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An attribute-based approach to contingent valuation of forest protection programs

Christopher C. Moore[a,*], Thomas P. Holmes[b], Kathleen P. Bell[c]

[a] National Center for Environmental Economics, US Environmental Protection Agency, 1200 Pennsylvania Ave, NW, MC - 1809T, Washington, DC 20460, United States
[b] Southern Research Station, USDA Forest Service, United States
[c] School of Economics, University of Maine, Orono, United States

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ABSTRACT

The hemlock woolly adelgid is an invasive insect that is damaging hemlock forests in the eastern United States. Several control methods are available but forest managers are constrained by cost, availability, and environmental concerns. As a result forest managers must decide how to allocate limited conservation resources over heterogeneous landscapes. We develop an attribute-based contingent valuation approach that allows us to perform cost-benefit analysis on control programs and inform the distribution of mitigation effort over land units that provide different types of environmental services. We use this approach to examine conservation efforts on three land management units in the southern Appalachian Mountains: Great Smoky Mountains National Park and Pisgah and Nantahala National Forests. Managers of these forests are focusing their efforts on specific conservation areas chosen for their importance to human-use or ecological services. The result is a network of sites that implicitly defines a tradeoff between ecological and human-use services. Our survey is designed to examine the public's perception of this tradeoff and estimate WTP for hemlock conservation programs. The estimated benefits of conserving hemlocks in the study area outweigh the cost of the mitigation programs by two orders of magnitude. We find that there is substantial support for protection of hemlock stands providing ecological services with very little human-use value. Further, we show that benefits

* Corresponding author. Tel.: +1 202 566 2348; fax: +1 202 566 2338.
E-mail address: moore.chris@epa.gov (C.C. Moore).

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from the current mitigation strategy could be increased by shifting effort to protect more ecological services at the expense of sites that generate primarily human-use value.

Introduction

Biological invasions are probably the most significant environmental threat to forest ecosystems in North America and elsewhere (Liebhold et al., 1995). Protecting forest services from these and other threats requires land managers and policy makers to prioritize when allocating scarce conservation resources (Holmes et al., 2008). The heterogeneity of the landscape, including the health of individual stands, spatial distribution of conservation areas, genetic diversity, and ecological and economic values, influences the development of effective and efficient mitigation plans (Jacobs, 2005). It is the latter criteria that are the focus of this paper; we are interested in the implicit tradeoff that resource managers are making between different types of forest services when they choose to protect one area of forest rather than another. We developed an attribute-based contingent valuation (CV) survey to explore the public's perception of this tradeoff in order to provide guidance to forest managers when allocating conservation resources.

The CV method is consistent with welfare economic theory and provides an empirical method that can capture nonuse values of environmental goods (Boyle, 2003). A recent meta-analysis by Barrio and Louriero (2009) examines how characteristics of the survey instrument, the sample, and the study area tend to influence CV estimates for forest services. Krieger (2001) provides a detailed review of the forest valuation literature by approaching sources of value separately, some of which are dominated by the CV method. Of particular interest to this study is how CV has been used to examine the effects of landscape heterogeneity on the value of forest management programs. To inform the efficient combination of timber production and environmental quality Holgen et al. (2000) estimate the value of different silvicultural approaches to forest recreationists. They find significantly positive WTP to support approaches that leave some mature trees and show that respondents tend to prefer natural regeneration of forest over regeneration from seed trees. Mogas et al. (2006) use choice modeling and CV to value recreational and ecological services in an afforestation program. Under both formats, respondents are presented with hypothetical scenarios in which different levels of ecological services, such as carbon dioxide sequestration, are combined with recreational opportunities. The authors find positive willingness to pay for some ecological and recreational forest services but do not use the data to examine the tradeoff people are willing to make among them.

Our attribute-based contingent valuation survey allows us to estimate economic value of forest protection programs and examine the tradeoff that people are willing to make between ecological and human-use services. Using a payment card response format, we ask respondents to provide WTP values for various conservation programs aimed at the suppression of an introduced forest pest, the hemlock woolly adelgid (Adelges tsugae, *henceforth* HWA). The payment card response format, in which people are typically asked to use an ascending list of payment amounts to indicate WTP, has been gaining some favor in the contingent valuation literature (Boyle, 2003; Roach et al., 2002). This is likely due to the increased statistical efficiency relative to dichotomous choice (Boxall et al., 1996; Hanemann et al., 1991) and the apparent advantage in reliability over open-ended and multiple bounded dichotomous choice formats (Rowe et al., 1996).

Controlling for preference heterogeneity can improve the fit of models estimating WTP. Aldrich et al. (2007) compare cluster analysis and latent class analysis as methods to account for unobserved heterogeneity; Provencher and Bishop (2004) perform a similar comparison between random parameters logit and a latent class model. Other studies rely on sociodemographic variables or answers to attitudinal and behavioral questions to serve as proxies for unobserved preference heterogeneity. For example, Johnston et al. (2001) asks respondents about the importance of some environmental concerns to model preference heterogeneity in decisions to purchase eco-labeled seafood. Holmes and Kramer (1996) and Jenkins et al. (2002) use questions about recreation behavior to help explain differences in WTP for forest conservation. In this study we take the latter approach to modeling preference heterogeneity. We use responses to behavioral and attitudinal questions, as well as some sociodemographic variables, to explain variation in WTP.

In the following section we provide background on the HWA invasion and mitigation efforts that are taking place throughout the eastern United States. In subsequent sections we discuss the design and administration of the CV survey and develop the model we use to estimate WTP. We will use the estimation results and information on HWA suppression efforts in western North Carolina to conduct a cost benefit analysis. Finally, we use the estimated WTP function in a static optimization routine to evaluate the economic efficiency of HWA suppression programs.

Hemlock resources in decline

Eastern hemlock (*Tsuga canadensis*) is a slow-growing, long-lived species that occurs in cool hillside and ravine environments throughout the eastern United States. Hemlocks often reach 60–100 ft in height and, when not subject to disturbance, can live for 800 years or more, forming 'old-growth' climax forest stands. Hemlock ecosystems provide critical habitat for several species of birds (Benzinger, 1994) and support populations of native brook trout (Ross et al., 2003). The Carolina hemlock (*Tsuga caroliniana*) is an extremely rare tree species found only on the slopes of the southern Appalachian Mountains in western North Carolina.

The HWA is a phytophagous insect native to Asia where it is a common, but largely harmless, pest of several hemlock species. In North America western hemlocks are relatively immune to this exotic pest but HWA causes crown die-back and extensive mortality to stands of eastern and Carolina hemlock. It can take as few as 4 years for HWA to kill a mature hemlock, though some have survived infestation for a decade or more (McClure et al., 2003). Infestations have been found in 15 eastern states and, in the absence of an aggressive and successful mitigation strategy, 90% of hemlock stands in the eastern United States are anticipated to experience severe mortality over the next 20 years (Jacobs, 2005).

Hemlock mortality from HWA is creating an ecological transition to black birch (*Betula lenta*) dominated forests (Kizlinsky et al., 2002). During the transition period, dead and dying hemlocks increase fire risk and risk to humans from falling stems and branches and diminish the aesthetic value of stands. Some landowners seek to mitigate financial losses from hemlock decline either by pre-emptive or salvage logging of stands. Micro-environmental and vegetative changes due to hemlock mortality are exacerbated on logged stands, and ecosystem impacts can be reduced by foregoing logging activities (Foster and Orwig, 2006).

