further support for areawide management of invasive species. To realize the potential benefits from the neighborhood effect estimated in this study, local forestry extension offices could facilitate information sharing regarding where invasive species control takes place to increase the likelihood of control by neighbors. Assessing which effect will prevail—the lower effectiveness of the preferred control method or the increased level of control due to facilitated neighborhood effects—requires landscape-level analyses that use empirical welfare estimates such as the ones presented here, account for how preference heterogeneity might lead to different method selections, and model the invasive shrub dynamics within and across forestlands as a function of the effectiveness of selected control methods by landowners and the actions of neighbors.

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OPEN RESEARCH BADGES



This article has earned an Open Data badge for making publicly available the digitally-shareable data necessary to reproduce the reported results. The data is available at <https://databank.illinois.edu/datasets/IDB-3482782>.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in the Illinois Data Bank at https://doi.org/10.13012/B2IDB-3482782_V1.

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