

# International Willingness to Pay for the Protection of the Amazon Rainforest

*Juha V. Siikamäki*

*Alan Krupnick*

*Jon Strand*

*Jeffrey R. Vincent*



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## Abstract

The Amazon rainforest, the world's largest tropical rainforest and an important constituent of the global biosphere, continues degrading by rapid deforestation, which is expected to continue despite policies to prevent it. Current international funding to protect the Amazon rainforest focuses on benefits from reduced carbon emissions. This paper examines an additional rationale for Amazon protection: the valuation of its biodiversity and forests as natural heritage to the international community. To measure the economic value of this benefit, the paper examines U.S. and Canadian households' willingness to pay to help finance Amazon rainforest protection. The analysis finds that mean willingness to pay to avoid forest losses projected to occur by 2050 despite

current protective policies is \$92 per household per year. Aggregating across all households and considering the area protected, the analysis finds that preserving the Amazon rainforest is worth \$3,168 per hectare (95-percent confidence interval \$1,580-\$4,756), on average, to households in the United States and Canada. Considering households in other developed countries would generate yet larger estimates of aggregate value, likely comparable to the carbon benefits from rainforest protection. The results reveal high values of the Amazon rainforest to people geographically distanced from it, lending support to international efforts to reduce deforestation in the Amazon.

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Juha V. Siikamäki, Alan Krupnick, Jon Strand and Jeffrey R. Vincent<sup>1</sup>

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<sup>1</sup> Siikamäki: International Union for Conservation of Nature, 1630 Connecticut Ave NW, Washington DC, USA (corresponding author). Krupnick: Resources for the Future, 1616 P St NW, Washington DC, USA. Strand: Consultant, World Bank, 1818 H St NW, Washington DC, USA. Vincent: Nicholas School of the Environment, Duke University, Durham NC, USA. This work has been funded by a grant from the Knowledge for Change Program Trust Fund. We thank Michael Toman, Yoanna Kraus, and participants at a World Bank seminar for helpful comments.

# **International Willingness to Pay for the Protection of the Amazon Rainforest**

## **1. Introduction**

The Amazon rainforest, the world's largest tropical rainforest, is an important constituent of the global biosphere and a global public good that benefits the international community by supporting an array of ecosystem services (Daily 1997). It is home to possibly a quarter of the world's terrestrial species (Dirzo and Raven 2003), accounts for about 15% of global terrestrial photosynthesis (Field, Behrenfeld et al. 1998), provides a major carbon sink (Pan, Birdsey et al. 2011; Grossman 2016), and drives atmospheric circulation and precipitation across South America and beyond (Werth and Avissar 2002). However, the Amazon rainforest is also one of the most threatened environments worldwide, with deforestation (Achard, Eva et al. 2002; Hansen, Potapov et al. 2013) a particularly pressing problem (Soares-Filho, Nepstad et al. 2006; Malhi, Roberts et al. 2008), mostly in the form of agricultural expansion (Nepstad, Stickler et al. 2006; Barona, Ramankutty et al. 2010). Since 1970, about 15% of the Amazon rainforest, an area larger than France, has been lost, and deforestation is expected to continue despite efforts to control it (Malhi, Roberts et al. 2008; Soares-Filho, Moutinho et al. 2010). Much of the current international funding to prevent deforestation aims at reducing carbon emissions (UNDP 2008). Although a global carbon market might someday generate adequate funds to protect the Amazon rainforest, progress toward a global climate agreement required to create such a market remains slow (Angelsen 2012).

Here, we examine an additional rationale for international funding of Amazon protection: its value to the international community as part of global natural heritage. Using the classification of ecosystem services by the Millennium Ecosystem Assessment (Assessment 2005), this value corresponds to the value of cultural ecosystem services associated with the nonmaterial benefits supported by the continued existence of the Amazon rainforest. This benefit, as an economic value,

is an essential but poorly understood value of the Amazon rainforest. Measuring such values for nature, denoted “existence” values below, but also sometimes referred to as “intrinsic” values, in economic terms involves estimating the public’s willingness to pay (WTP) to protect ecosystems (Krutilla 1967; Bockstael, Freeman et al. 2000; Freeman III, Herriges et al. 2014). To do so, we used choice experiments (Louviere, Hensher et al. 2000; Train 2009; Hensher, Rose et al. 2015) to elicit representative data from the general public in the U.S. and Canada about WTP to avoid forest losses and species threats projected to occur by 2050 despite current protective policies.