There are three forms of control being used to suppress HWA infestations and contain their migration. Cultural controls rely on quarantine efforts and information campaigns to prevent introductions to areas that are currently free of established HWA infestations. When new infestations are discovered in these areas the response has included treating the affected trees with chemical insecticide and introducing non-native predators of HWA. Chemical control usually involves a combination of foliar treatment with insecticidal oil and applications of the systemic insecticide Imidacloprid. Foliar treatments will kill virtually all of the HWA that are on a tree at the time of treatment but reinfestation can occur almost immediately. Injecting systemic insecticide into the soil or, in cases where contamination of surface or ground water is a concern, the trunk of the tree will kill all HWA feeding on the tree and prevent reinfestation for 3–5 years (Cowles, 2009). Chemical control can be an effective measure in the near term but biological control is considered the only viable long-term option (Jacobs, 2005). Several beetle species that prey on HWA meet the criteria for effective biological control agents. These criteria include negligible impact on species other than HWA, the ability to establish a reproducing population in the wild that will migrate to other areas, and the feasibility of laboratory rearing (Cheah et al., 2004).

While each method can be effective in controlling HWA, the extent to which they can be used is constrained by various factors that prevent resource managers from fully optimizing. Foliar treatment is relatively inexpensive but trees greater than 30 ft tall require powerful sprayers that are typically mounted on a truck, restricting their use to areas that are accessible by road. Trees taller than 80 ft cannot be treated effectively with insecticidal sprays (McClure, 1998). Use of the systemic insecticide Imidacloprid is limited by several environmental concerns. If the insecticide reaches surface water wildlife can be adversely affected (Jacobs, 2005). There is also a risk of insects developing resistance to Imidacloprid; such was the case with the Silverleaf whitefly and the brown planthopper (Wen et al., 2009). To guard against these possibilities there are strict limits on the amount of Imidacloprid that can be applied per acre per year. As a result of these limitations on the chemical forms of control, resource managers have turned to biological control agents. However, the predatory beetles cost $1–$2 each to raise in a laboratory and the numbers available are limited by the relatively few facilities producing them (Parades and Elkinton, 2008).

Working within these parameters, resource managers are engaged in comprehensive efforts to mitigate damages to hemlock resources from HWA. A few isolated infestations in the state of Maine represent the northern boundary of the generally infested area in North America. A state quarantine was established in 1988 to prevent the artificial introduction of HWA on infested nursery stock and log shipments. The state is now providing chemical treatments (both spray and injections) to private landowners and pursuing a mixed chemical and biological control strategy on public lands (Maine Forest Service, 2007). In Maryland a Hemlock Woolly Adelgid Task Force was assembled to prioritize stands of highest resource value and recommend actions in the highest priority stands. The treatment plan was developed based on the recreation, fisheries, wildlife, heritage, and forestry value of each stand (Rabaglia, 2005). In Great Smoky Mountains National Park (GSMNP) forest managers are also pursuing a mixed chemical and biological control strategy. Two goals guiding the strategy there are, "(1) Minimize losses in hemlock old-growth forests," and "(2) Protect trees in high use developed areas" (Soehn et al., 2005). These goals are stated explicitly to ensure that ecological and human-use services are sufficiently represented in the conservation design. The conservation strategy in neighboring Pisgah and Nantahala National Forests designates each treatment site as either ecologically or culturally significant; again making a distinction between the ecological and human-use values of forest services (Jacobs, 2005).

The HWA suppression efforts discussed above are only a few of those that are in place in the eastern United States but they show that forest managers are considering different types of forest services when allocating conservation resources. Given the binding constraints on all forms of control, managers could realize efficiency gains by balancing the conservation of different types of forest services. We have developed a valuation study that makes a fundamental distinction between forest services in an effort to aid forest managers in their conservation decisions. The results of this study can be used to estimate benefits from current HWA suppression efforts, examine how the public feels about the tradeoff between these two types of services, and suggest ways to reallocate conservation resources to increase net benefits.

Data

Our survey asks respondents to consider conservation of forest services provided by three adjacent federal land management units. Pisgah and Nantahala National Forests lie entirely in the state of North Carolina while GSMNP straddles the border with Tennessee. Combined, these three areas received approximately 15 million visitors in 2006 (National Park Service; US Forest Service). Out of the nearly two million acres covered by these federal lands, hemlocks are a significant component on about 350,000 acres and are the dominant species on roughly 32,000 acres (Soehn et al., 2005). Some groves contain hemlocks that are 500–800 years old reaching heights greater than 40 meters (Jacobs, 2005). Old growth stands in the southern Appalachian Mountains provide unique habitats and recreational opportunities, as trees of this size are only found in the southern reaches of the species' range (Earle). Several forest valuation studies have found a premium on WTP to conserve old growth forest (Hagen et al., 1992; Adamowicz et al., 1998; Loomis et al., 1994).

Two focus groups of North Carolina residents were held to refine the survey instrument. Specifically, our goals were to evaluate participants' ability to comprehend the questionnaire, identify perceived biases, and determine what additional information was needed to convey the context of the valuation exercise. A total of 14 adults were recruited and screened by phone to participate in the focus groups. Overall respondents were comfortable with the survey and they did not perceive any bias in the material. Only minor formatting changes were made as a result of the focus groups.

The survey begins with a series of questions to gauge the respondents' awareness of the HWA infestation, their attitudes toward forest conservation, and their outdoor recreation activities. The second section of the survey presents a map of the study area and asks about previous visits to the three land management units therein. We then ask respondents if, during those visits, they noticed a reduction in forest health and how it affected their experience. In the third section we provide information on hemlock resources and the threat posed by HWA. This information is followed by two questions on the importance of protecting different types of forest services. The fourth section is designed to probe respondents' attitudes toward chemical and biological control of HWA. We present a summary of the effectiveness and costs of different control options and ask whether chemical and/or biological control should be used in the study area. The four sections of the survey that precede the valuation question serve at least two purposes. First, the answers to these questions can provide useful conditioning variables in our effort to estimate WTP. Secondly, they prepare the respondent for the valuation questions by asking them to think carefully about the resource and the services it provides.

The contingent valuation questions are preceded by another information section. Here respondents are told that resource managers in the study area have identified 200 potential conservation sites[1] but have not yet begun treatment. Each site is about 125 acres of hemlock-dominated forest. One hundred of these sites were chosen for their high ecological value, meaning that they are important for natural diversity and contain rare plants and animals. Ecological sites are typically in remote locations that are difficult for visitors to access. The remaining 100 potential conservation sites were chosen because they have a history of human-use, include areas used for recreation, and tend to be in areas that are easy for visitors to access. Respondents are told that sufficient funding may not be available to protect all 200 sites and that any conservation effort would be funded by an increase in annual taxes for the next 3 years. The information section concludes with a description of the CV questions that follow and a reminder telling them to consider their household income and other expenses when answering.

Respondents are asked three contingent valuation questions; each presents them with a different treatment network defined by a number of ecological sites and a number of human-use sites[2]. We provide an example in Fig. 1 in which the respondent was presented with a treatment strategy that protects 50 of the 100 potential ecological sites and 50 of the 100 potential human-use sites. They are then asked to indicate if they are willing to pay each of the amounts in the list below. The amounts are listed in ascending order beginning with $2. A person with a WTP greater than $2 would indicate 'Yes' for each amount that is less than or equal to their WTP for the referenced program. Because the survey is web-based we are able to take the respondent to the next question after their first 'No' response. We refer to the valuation questions as 'attribute-based' because they present the respondent with varying levels of multiple attributes – similar to stated choice attribute-based methods (Holmes and Adamowicz, 2003) – but rather than choosing one treatment network from a set of alternatives we ask them to provide a WTP response for each. Varying the number of ecological and human-use sites this way allows us to estimate a WTP function that isolates the marginal contribution of each type of ecosystem service to the total estimated value.