The global existence value of the Amazon rainforest is distinct from other benefits provided by it, such as its global carbon sink function (Pan, Birdsey et al. 2011; Grossman 2016), local and regional climatic and regulating services, biodiversity-derived products (including pharmaceuticals), and recreation and ecotourism, in that the intrinsic value is not associated with beneficiaries’ current direct or indirect uses of the rainforest or the resources within it (Assessment 2005; Freeman III, Herriges et al. 2014). Such non-use values may arise from people’s desire to protect species, forests, and nature in general for their worth as cultural and natural heritage. Previous studies (Kramer and Mercer 1997; Horton, Colarullo et al. 2003) indicate that the international existence value of tropical rainforests could be substantial, but representative population-based estimates of values specific to the Amazon are not available. This prevents considering these values in the assessments of the many programs already undertaken or currently proposed to reduce Amazon rainforest losses. Examples of such programs include the Brazilian government’s Amazon Protected Areas Program (Soares-Filho, Moutinho et al. 2010), various activities under the UN-REDD umbrella (UNDP 2008), and the failed initiative by Ecuador to permanently suspend oil development in the Amazonian Yasuni National Park in return for payments from the international community to compensate for the forgone oil revenues (Martin

and Scholz 2014). We find that that the existence value of the Amazon rainforest is considerable and possibly comparable to carbon benefits (Song, Huang et al. 2015).

## **2. Methods**

### *2.1 Survey approach*

Measuring intrinsic economic values requires using survey-based approaches, as intrinsic values cannot be observed from market prices or behavior (Freeman III, Herriges et al. 2014). A widely used current approach to eliciting WTP involves conducting choice experiments. They are frequently used for environmental valuation and empirical evaluations of individual preferences and decision making more generally (Louviere, Hensher et al. 2000; Siikamäki and Layton 2007; Train Kenneth 2009; Hensher, Rose et al. 2015; Newell and Siikamäki 2015). Choice experiments view the objects of choice, in this study alternative Amazon protection plans, as bundles of attributes.

We measured WTP for two attributes addressed by Amazon protection, avoided loss of forest area, and reduced risk of species extinctions, by conducting random population surveys in the U.S. and Canada (1,024 respondents from the U.S. and 377 respondents from Canada). By conducting experiments, we elicited individuals' choices between sets of different Amazon protection options, each with specified forest losses and species extinction risks between now and 2050 achievable through new policy interventions. Each option also involved different expected costs to the household. WTP for the protection of Amazon rainforest, the measure of its economic value (Louviere, Hensher et al. 2000; Freeman III, Herriges et al. 2014), is implicit in the choices. For example, if a person selects a program that yields certain environmental benefits but also carries specific costs to that individual, we know that this person's WTP for the

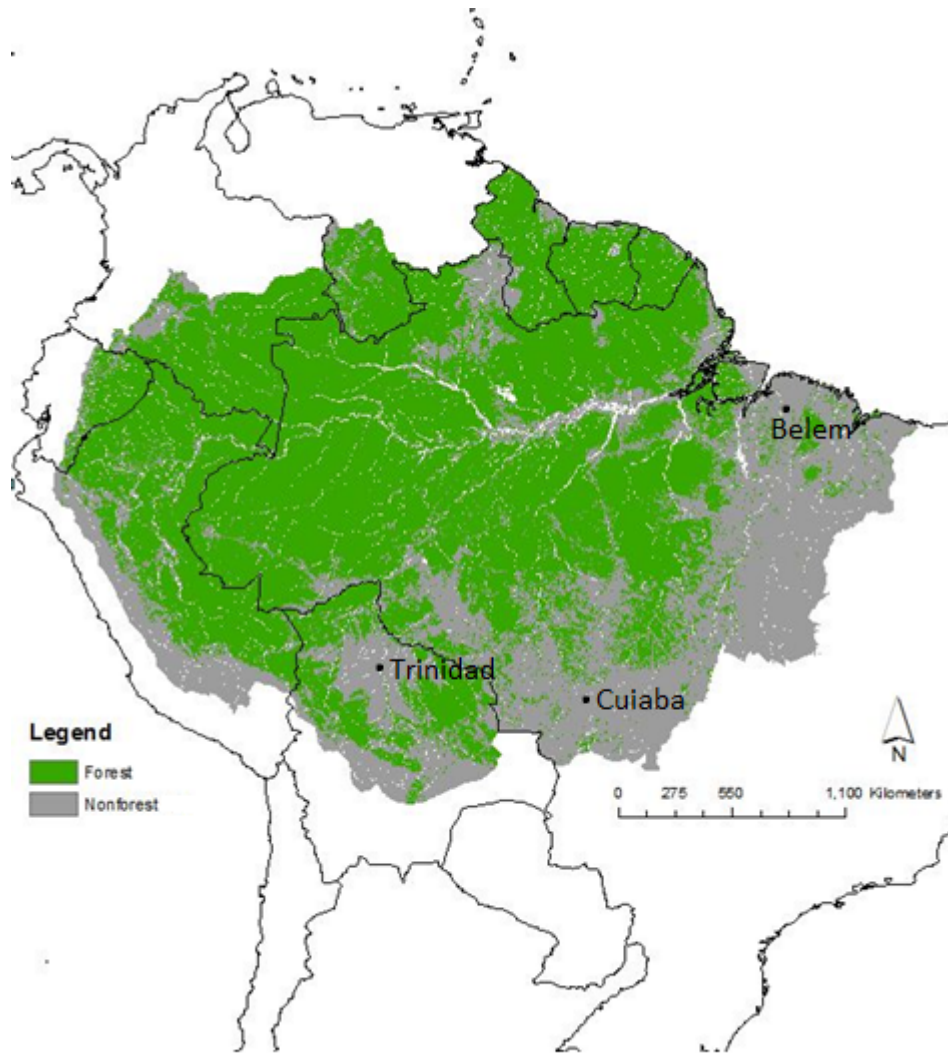
environmental benefits is at least equal to, and possibly greater than its costs to the person. Using data on a large number of selections by many respondents among many plans with an array of characteristics, including varying costs of the plans, we statistically estimated mean WTP for avoided loss of forest area and reduced risk of species extinctions.

We developed the survey with the help of focus groups and individual interviews. All of the essential issues in stated-preference survey development were extensively tested in five focus groups and through a pilot survey using the same sampling frame as the one we used for the main survey (see below), following the generally accepted guidelines for survey development and stated preference valuation (Arrow, Solow et al. 1993; Dillman 2000; Bateman and Transport 2002; Hensher, Rose et al. 2015). We supplemented the pilot survey by individual briefings with a few pilot study participants, with discussions of survey details conducted with them within hours after the subjects had completed their test surveys.

## *2.2 Survey outline and valuation questions*

The survey first informed participants that its objective is to learn about the preferences of the U.S./Canadian population for the protection of the Amazon rainforest. The survey then used text in combination with the maps shown in Figures 1-3, as well as an additional map of global rainforests, to describe the Amazon rainforest and its current and projected future status.

Thereafter, the survey explained, using estimates adapted from Soares-Filho et al. (Soares-Filho, Moutinho et al. 2010), future threats to forests and animal and plant species in the Amazon. The survey included pictures of selected threatened species, with hyperlinks to the names of