Choosing a CV response format typically requires a trade-off between efficiency and reliability. Formats yielding the most information, such as the open-ended format, which provides a point-value for WTP, have been criticized for lack of incentive compatibility (Carson and Groves, 2007) and producing responses that are statistically lower than actual payments (Brown et al., 1996). The single-bounded dichotomous choice format is theoretically incentive compatible (Carson and Groves, 2007) but provides less efficient estimates because responses reveal an interval for WTP which can be large or even unbounded from above (Boyle, 2003). The payment card response format has been used extensively in health valuation studies (Ryan and Watson, 2009; Lamiraud et al., 2009) and is becoming more popular in the valuation of environmental amenities (MacMillan et al., 2006; Duffield et al., 2007). Depending

[1] When the survey was being developed information on the number of potential treatment sites was not available. We chose 100 of each site type so that respondents could more easily consider the tradeoffs between the two types of services. We later learned that 351 sites were considered for treatment and eventually 159 were chosen. We use this information in our analysis but were unable to use it in the design of the survey.

[2] The combinations of ecological and human-use sites referenced on three different version of the survey covered eight pair-wise combinations of zero, 50, and 100, excluding the zero–zero combination.

50 of the 100 ecologically important sites

and 50 of the 100 socially important sites.

In the table below indicate whether or not you would be willing to pay the listed amounts in increased annual taxes to support this treatment program. (Check "Willing to pay" or "Not willing to pay" for each amount.)

Increase in taxes each year for the next three years	Willing to pay this tax	Not willing to pay this tax
$2	□	□
$4	□	□
$6	□	□
$8	□	□
$10	□	□
$15	□	□
$20	□	□
$25	□	□
⋮	⋮	⋮
$450	□	□
$500	□	□
More than $500	□	□

Fig. 1. Example contingent valuation question.

upon a researcher's needs, the payment card response format can strike a balance between efficiency and reliability by providing narrower intervals than dichotomous choice and more reliable responses than the open-ended format (Brown et al., 1996). While the payment card response format lacks incentive compatibility it has been shown to be robust to centering and range bias as long as the range of bids shown on the card do not truncate the distribution of WTP (Rowe et al., 1996; Holmes and Kramer, 1996).

We used a payment card format in which respondents viewed a list of dollar amounts and were asked to indicate if they would be willing to pay each amount. The highest amount to which they answered in the affirmative and the lowest amount they refused reveal an interval that includes their WTP for the good in question. The smallest amount on the payment card is $2. The largest amount on the payment card is $500 with another option for 'More than $500.' Focus group research helped determine that $500 is large enough to avoid truncating the WTP distribution from above.

Table 1
Sociodemographic comparison of sample with 2006 census data.

	Sample (%)	95% Confidence interval (%)	Population (%)
Female	63.6	58.9–68.3	51.8
High school diploma	99.2	98.3–100.0	82.0
Four-year college degree	75.2	71.0–79.4	24.8
Household income			
Less than $15,000	9.4	6.5–12.3	16.0
$15,000–$35,000	26.5	22.2–30.8	25.4
$35,000–$75,000	41.0	36.2–45.8	34.5
$75,000–$150,000	21.0	17.0–25.0	19.3
More than $150,000	2.1	0.7–3.5	4.9

The sample was drawn from North Carolina residents and stratified so that one half of the sample lived in the 28 westernmost counties. This was done to ensure sufficient representation from the less populated part of the state that includes the study area. We took a somewhat novel approach to administering the survey. The sample was recruited via random digit dialing (RDD) during the summer of 2006. Eligible individuals who agreed to participate in the survey were given a password and directed to a website to complete the survey. Respondents received a $10 Amazon.com gift card for completing the survey as an incentive. Only about 1% of contacted households could not participate for lack of internet access.

While we lack other 'phone-web' studies for direct comparison, the response rate is low by conventional standards. 3912 people were contacted using RDD of which 897 agreed to participate. However, only 401 completed surveys were submitted. This amounts to about a 10% response rate for all contacts and 45% for people who agreed to participate. While we acknowledge these rates are low, the effect is mitigated by the fact that some people contacted were screened from the sample to more closely approximate population demographics, which is not reflected in this calculation. However we also acknowledge that low response rates make selection bias a greater concern. Because we have incomplete information on the people that refused to participate we cannot employ statistical methods such as Heckman (1979) estimation or double hurdle modeling (Cragg, 1971) to address selection bias in a rigorous way. However, we use answers to attitudinal and demographic questions to create a profile of our sample and present our estimation results with the caveat that selection bias may influence the reported parameter estimates.

Table 1 compares a sociodemographic summary of our sample with the 2006 census data for the state of North Carolina. Our sample includes a larger proportion of females and tends to have more education than the population. The distribution of household income in our sample is similar to the population but tends to include disproportionately more people from the center of the distribution. Differences between the demographic profile of our sample and the population can be addressed by including these variables in the estimating equation and using census values when calculating benefits for North Carolina residents. However, other characteristics that may lead to self-selection and systematic bias in WTP responses are not available in census data.

Characteristics that could lead to self-selection into the sample include history of visitation to the study area, preferences about conserving different types of forest, and attitudes about chemical and biological control. Table 2 summarizes some of the visitation data we collected from the sample. More

Table 2
Visitation responses.

	Yes	No	'No' to all three areas
Have you ever visited Great Smoky Mountains National Park	307 (77%)	94 (23%)	
Have you ever visited Pisgah National Forest	237 (59%)	164 (41%)	
Have you ever visited Nantahala National Forest	172 (43%)	229 (57%)	71 (18%)
Did you visit Great Smoky Mountains National Park in 2005	125 (31%)	276 (69%)	
Did you visit Pisgah National Forest in 2005	118 (30%)	283 (70%)	
Did you visit Nantahala National Forest in 2005	66 (17%)	335 (83%)	223 (56%)

Table 3
Reasons for forest protection.

	How important are the following reasons in the decision to protect hemlock forests? ('5' being extremely important and '1' being not at all important.)					
	5	4	3	2	1	Don't know
Providing wildlife habitat	281 (70%)	88 (22%)	23 (6%)	4 (1%)	1 (<1%)	4 (1%)
Providing scenic views	137 (34%)	141 (35%)	91 (23%)	22 (6%)	3 (<1%)	7 (2%)
Providing recreation opportunities	105 (26%)	126 (31%)	120 (30%)	34 (9%)	9 (2%)	7 (2%)
Providing timber	63 (16%)	78 (20%)	109 (27%)	77 (19%)	61 (15%)	13 (1%)
Preserving seed sources for the future	262 (65%)	98 (24%)	33 (8%)	3 (<1%)	0 (0%)	5 (2%)

Table 4
Types of landscapes to protect.

	How important is it that hemlocks in the following areas be protected? ('5' being extremely important and '1' being not at all important.)					
	5	4	3	2	1	Don't know
Along roads	185 (46%)	127 (32%)	61 (15%)	19 (5%)	2 (<1%)	7 (2%)
Along hiking trails	238 (59%)	121 (30%)	28 (7%)	7 (2%)	1 (<1%)	6 (1%)
Campgrounds and picnic areas	230 (57%)	109 (27%)	45 (11%)	10 (3%)	1 (<1%)	6 (1%)
Wilderness areas	277 (69%)	75 (19%)	26 (7%)	11 (3%)	5 (1%)	7 (2%)
Designated conservation areas	297 (74%)	67 (17%)	27 (7%)	4 (1%)	1 (<1%)	5 (1%)

than four fifths of the sample visited the study area at least once and nearly half did so in the calendar year preceding the survey. These proportions may seem high, but considering that the study area includes the nation's most visited park and most of the sample frame lives within a 2-h drive it is not obvious to us that users of the resource are disproportionately represented in the sample.