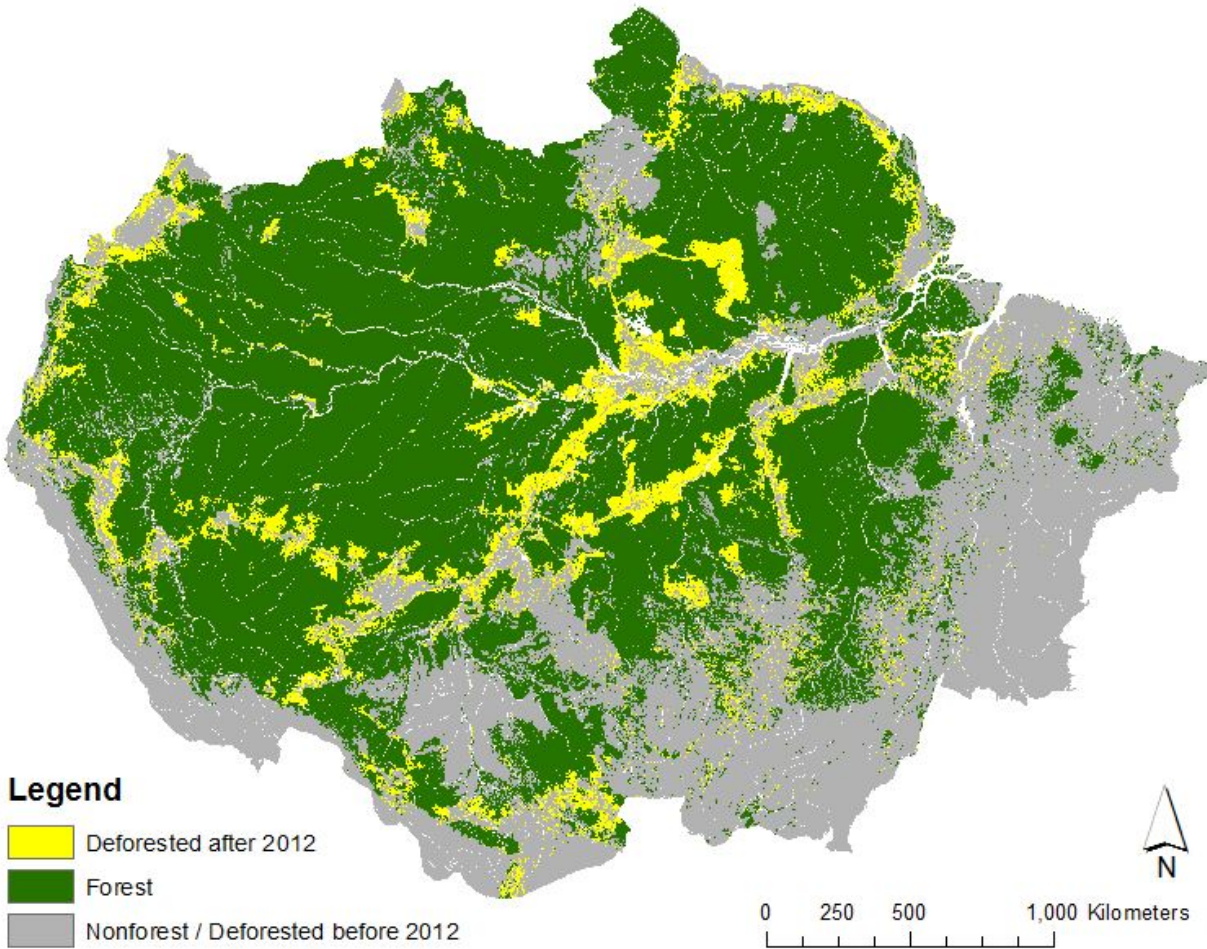


**Figure 1.** Amount of Amazon region covered by rainforest in 2012 (map courtesy of Britaldo Soares-Filho at the Federal University of Minas Gerais, Belo Horizonte, Brazil).

displayed species. The images of species threatened by the Amazon deforestation had no particular focus on more or less charismatic species. See Supporting Information for more detail on the survey design.

The survey next noted that governments in the Amazon region and around the world are considering new measures to protect the forests and species in the Amazon rainforest, including activities such as creating new national parks, limiting road building, and reducing government





**Figure 2.** Projected remaining area of the Amazon rainforest in 2050. Yellow indicates areas predicted to be deforested between 2012 and 2050 despite current policies to protect forests (Soares-Filho, Nepstad et al. 2006). “Nonforest” includes areas that had already been deforested by 2012. Figure courtesy of Britaldo Soares-Filho, Universidade Federal de Minas Gerais, Belo Horizonte, Brazil.

incentives for ranching and other agricultural developments in the Amazon region. The survey explained that the Amazon region countries themselves have insufficient funds to implement these plans on their own, and so the plans call for supplemental funding by countries in North America and other industrialized countries. Then, the survey explained several new protection alternatives in more detail, explaining their outcomes using two attributes: reduction in the extent



**Figure 3.** The Amazon region and its size relative to the lower 48 states of the U.S.

of rainforest area lost and reduction in the percentage of species threatened with extinction. All else being equal, one would expect the loss of species to be correlated with the loss of forest area (Koh, Lee et al. 2010), but in a forest as large and as heterogeneous as the Amazon, species loss is influenced by the particular locations where deforestation occurs, as the ranges of all species do not perfectly overlap (Soares-Filho, Nepstad et al. 2006).

Following the above program descriptions, each respondent was asked to make five separate program choices, each of which asked the person to select the preferred option among several specific Amazon protection program alternatives presented in that question. Each program alternative presented would result in specified reductions, as percentages of the current forest size.

This new choice has the following options: **No Plan** and **Amazon Protection Plans B** and **C**. With **Plans B** and **C** some forest loss will occur, though less than in the No Plan scenario. In Plan B, one fifth of the current area of the Amazon Rainforest will be lost by 2050 and one tenth of existing species will be threatened with extinction. With Plan C, very little forest loss will occur (5%) and very few species will face a high risk of extinction (2%). Please choose between **No Plan** and **Amazon Protection Plans B** and **C** as though they are the only options on the ballot.

What is your choice?

|  | <b>No Plan</b>   | <b>Plan B</b>  | <b>Plan C</b>   |
|--|--|--|---|
| <b>Forest loss</b>                                     | <b>30%</b> of current forested area is lost by 2050          | <b>20%</b> of current forested area is lost by 2050          | <b>5%</b> of current forested area is lost by 2050          |
| <b>Species loss</b>                                    | <b>24%</b> of species are threatened with extinction by 2050 | <b>10%</b> of species are threatened with extinction by 2050 | <b>2%</b> of species are threatened with extinction by 2050 |
| <b>Increase in your household's federal income tax</b> | <b>\$0</b>   | <b>\$25 per month</b> (\$300 per year)                       | <b>\$35 per month</b> (\$420 per year)                      |
| <b>Check the option you prefer</b>                     | <input type="checkbox"/>                                     | <input type="checkbox"/>                                     | <input type="checkbox"/>                                    |

**Box 1:** Example of a Choice Experiment Question terms, in forest loss and species

It also includes the projected shares of threatened species, while also involving a cost on households to finance the program.

Box 1 shows an example of a choice question with the Status Quo and two Amazon protection plans as choice alternatives. Choice questions varied the conservation (avoided forest loss and species threats) and cost outcomes across the program alternatives among which different respondents made choices. This generates data on how choices vary with program attributes, revealing trade-offs between different conservation outcomes as well as WTP for them. Choice alternatives were determined using the principles of Bayesian statistically efficient experimental design (Kessels, Jones et al. 2009; Hensher, Rose et al. 2015), with the survey conducted in two waves with updating of the experimental design between the waves.

### *2.3 Survey administration*

The surveys were administered in both countries using probability-based respondent panels designed to be representative of the country's population. The U.S. sample aimed at full representation of the population, whereas the Canadian sample was fielded only in English so the French-speaking population in Quebec province was effectively excluded. Once the study samples were selected and fielded, and all the survey data were edited and made final, weights were determined for each respondent to adjust for any survey nonresponse as well as any under- or over-coverage imposed by the study-specific sample design (Supporting Information). The survey completion rate is 41.7% for the U.S. sample and 18.9% for the Canadian sample. The completion rates differ between the U.S. and Canada but are typical for each panel (Newell and Siikamäki 2014; Worthington, Calzavara et al. 2015). The geographic distributions of the samples within the U.S. and Canada are broad and the shares of the samples by state/province closely match the geographic distributions of the country populations even without the use of weights (apart from

Quebec being unrepresented). Regardless, we use population weights in all estimations to construct estimates that are representative of target populations.

### 3. Estimation procedures

#### 3.1 Mixed Logit Model to Estimate Willingness to Pay from Choice Experiment Data: Background

Using econometric analyses, we predicted respondents' choices between alternative Amazon protection plans as products of program attributes (program cost and reductions in species threats and forest loss). By doing so, we could recover preferences (and WTP) for the different attributes of the programs considered in the survey, implicit in the choices elicited between different program alternatives. As conventional for modeling choice data, we began from a random utility model (McFadden and Train 2000; Train Kenneth 2009; Hensher, Rose et al. 2015) framework. Within that framework, we developed a mixed logit model (see below) to estimate WTP for reduced forest losses and species threats.

More specifically, we consider an individual  $i$  choosing the preferred alternative from several available options (in our survey, two or three alternative Amazon protection programs, depending on the choice question). The utility that person  $i$  derives from alternative  $j$ ,  $U_{ij}$ , separates into an unobserved stochastic component  $\varepsilon_{ij}$  and a deterministic component  $V_{ij}$  so that  $U_{ij} = V_{ij} + \varepsilon_{ij}$ . Individual choices contrast utility among available alternatives and the chosen alternative provides the highest utility in each choice problem. Therefore, the probability of person  $i$  choosing alternative  $j$  from the available alternatives equals the probability that alternative  $j$  provides person  $i$  with a greater utility  $U_{ij}$  than any other available alternative in the choice problem:  $P_{ij} = P(U_{ij} > U_{ik}, k = 1, 2, 3, \forall k \neq j)$ .