Tables 3 and 4 summarize responses to questions designed to examine motivation and preferences for protecting forests. The first set of responses shows that providing wildlife habitat and seed sources for the future tend to be the most important reason for protecting hemlock forests. Providing scenic views, recreation opportunities, and timber are generally less important. The emphasis on ecological services continues in the second set of questions with protection of wilderness areas, designated conservation areas, and old-growth stands receiving the largest shares of 'Extremely Important' responses. Protection of hiking trails, campgrounds, and picnic areas are also ranked as 'Extremely Important' by more than half the sample. Finally, after providing them with cost and effectiveness information on the control media, we ask people how they feel about those options being used in the study area as a whole and then in congressionally designated wilderness areas. There was some concern that a large proportion of the sample would object to releasing another non-native species or using any form of chemical control. If true, this could lead to scenario rejection and protest bids in the CV question. Table 5 shows that nearly all respondents favored using at least one type of control to mitigate damages from HWA infestations.

We have summarized responses to a number of sociodemographic, behavioral, and attitudinal questions in order to create a profile of our sample. However, without analogous data on people who opted out of the survey we cannot control for selection bias in a rigorous way. We proceed with the recognition that a low response rate is often an indication of self-selection bias which can lead to inconsistent parameter estimates for the general population (Heckman, 1979).

Estimation

Responses to payment card CV surveys can be represented as an interval that includes the respondents latent WTP for the referenced nonmarket good. In this case respondents were asked to provide 'yes' or 'no' responses to a list of ascending dollar amounts. The interval that contains their stated

Table 5
Control methods.

	Do you believe these control methods should be used in the Great Smoky Mountains National Park and Pisgah and Nantahala National Forests?		
	Yes	No	'No' to all three forms of control
Chemical insecticide	276 (69%)	125 (31%)	
Insecticidal soaps and oils	171 (43%)	230 (57%)	
Predatory beetles	275 (69%)	126 (31%)	10 (2%)
	...In congressionally designated wilderness areas?		
	Yes	No	'No' to all three forms of control
Chemical insecticide	246 (61%)	155 (39%)	
Insecticidal soaps and oils	163 (41%)	238 (59%)	
Predatory beetles	278 (69%)	123 (31%)	22 (5%)

WTP is bounded by the largest amount they agreed to pay and the smallest amount they refused[3]. Cameron and Huppert (1989) showed that using the center point of the interval in an OLS regression model can lead to biased parameter estimates. They suggested that the appropriate model should treat the contribution of each response to the likelihood function as the probability that the latent WTP value falls within the chosen interval. This probability is found by taking the integral of the conditional probability density function over the range of WTP indicated by the interval response. It is often more convenient to express the probability as the difference between two cumulative density functions evaluated at the interval bounds. Assuming the regression error is normally distributed the conditional probability of observing an interval response y_i is

$$P(y_i|x_i) = \Phi\left(\frac{y_i^u - x_i\beta}{\sigma}\right) - \Phi\left(\frac{y_i^l - x_i\beta}{\sigma}\right), \quad \text{for } i = 1, \ldots, N \tag{1}$$

where x_i is the data, Φ is the standard normal CDF, y_i^u and y_i^l are the upper and lower bounds of the interval response, β is a vector of coefficients, and σ is the model standard deviation.

The decision to ask each respondent three CV questions requires further generalization of the model. Multiple solicitations are likely to induce some degree of correlation within responses. To control for potential intra-individual correlation, we used a random effects panel model, which assumes that intra-individual correlation is randomly distributed over the sampled population. A random effects model with normally distributed errors and latency in the dependent variable yields

$$\begin{aligned} &y_{ij}^* = x_{ij}\beta + u_i + \varepsilon_{ij} \\ &u_i \sim N(0, \sigma_u^2), \quad \varepsilon_{ij} \sim N(0, \sigma_\varepsilon^2) \\ &\text{for } i = 1, \ldots, N; \quad j = 1, 2, 3, \end{aligned} \tag{2}$$

where y_{ij}^* is the latent value known to individual i in response to the jth question but unobserved by the researcher, x_{ij} is a vector of the data for that response, and β is a vector of coefficients. In the random effects model the error is decomposed into two components. The term u_i is a random error that varies across individuals but is constant within an individual's set of responses. The term ε_{ij} is a random error that can vary across individuals and responses. The two error components, u_i and ε_{ij}, are assumed to be IID and independent of each other. For a complete discussion of the random effects model see Baltagi (2001, pp. 15–20). When consideration is given to the interval and random effects

[3] The situation in which a person says 'Yes' to an amount that is greater than an amount they previously refused is not allowed by the web-based version of the survey.

nature of the responses, the probability of observing interval response y_{ij} is

$$P(y_{ij}|x_{ij}) = \int_{-\infty}^{\infty} \frac{e^{-u_i^2/2\sigma_u^2}}{\sqrt{2\pi}\sigma_u} \left[\prod_{j=1}^{3} \Phi\left(\frac{y_{ij}^u - x_{ij}\beta + u_{ij}}{\sigma_\varepsilon}\right) - \Phi\left(\frac{y_{ij}^l - x_{ij}\beta + u_{ij}}{\sigma_\varepsilon}\right)\right] du_i, \quad \text{for } i = 1, \ldots, N \tag{3}$$

The model was estimated using the random effects interval data model (xtintreg) in the Stata statistical package.

We tested several functional forms for the WTP equation. Taking natural logarithms of the dependent variable, independent variables, or both can capture nonlinearities in the WTP function. Compared to other functional forms, regressing the natural logarithm of bid amounts on a linear function of independent variables produces coefficient estimates that are more often statistically significant and of the expected algebraic sign and relative magnitude[4]. This form of the regression equation is intuitively appealing because it imposes a non-negativity constraint on expected WTP. Additionally, the log-normal distribution is well-suited to the right-skewed distributions of WTP that are typically observed in CV studies (Cameron and Huppert, 1989; Payne et al., 2000; Brown and Taylor, 2000).

The payment vehicle in the CV questions is an increase in annual taxes over the next 3 years. Because we are evaluating a public project that is being funded with federal tax dollars, we appeal to the Office of Management and Budget Circular A-4 which guides federal agencies in discounting for cost-benefit analysis. This document recommends that agencies consider costs and benefits that are discounted at 3% and 7%. We take the average of these two rates and consider total WTP by calculating the present value of those three annual payments discounted at 5%. Our choice of a 5% discount rate is simply the average of the two recommended rates. This can be accomplished in the interval response models by finding the present value of the lower and upper bounds of the intervals and then taking the natural log of the result to impose the log-linear functional form.

The specification of the independent variables in the WTP function focuses attention on the relative importance of protecting ecological versus human-use sites. Similar to Adamowicz et al. (1998) we include variables representing the number of ecological (*Eco*) and human-use (*Use*) sites in the model specification and quadratic transformations of these variables (Eco^2, Use^2) so that the curvature of the WTP function can be evaluated for scope. A valid WTP function will be increasing in provision at a decreasing rate (Rollins and Lyke, 1998). We also include a provision-interaction variable ($Eco \times Use$) to test whether these types of sites are complements (the parameter estimate would be positive) or substitutes (the parameter estimate would be negative) in the treatment network.