We model the deterministic portion of the utility  $V_{ij}$  as a linear additive function of the different attributes of the Amazon protection plan, including its cost to the household, denoted by  $p_{ij}$ , and other attributes  $X_{ij}$  (forest loss, species loss):  $U_{ij} = \lambda_i p_{ij} + \omega_i X_{ij} + \varepsilon_{ij}$ . Willingness to pay for the Amazon protection plan is given by the ratio between the coefficients for the program cost and other attributes, denoted  $\gamma = \omega / \lambda$ . Using this relationship, we re-write  $U_{ij}$  in “WTP space” (Train and Weeks 2005) as follows:

$$U_{ij} = \lambda_i [p_{ij} + \gamma_i X_{ij}] + \varepsilon_{ij} \quad (1)$$

We estimate equation (1) to determine WTP for the different attributes of the Amazon protection plan (avoided forest losses and species extinction risks) within the estimation framework. We specify a flexible model structure that incorporates multiple forms of heterogeneity, including preference variation systematically associated with the observed socioeconomic characteristics of the respondent as well as any remaining unobservable individual heterogeneity, as explained below.

We model the *WTP* coefficients for reduced forest loss and species threats as normally distributed and correlated random parameters  $\gamma_i = \gamma + L \cdot \eta$ , where  $\gamma_i$  is a  $2 \times 1$  vector of coefficients for forest and species loss,  $\gamma$  is a vector of their distribution means, and  $\eta$  is a vector of independent standard normal deviates. The matrix  $L$  is a  $2 \times 2$  lower triangular matrix such that  $Chol(L * L') = \Omega$ , where  $\Omega$  is the covariance matrix of the estimated random coefficients. To characterize their parameter distributions, we estimate their shape parameters, including standard deviations (the diagonal elements of  $L$ , denoted here  $L_F$  and  $L_S$ ) and covariance (the off-diagonal elements  $L_{F,S}$ ).<sup>2</sup>

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<sup>2</sup> The correlations are of the form  $\rho_{F,S} = \frac{\text{cov}(F,S)}{\delta_F \delta_S}$ , where  $\delta_F$  and  $\delta_S$  are the estimated standard

deviations of the coefficient distributions for WTP for reduced forest and species loss.

The coefficient  $\lambda_i$ , estimated on program cost, measures the marginal utility from income. We model it as a heterogeneous parameter as follows:

$$\lambda_i = \tilde{\lambda}_{0i} + \sum_{k=1}^K \tilde{\lambda}_k Z_{ik} \quad (2)$$

where  $Z_{ik}$  denotes the  $k^{\text{th}}$  observable individual attribute (respondent, household) and  $\tilde{\lambda}_{0i} \sim N(\mu_\lambda, \sigma_\lambda^2)$ . This allows the program cost coefficient to vary by the observable characteristics of the respondent, but it also accounts for any remaining unobservable heterogeneity by incorporating a random parameter (Newell and Siikamäki 2014). We use information on a large number of variables to model the heterogeneity of  $\lambda$ . We use 0/1 dummies for all variables associated with the program cost coefficient so that model structure can address possible nonlinearities. For continuous variables, such as household income or household size, we transform the original variable into a categorical variable and then estimate a dummy for each category, except for the excluded category required for identification. Finally, we model  $\lambda$  as a log-normal parameter to ensure that it only takes positive values, as one would expect any increases in income to generate positive utility (and program cost increases reduce utility, keeping everything else constant).

Assuming  $\varepsilon_{ij}$  in Equation (1) is a type I extreme value random variable leads to a mixed logit model (Train 2009; Hensher, Rose et al. 2015). In it, the probability of person  $i$  choosing alternative  $j$  out of  $M$  alternatives in choice problem  $h$ , conditional on individual random components  $\lambda_i$  and  $\gamma_i$ , is determined as:

$$P_{ijh}(\lambda_i, \gamma_i) = \frac{\exp[V_{ijh}(\lambda_i, \gamma_i) / \sigma]}{\sum_{k=1}^M \exp[V_{ikh}(\lambda_i, \gamma_i) / \sigma]} \quad (4)$$

The parameter  $\sigma$  is a scale parameter typically assumed to equal one (and dropped out). When eliciting  $Z$  consecutive choice questions, the joint probability of the sequence of choices made by individual  $i$  across all choice problems is:

$$P_{i\Box}(\lambda_i, \gamma_i) = \prod_{h=1}^Z P_{ijh}(\lambda_i, \gamma_i) \quad (5)$$

To estimate the probability (5) over all possible values of  $\lambda_i$  and  $\gamma_i$ , we use simulated log-likelihood estimation using 200 Halton sequences (Bhat 2003; Train Kenneth 2009).

The above estimation framework with varying preference parameters for all program attributes, including its costs and environmental outcomes among different individuals, enables accommodation of many different drivers of heterogeneity potentially relevant to different respondents. The flexibility of the model specification helps to avoid model misspecification that can lead to biased estimates of WTP.

### *3.2 General Estimation Approach*

A commonly raised concern in using an SP approach is that the people may choose differently in a survey than in actual choice situations. For example, some respondents may in the survey select programs so costly that in reality they would not be willing or able to pay for them, leading to overestimation of WTP. Moreover, some respondents may reject programs presented in a survey for reasons unrelated to their environmental and/or cost outcomes. This can happen for several reasons, including when people feel uncompromised opposition towards new government programs, lack confidence in the programs' effectiveness, or hold general mistrust towards experts and scientific information presented in the survey. Regardless of its origins, such prejudices, positive or negative, can make preferences expressed in surveys differ from a person's actual values for the environment. Careful development and testing of the survey instrument help alleviate these concerns but may not completely remove them. To address the remaining concerns



about respondents' choices, we use multiple approaches, including econometrically controlling for biased program perceptions and misinterpretation of survey information and examining the sensitivity of our results to alternative estimation data sets that include/exclude potential problem cases, as explained below.

When constructing alternative estimation data sets, we considered two options: data on "*all respondents*" and "*validated respondents*". *All respondents* comprise data from each respondent who completed the choice experiments (1,373 respondents in total). *Validated respondents* include data only from the respondents whose choices we expect most reliably reflect true preferences for the Amazon rainforests (849 respondents in total). To identify *validated respondents*, we used debriefing questions, at the end of the survey, to recognize and drop respondents who: (i) indicated "infinite WTP" by stating that that they would always support increased protection, no matter how high its costs would be (277 respondents); (ii) chose the Status Quo option mostly because "countries in the Amazon region, not U.S. or Canada, should finance Amazon protection" (334 respondents); or (iii) stated that they did not understand that the implementation of increased protection in the Amazon would incur additional expenses to their household (120 respondents). Note that the classifications are not mutually exclusive; each respondent can qualify under more than one criterion.

We use data on *all respondents* for our main estimation results, as those models most fully address the general public. Using those data also produces a more conservative approach to estimating of WTP (more likely to under- than overestimate WTP), as using data on *validated respondents*, a subset of *all respondents*, generates somewhat higher estimates (see Supporting Information), although the differences between results from alternative estimation data sets are not large.