Our most parsimonious specification adds a dummy variable for residents of western North Carolina (*WNC*), categorical income variables (*Income#*), and a dummy variable for gender (*Female*) to the quadratic function of the provision variables. Because the natural occurrence of hemlocks in North Carolina is largely restricted to the western part of the state, a dummy variable was created for residents of the 28 westernmost counties. Including this variable in the specification allows a test of the hypothesis that households in that part of the state have a larger WTP to preserve hemlocks. Categorical income variables refer to the response ranges in Table 1 and are used to allow testing of the hypothesis that household income shifts the WTP function. Since education and gender were the largest discrepancies between our sample and the population we tested the effect of those characteristics on WTP. We tested continuous and binary representations of the education variable in specifications with and without the categorical income variables since education and income tend to be highly correlated. We find that, at least in-sample, education does not have a significant effect on WTP and is thus excluded from our reported results. Following Lehtonen et al. (2003) we hope to capture some preference het-

[4] A refusal to pay \$2 indicates a WTP on the interval $\{\$0, \$2\}$. Because the semi-log specification of the estimating equation require taking the natural log of the interval bounds, the transformation of the lower bound on the lowest interval is undefined: $\ln(0) = -\infty$. To avoid this problem the lowest interval was recoded to $\{\$1, \$2\}$ so that the log transformation of the lowest interval is now $\{\$0, \$\ln(2)\}$. Sensitivity analysis on this assumption produced no perceivable difference in our results.

Table 6
Recreationist and environmentalist variables.

Environmentalist	Recreationist		
	0	1	Total
0	193 (48%)	11 (3%)	204 (51%)
1	130 (32%)	67 (17%)	197 (49%)
Total	323 (81%)	78 (19%)	401 (100%)

erogeneity with these variables and provide a way to adjust for potential sample selection bias when extrapolating our results to the population.

Respondents were asked a number of attitudinal questions, some of which we reported earlier. Since responses to these questions are likely to be collinear we create two new dummy variables based on responses to a number of attitudinal questions. The variables *environmentalist* and *recreationist* represent categories that are neither mutually exclusive nor exhaustive. Respondents were asked to rate the importance of different objectives of mitigation programs and the importance of protecting hemlocks providing different services (Tables 3 and 4). Individuals who rated environmental objectives as 'extremely important' *and* who rated hemlocks providing primarily ecological services as 'extremely important' to protect are placed in the environmentalist category. Individuals who rated recreational objectives as being 'extremely important' *and* rated hemlocks providing human-use services as 'extremely important' to protect are categorized as recreationists. The result is two dummy variables for which a given individual could have a value of unity for one, both, or neither. Table 6 shows a cross-tabulation of the attitudinal dummy variables. Model 2 adds the *Environmentalist* and *Recreationist* variables to the estimating equation.

Model 3 adds two more variables that interact the *WNC* dummy variable with the level measures of provision, *Eco* and *Use*. While the *WNC* dummy variables will capture an intercept shift, interaction variables allow us to test for differences in the slope of the WTP function for residents of the western part of the state.

Results

Table 7 reports the results from three econometric specifications of the WTP function. When viewing the coefficient estimates recall that a log-linear functional form was used. Coefficients should be interpreted as partial elasticities, so that a unit change in an independent variable approximately corresponds to a percentage change in the dependent variable. In all specifications, the parameter estimates on the number of ecological sites included in the treatment network, as well as the quadratic transformations, are significant at the 0.01 level. The number of human-use sites in the network and the quadratic transformations are significant at the 0.05 level in all specifications. These results indicate that respondents were sensitive to the level of provision of each type of site. The coefficients on the level provision measures are positive and those on the squared terms are negative and of much smaller magnitude. This is indicative of WTP that is increasing at a decreasing rate over at least some of the provision space. The parameter estimates on the interaction term between types of sites are positive in all model specifications, indicating that respondents perceive ecological and human-use sites services as complements, however the parameter estimates were not significantly different than zero at conventional significance levels ($p < 0.1$). The coefficient estimates for the level measures of ecological sites are about three times as large as those for human-use sites, which is consistent with the qualitative responses that placed a higher priority on protecting ecological forest services. However, the negative coefficient on Eco^2 is also about three times the magnitude of the coefficient on Use^2, indicating that WTP diminishes more quickly for ecological sites. We examine the implications of this result in the optimization section of the paper.

The statistical significance and relative magnitudes of the coefficients on the categorical income variables indicate that WTP tends to increase with income, however respondents in the two lowest income categories cannot be distinguished. In Model 1, the dummy variable for females is negative and significant at the 0.1 level but is not significant in the other two specifications. In Models 2 and

Table 7
Model results.

	Model 1		Model 2		Model 3	
Log likelihood	−2916.34		−2908.5		−2905.47	
Parameters	Model 1		Model 2		Model 3	
	Coefficient	*P*-value	Coefficient	*P*-value	Coefficient	*P*-value
$\hat{\sigma}_e^2$ – overall variance	0.697	0.000	0.695	0.000	0.692	0.000
$\hat{\sigma}_u^2$ – panel level variance	1.211	0.000	1.197	0.000	1.198	0.000
β_0 – constant	1.0616	0.000	1.8269	0.004	1.9507	0.001
β_1 – ecological sites	0.0241	0.000	0.0243	0.000	0.0234	0.000
β_2 – human use sites	0.0072	0.027	0.0076	0.019	0.0066	0.044
β_3 – eco squared	-1.66×10^{-4}	0.000	-1.67×10^{-4}	0.000	-1.68×10^{-4}	0.000
β_4 – use squared	-5.06×10^{-5}	0.029	-5.35×10^{-5}	0.020	-5.26×10^{-5}	0.021
β_5 – *Eco* × *Use*	3.08×10^{-5}	0.169	2.97×10^{-5}	0.189	2.95×10^{-5}	0.190
β_6 – Western NC	0.2261	0.046	0.1835	0.110	−0.0547	0.716
β_7 – income2	0.2375	0.201	0.2530	0.202	0.2505	0.206
β_8 – income3	0.4568	0.010	0.4241	0.024	0.4223	0.024
β_9 – income4	1.0246	0.000	1.1286	0.000	1.1265	0.000
β_{10} – income5	1.3044	0.000	1.3631	0.000	1.3608	0.000
β_{11} – female	−0.2057	0.075	−0.1701	0.127	−0.1674	0.128
β_{12} – environmentalist			0.3184	0.004	0.3183	0.003
β_{13} – recreationist			0.1192	0.368	0.1220	0.353
β_{14} – WNC × Eco					0.0020	0.069
β_{15} – WNC × Use					0.0018	0.093

3 the coefficient on the *environmentalist* dummy is positive and significant, indicating that people who feel strongly about protecting hemlocks for ecosystem services are willing to pay more for a conservation program. In contrast, the parameter estimates on the *recreationist* dummy variables are not statistically significant. Model 3 adds interactions between the *WNC* dummy variable and the number of ecological and human-use sites included in the hypothetical conservation networks. Both coefficients are positive and statistically significant indicating that marginal WTP to protect both types of sites is larger for residents of the western part of the state, near the study area. These interaction terms pick up the influence that the *WNC* dummy variable exhibited in the other two specifications.

Overall, the estimation results show that there is substantial support for programs that protect ecological sites despite their description as "difficult for visitors to access." This regard for ecological services is also apparent in the tendency for those categorized as *environmentalist* to bid more than *recreationists* for hemlock conservation. The relative importance of these two types of forest services has meaningful implications in the following cost-benefit and efficiency analyses.

Evaluation of an ongoing mitigation effort

Here we examine the HWA control efforts that are taking place in the study area. We show that the costs are low enough – less than $1 per household in the sample frame – so that virtually any positive benefits would show that this program passes a cost-benefit test. The interesting question then becomes one of efficiency. Given what we know about these programs and what we have learned about peoples' preferences, can conservation resources be reallocated to improve efficiency?

The *Environmental Assessment for the Suppression of Hemlock Woolly Adelgid Infestations* (Jacobs, 2005) provides information on the costs of control and the conservation strategy that is being pursued in Nantahala and Pisgah National Forests. Less information is available on the effort in GSMNP but extrapolating what is known of the effort in the neighboring National Forests we conduct a cost benefit analysis for the three land management units. Table 8 summarizes the information we have on the costs of control in the study area and calculates the present value.

In Pisgah and Nantahala National Forests an annual fixed cost of $15,000 is required to identify and monitor treatment sites. All of the 159 treatment sites will receive biological control at a cost of

Table 8
Costs of HWA control programs in the study area.

Year	Pisgah and Nantahala NFs ($)		Great Smoky Mountains NP ($)	Total discounted at 5%
	Fixed	Variable		
1	15,000	469,800	476,000	960,800
2	15,000			14,285
3	15,000			13,605
4	15,000	120,000		116,618
5	15,000			12,340
			Total present value	1,117,650

$2200 per site, for a total of $349,800. About half of these sites will also receive chemical treatment at a cost of $1500 per site, totaling $120,000. The total variable costs in the first year will be $469,800 and are reported in the third column of Table 8. The current strategy calls for biological control agents being introduced just once but it is not clear how many times chemical treatment will be repeated. The purpose of chemical treatment is to maintain core populations of healthy hemlocks until the biological control agents become established. A general rule of thumb for biological control is that it takes 6–10 generations of the prey species for the introduced predator to become established (DeBach, 1964). Since HWA produce two generations each year we assume two rounds of chemical treatment, spaced 3 years apart is sufficient. The second round of chemical control in the fourth year results in another $120,000 of variable costs for Pisgah and Nantahala National Forests.

The *Environmental Assessment of Hemlock Woolly Adelgid Control Strategies in Great Smoky Mountains National Park* (Soehn et al., 2005) provides some information on the mitigation strategy but does not include cost estimates. However, $476,000 was earmarked out of the National Parks System Budget in 2005 to fund HWA control in GSMNP (OMB, 2007). Since the money was allocated in a single year, we assume all costs are incurred in that year and we record this amount in the fourth column of Table 8. The last column of Table 8 shows the expected costs of the current strategy in each year, discounted to present value at using a rate of 5%. When the discounted costs are divided among over 3 million households in the sample frame of North Carolina the result is about 36 cents per household.

Benefits are calculated using the expected value of the WTP function evaluated at provision values that approximate the efforts in the study area. The log-linear functional form for the WTP function implies that benefits follow a log-normal distribution. Expected WTP for a representative household is calculated by

$$E(\text{WTP}) = \exp\left(\hat{\beta}\breve{x} + \frac{\hat{\sigma}_u^2 + \hat{\sigma}_\varepsilon^2}{2}\right), \tag{4}$$

where $[\hat{\sigma}_u^2, \hat{\sigma}_\varepsilon^2, \hat{\beta}]'$ is the vector of parameters from Model 1 reported in Table 7 and $\breve{x}$ is a row vector containing provision values and demographic data for the representative household.

When estimating benefits from the control programs we are forced to make some assumptions regarding the effort in GSMNP because detailed information is not available. Since the funds allocated to the two programs in the first year of the planning horizon are nearly identical (Table 8) we assume that the strategy being pursued in the National Forests is being replicated in GSMNP. To maintain consistency with the attribute levels used in the valuation questions and the interpretation of the estimated parameters, we express the number of each type of site as a proportion of the total number of potential sites. In Pisgah and Nantahala National Forests 29 of the treatment sites were chosen for high ecological value and 130 were chosen for human-use value. Through personal correspondence we have learned that a total of 351 sites were considered for treatment before the final network was chosen. We do not have information on how many of those sites were considered for their ecological value versus human-use value. To express the number of ecological and human-use sites in the treatment network as a proportion of the larger set of potential sites, we assume that an equal number of ecological and human-use sites were initially considered. This is a critical assumption with substantial influence on our results. Nonetheless, this assumption results in values of $100 \times (29/175.5) \approx 16.5$ for ecological sites and $100 \times (130/175.5) \approx 74$ for human use sites. Because we assume these proportions

Table 9
Values used to calculate benefits for the representative household.

Ecologically important sites	16.5
Human-use sites	74
Western North Carolina residents	0.179
Income category 2	0.254
Income category 3	0.345
Income category 4	0.192
Income category 5	0.049
Female	0.518

are being reproduced in GSMNP, no further calculations are necessary. Values for demographic variables are taken from 2006 Census data for the state of North Carolina and thus WTP is calculated for the representative individual of our sample frame. Using these values and the estimated parameters from Table 7 in Eq. (4) we find the expected present value of three annual payments is about $60 with a 95% confidence interval of $\{\$51, \$71\}$.

Given the low per-household costs of the conservation programs a formal cost-benefit analysis is probably not necessary. However, the attribute based design of the CV questions allows us to examine the efficiency of the current strategy and suggest a reallocation of resources that is likely to increase net benefits. Specifically, we exploit the implied tradeoff between ecological and human-use services that respondents are making when answering the CV questions to solve for the combination of ecological and human-use sites that provides the largest net benefit.

We apply the parameter estimates from Model 1 (Table 7) which does not interact attitudinal or demographic variables with provision, so their values will not affect the optimal allocation, only the resulting level of net benefits. As such, the attitudinal and demographic variables are combined with the constant term *C* in the objective function. Similarly, we can maximize the linear function on the right hand side of the estimating equation and ignore the semi-log specification because taking the natural log of WTP is a monotonic transformation. We use Lagrange's method for optimization so that (Table 9)

$$L = C + \hat{\beta}_1 Eco + \hat{\beta}_2 Use + \hat{\beta}_3 Eco^2 + \hat{\beta}_4 Use^2 + \hat{\beta}_5 EcoUse + \lambda(B - Eco - Use), \quad (5)$$

where λ is the Lagrange multiplier and *B* is the maximum number of sites that can be included in the network. The Kuhn–Tucker conditions for a budget constrained optimum are

$$\frac{\partial L}{\partial Eco} = \hat{\beta}_1 + 2\hat{\beta}_3 Eco + \hat{\beta}_5 Use - \lambda \le 0, \quad 0 \le Eco \le 100 \quad (6)$$

$$\frac{\partial L}{\partial Use} = \hat{\beta}_2 + 2\hat{\beta}_4 Use + \hat{\beta}_5 Eco - \lambda \le 0, \quad 0 \le Use \le 100 \quad (7)$$

$$\frac{\partial L}{\partial \lambda} = B - Eco - Use \ge 0, \quad \lambda \ge 0, \quad (8)$$

all with complementary slackness.

Leaving the *B* undefined and solving these conditions in terms of the choice variables, *Eco* and *Use*, yields an expansion path for the optimal treatment network. To simplify the following expressions, we let $H = (\beta_2 - \beta_1)/(\beta_5 - 2\beta_4)$ and $J = (\beta_5 - 2\beta_3)/(\beta_5 - 2\beta_4)$.

$$Use = 0,\ Eco = B \quad \text{for } 0 \le B \le H \quad (9)$$

$$Use = H + J \cdot Eco \quad \text{for } H < B \le 100 + \frac{100 - H}{J} \quad (10)$$

$$Use = 100,\ Eco = \frac{100 - H}{B} \quad \text{for } 100 + \frac{100 - H}{J} < B \le 200 \quad (11)$$

The points along this piecewise linear path are combinations of ecological and human-use sites that yield the largest net benefit for a given budget. We infer a budget constraint from the total number of

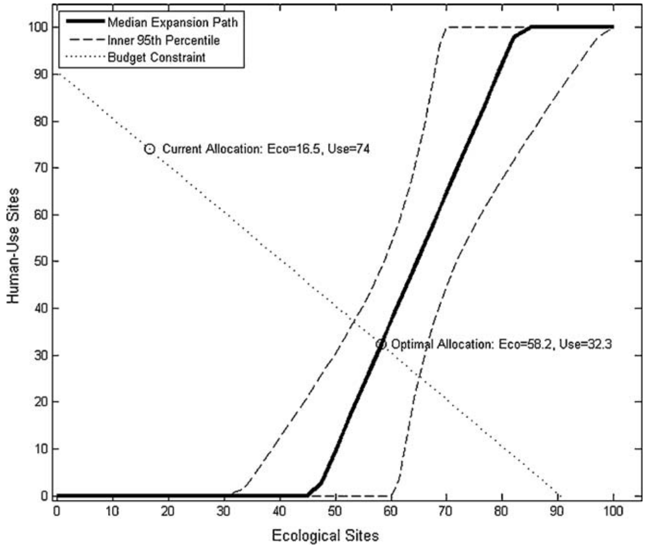

Fig. 2. Constrained optimization.

sites being treated in the current program. After rescaling, the total number of ecological and human-use sites in the network is restricted to 90.5 or less. This places *B* in the interval corresponding to expression (10), implying the interior solution of $\{Eco^* = 58.2, Use^* = 32.3\}$. Second order sufficient conditions require this solution to satisfy $F_{Eco,Eco}F_{Use}^2 - 2F_{Eco,Use}F_{Eco}F_{Use} + F_{Use,Use}F_{Eco}^2 < 0$, where *F*(*Eco*, *Use*) is our objective function and subscripts indicate partial derivatives. We evaluate this expression at the budget constrained optimum and every other point on the expansion path. We find that second order conditions are satisfied at all points along the expansion path for values of *Eco* and *Use* that sum to less than 200.

Thus far, our solution treats the estimated coefficients as fixed points and ignores the uncertainty surrounding them. Here we use a Krinsky and Robb (1986) procedure to generate an empirical distribution for points along the expansion path. First, we take 100,000 draws of the coefficient vector from a multivariate normal distribution using the estimated coefficient vector and covariance matrix for the mean and variance. We then evaluate expressions (9)–(11) for each of the draws and for budget constraints $B = \{1, 2, \ldots, 200\}$. In Fig. 2 we plot the median treatment network and inner 95th percentile for each value of *B*. We also plot the budget constraint which intersects the expansion path of the median treatment network near the solution to our constrained optimization problem.

Our choice of a quadratic benefit function ensures a piecewise linear expansion path, so we should be careful not to place too much weight on that result. However, a fairly robust result is that ecological sites dominate the optimal treatment network at low levels of protection. As the network expands to include more conservation sites those with human-use value become more important. This trend appears to continue until all potential use sites are treated and we reach another corner solution. At the risk of putting too fine a point on this result given the resolution of our data, this may indicate that people want to ensure some minimum level of ecological protection beyond which there is little marginal value and recreation sites begin to dominate.

When evaluated at the optimal allocation, per capita benefits from conservation (via Eq. (4)) are \$122, approximately doubling that of the current strategy. Table 10 compares benefits from the current and optimal strategies. While it may not be possible for resource managers to match the optimal allocation exactly (due to spatial and other constraints which are ignored in this model) a movement along the budget constraint in the direction of the optimal allocation would result in larger net benefits because the benefit function is monotonically increasing in that direction.

Table 10
Static optimization results.

Conservation network	$E(\text{WTP}\mid Eco,\ Use)$ ($)		
	95% confidence interval lower bound	Median	95% confidence interval upper bound
Current strategy			
Eco = 16.5	51	60	71
Use = 74			
Optimal strategy			
Eco = 58.2	96	122	156
Use = 32.3			

Conclusion

We have developed an attribute-based CV questionnaire to model the effect of landscape heterogeneity on WTP for forest protection programs. By asking respondents to distinguish between two types of conservation sites, each with its own set of environmental services, we are able to isolate the marginal value of each type. A benefit function estimated from these data can provide a more accurate measure of benefits for the study site, allow more precise benefit transfer to conservation networks with a different combination of ecological and human-use sites, and suggest ways to increase the efficiency of conservation programs by reallocating resources over the landscape.

The statistical efficiency of CV makes our attribute-based method an attractive alternative to conjoint analysis when small sample size is a concern (Boxall et al., 1996). We also point out that, at least in this case, the level of benefits is not as important as being able to model the implicit tradeoff between ecosystem and human-use services. While virtually any positive benefits would justify the conservation effort, the finding that respondents feel strongly about preserving ecological services provides justification for expanding the protection of such sites perhaps at the expense of some human-use sites.

Thus, we are pleased with the results of this somewhat novel approach to CV. Our view of the survey administration mode however is less favorable. The decision to recruit a sample via RDD to complete an internet-based survey yielded a low response rate. While the phone-web mode provides cost savings and prevents certain types of data problems, such as item non-response and inconsistent bid responses, the possibility of sample selection bias needs to be rigorously addressed in future applications of this approach.

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References

Adamowicz, W., Boxall, P., Williams, M., Louviere, J., 1998. Stated preference approaches for measuring passive use values: choice experiments and contingent valuation. American Journal of Agricultural Economics 80, 64–75.
Aldrich, G.A., Grimsrud, K.M., Thacher, J.A., Kotchen, M.J., 2007. Relating environmental attitudes and contingent values: how robust are methods for identifying preference heterogeneity? Environmental and Resource Economics 37, 757–775.
Baltagi, B.H., 2001. Econometric Analysis of Panel Data. John Wiley and Sons, Ltd, West Sussex, England, p. 293.
Barrio, M., Louriero, M.L., 2009. A meta-analysis of contingent valuation forest studies. Ecological Economics.
Benzinger, J., 1994. Hemlock decline and breeding birds. Records of New Jersey Birds 20, 2–12.
Boxall, P.C., Adamowicz, W.L., Swait, J., Williams, M., Louviere, J., 1996. A comparison of stated preference methods for environmental valuation. Ecological Economics 19, 243–253.
Boyle, K.J., 2003. Contingent valuation in practice. In: Champ, P.A., Boyle, K.J., Brown, T.C. (Eds.), A Primer on Nonmarket Valuation. Kluwer, Dordrecht.
Brown, T.C., Champ, P.A., Bishop, R.C., McCollum, D.W., 1996. Which response format reveals the truth about donations to a public good? Land Economics 72 (2), 152–166.
Brown, K.M., Taylor, L.O., 2000. Do as you say say as you do: evidence on gender differences in actual and stated contributions to public goods. Journal of Economic Behavior and Organization 43, 127–139.

Cameron, T.A., Huppert, D.D., 1989. OLS versus ML estimation of non-market resource values with payment card interval data. Journal of Environmental Economics and Management 17 (3), 230–246.
Carson, R.T., Groves, T., 2007. Incentive and informational properties of preference questions. Environmental and Resource Economics 37, 181–210.
Cheah, C., Montgomery, M.E., Salom, S., Parker, B.L., Costa, S., Skinner, M., 2004. Biological Control of Hemlock Woolly Adelgid. USDA Forest Service FHTET-2004-04.
Cowles, R., 2009. Optimizing dosage and preventing leaching of imidacloprid for management of hemlock woolly adelgid in forests. Forest Ecology and Management 297, 1026–1033.
Cragg, J.G., 1971. Some statistical models for limited dependent variables with application to the demand for durable goods. Econometrica 5, 829–844.
DeBach, P., 1964. Biological Control of Insect Pests and Weeds. Reinhold Publishing, New York, NY.
Duffield, J.W., Neher, C.J., Patterson, D.A., Champ, P.A., 2007. Field testing existence values for riparian ecosystems. In: Watson, A., Sproull, J., Dean, L., (comps.), Science and Stewardship to Protect and Sustain Wilderness Values: Eighth World Wilderness Congress symposium, September 30–October 6, 2005, Anchorage, AK. Proceedings RMRS-P-49. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO, pp. 550–557.
Earle, C.J. The Gymnosperm Database. Updated July 4, 2009. Available at: http://www.conifers.org/pi/ts/canadensis.htm (accessed 01.03.10).
Foster, D.R., Orwig, D.A., 2006. Preemptive and salvage harvesting of New England forests: when doing nothing is a viable alternative. Conservation Biology 20, 959–970.
Hagen, D.A., Vincent, J.W., Welle, P.G., 1992. Benefits of preserving old-growth forests and the spotted owl. Contemporary Policy Issues 10, 13–26.
Hanemann, M., Loomis, J., Kanninen, B., 1991. Statistical efficiency of double-bounded dichotomous choice contingent valuation. American Journal of Agricultural Economics 73, 1255–1263.
Heckman, J.J., 1979. Selection bias as a specification error. Econometrica 47, 153–161.
Holgen, P., Mattsson, L., Li, C.Z., 2000. Recreation values of boreal forest stand types and landscapes resulting from different silvicultural systems: an economic analysis. Journal of Environmental Management 60, 173–180.
Holmes, T.P., Bell, K.P., Byrne, B., Wilson, J.S., 2008. Economic aspects of invasive forest pest management. In: Holmes, T.P., Prestemon, J.P., Abt, K.L. (Eds.), The Economics of Forest Disturbances. Springer.
Holmes, T., Adamowicz, W., 2003. Attribute Based Methods. In: Champ, P.A., Boyle, K.J., Brown, T.C. (Eds.), A Primer on Nonmarket Valuation. Kluwer, Dordrecht, p. 554.
Holmes, T.P., Kramer, R.A., 1996. Contingent valuation of ecosystem health. Ecosystem Health 2, 56–60.
Jacobs, R.T., 2005. Environmental Assessment: Suppression of Hemlock Wooly Adelgid Infestations. U.S.D.A. Forest Service, National Forests in North Carolina, Asheville, North Carolina.
Jenkins, D.H., Sullivan, J., Amacher, G.S., Nicholas, N.S., Reaves, D.W., 2002. Valuing high altitude spruce-fir forest improvements: importance of forest condition and recreation activity. Journal of Forest Economics 8, 77–99.
Johnston, R.J., Wessells, C.R., Donath, H., Asche, F., 2001. Measuring consumer preferences for ecolabeled seafood: an international comparison. Journal of Agricultural and Resource Economics 26, 20–39.
Kizlinsky, M.T., Orwig, D.A., Cobb, R.C., Foster, D.R., 2002. Direct and indirect ecosystem consequences of an invasive pest on forests dominated by eastern hemlock. Journal of Biogeography 29, 1489–1503.
Krieger, D., 2001. Economic Value of Forest Ecosystems: A Review. The Wilderness Society, Washington, DC.
Krinsky, I., Robb, A.L., 1986. On approximating the statistical properties of elasticities. The Review of Economics and Statistics 4, 715–719.
Lamiraud, K., von Bremen, K., Donaldson, C., 2009. The impact of information on patient preferences in different delivery patterns: a contingent valuation study of prescription versus OTC drugs. Health Policy (93), 102–110.
Lehtonen, E., Kuuluvainen, J., Pouta, E., Rekola, M., Chuan-Zhong, L., 2003. Non-market benefits of forest conservation in southern Finland. Environmental Science and Policy 6, 195–204.
Liebhold, A.M., Macdonald, W.L., Bergdahl, D., Mastro, V.C., 1995. Invasion by exotic forest pests: a threat to forest ecosystems. Forest Science Monographs, 30.
Loomis, J., Gonzalez-Caban, A., Gregory, R., 1994. Do reminders of substitutes and budget constraints influence contingent valuation estimates? Land Economics 70, 499–506.
MacMillan, D., Hanley, N., Lienhoop, N., 2006. Contingent valuation: environmental polling or preference engine? Ecological Economics (60), 299–307.
Maine Forest Service, 2007. Environmental Assessment Regarding Management of Hemlock Woolly Adelgid Impacts in Maine, Augusta, Maine.
McClure, M., Salom, S., Shields, K., 2003. Hemlock Woolly Adelgid. U.S.D.A. Forest Service, Morgantown, West Virginia.
McClure, M., 1998. Hemlock Woolly Adelgid. Connecticut Agricultural Research Station Report. Updated June 4, 2007. Available at: http://www.ct.gov/CAES/cwp/view.asp?a=2815&q=376706.
Mogas, J., Riera, P., Bennett, J., 2006. A comparison of contingent valuation and choice modeling with second-order interactions. Journal of Forest Economics 12, 5–30.
National Park Service Great Smokey Mountains National Park – Statistics. Updated February, 2008. Available at: http://www.nps.gov/grsm/parkmgmt/statistics.htm (accessed 02.04.08).
Office of Management and Budget, 2007. Appropriations Report Language – Senate Full Committee. Available at: http://earmarks.omb.gov/earmarks/earmark_197003.html (accessed June 05.06.09).
Office of Management and Budget, 2003. Regulatory Analysis. Available at: http://www.whitehouse.gov/OMB/circulars/a004/a-4.pdf (accessed 09.03.10).
Parades, A., Elkinton, J., 2008. Mortality factors and population rate increase for the hemlock woolly adelgid. In: Fourth Symposium on Hemlock Woolly Adelgid in the Eastern united States Hartford, February 12–14, Connecticut.
Payne, J.W., Schkade, D.A., Desvousges, W.H., Aultman, C., 2000. Valuation of multiple environmental programs. Journal of Risk and Uncertainty 21, 95–115.

Provencher, B., Bishop, R., 2004. Does Accounting for preference heterogeneity improve the forecasting of a random utility model? A Case Study. Journal of Environmental Economics and Management 48, 793–810.
Rabaglia, R., 2005. The Maryland hemlock woolly adelgid management plan. In: Third Symposium on Hemlock Woolly Adelgid, February 1–3, Asheville, North Carolina.
Roach, B., Boyle, K.J., Welsh, M.P., 2002. Testing bid design effects in multiple bounded contingent valuation. Land Economics 78 (1), 121–131.
Rollins, K., Lyke, A., 1998. The case for diminishing marginal existence values. Journal of Environmental Economics and Management 36, 324–344.
Ross, R.M., Bennett, R.M., Snyder, C.D., Young, J.A., Smith, D.R., Lemarie, D.P., 2003. Influence of eastern hemlock (*Tsugae Canadensis* L.) on fish community structure and function in headwater streams of the Delaware River basin. Ecology of Freshwater Fish 12, 60–65.
Rowe, R.D., Schulze, W.D., Biffle, W.S., 1996. A test for payment card bias. Journal of Environmental Economics and Management 31, 178–185.
Ryan, M., Watson, V., 2009. Comparing welfare estimates from payment card contingent valuation and discrete choice experiments. Health Economics (18), 389–401.
Soehn, D., Taylor, G., Remaley, T., Johnson, K., 2005. Draft Environmental Assessment of Hemlock Woolly Adelgid Control Strategies in Great Smoky Mountains National Park.
US Forest Service[a]. National Forests in North Carolina – Fact Sheet FY2007. Updated March, 2008. Available at: http://www.cs.unca.edu/nfsnc/facts/forest_facts_07.pdf (accessed 02.04.08).
Wen, Y., Liu, Z., Bao, H., Han, Z., 2009. Imidacloprid resistance and its mechanisms in field populations of brown planthopper, Nilaparvata lugens Stal in China. Pesticide Biochemistry and Physiology 94, 36–42.