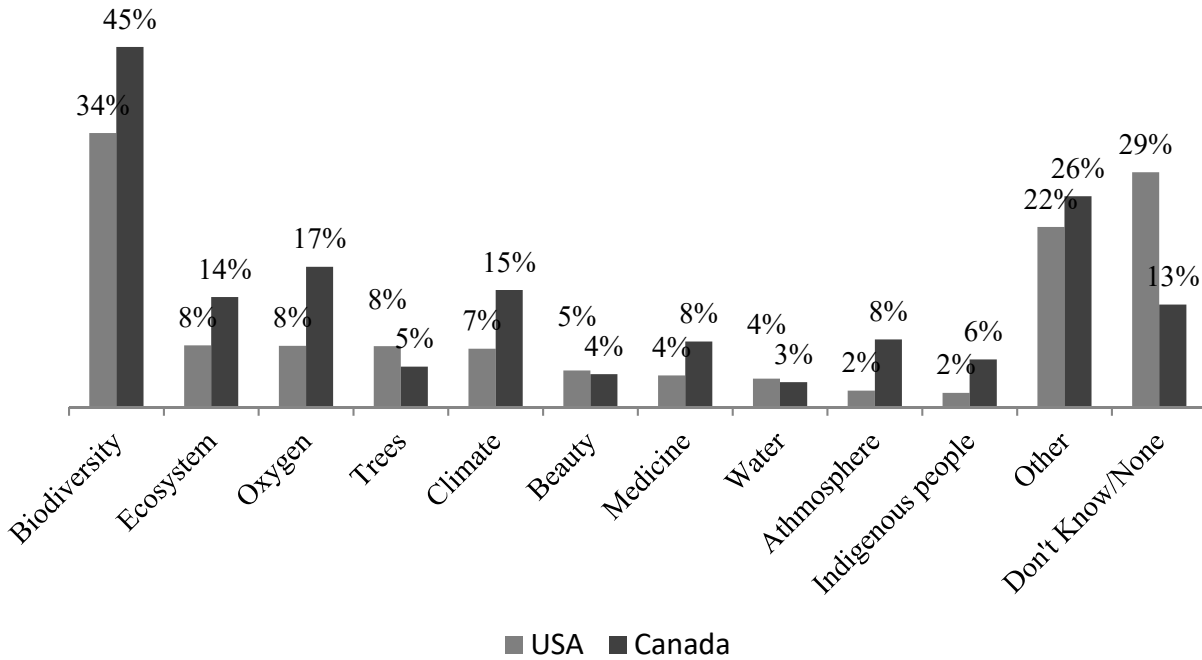
To control for biased program perceptions and misinterpretation of survey information, we used debriefing questions to identify individuals who believe that (i) the government will not consider this survey when making a decision about supporting plans to increase the protection of the Amazon rainforest (557 of *validated respondents*, 913 of *all respondents*); (ii) the benefits from the program, if implemented, will be lower than described in the survey (504 of *validated respondents*, 630 of *all respondents*); (iii) the carbon benefits of the program are important (241 of *validated respondents*, 654 of *all respondents*); and (iv) the benefits from the program, if implemented, will be greater than described in the survey (95 of *validated respondents*, 175 of *all respondents*). We created dummy variables to mark the presence/absence of these perceptions and then interacted those dummies with the Status Quo dummy in the estimation. The purpose of this approach is to help estimate WTP for a program most consistent with the proposed program in the survey instrument. Moreover, by identifying and controlling for respondents to whom the CO<sub>2</sub> benefits from increased forest protection are important, we seek to gather evidence on WTP that is not directly related to CO<sub>2</sub> emission reductions, given our view that using a social cost of carbon would be a more suitable means of estimating carbon-related benefits of Amazon protection.

#### 4. Results

##### 4.1 General Perceptions of the Importance of Rainforests

U.S. and Canadian households consider biodiversity to be the most important aspect of rainforests. Figure 4 shows the distribution of answers when respondents were asked to describe using their own words what aspects of rainforests, if any, they consider important to them. We classified those open-ended descriptions into 11 categories that capture the essential variation in the responses, including biodiversity, ecosystem (on the whole), oxygen (“lungs of the earth”), trees, climate,

(natural) beauty, medicine, water, atmosphere (not specified as oxygen or climate), home to indigenous peoples, and other.



**Figure 5.** Aspects of tropical rainforests that are important to U.S. and Canadian respondents. The histogram shows a categorical classification of open-ended responses to the question, “What aspects of tropical rainforests are important to you, if any?” Each open-ended response could be classified under multiple aspects, so the percentages do not sum to 100. Aspects other than “Other” and “Don’t know/None” are listed in decreasing percentage order according to the U.S. responses.

### *Willingness to Pay for Avoided Forest Loss and Species Threats*

Table 1 lists our primary estimation results using data on *all respondents* and all choice questions. We show results from two nested empirical model specifications (Models 1-2). Model 1 is a mixed logit model that predicts program choices as a product of random coefficients for the program attributes, including a log-normally distributed random coefficient for the program cost and normally distributed random coefficients for forest and species loss. Model 1 incorporates the environmental attributes of the program (avoided forest loss, reduced species threats) as correlated random coefficients to further increase econometric flexibility. As discussed above, this enables examining to what extent people view forest losses and species threats as complements versus substitutes. Besides modeling unobservable preference heterogeneity through random coefficients, Model 1 also incorporates observable heterogeneity in the program cost coefficient (see Equation 2). Model 2 extends from Model 1 by adding controls for biased program perceptions, as explained above. Coefficients for neither the socioeconomic characteristics to model observed heterogeneity nor the variables to control for biased program perceptions are included in Table 1 to save space.

The mean coefficients for avoided forest losses and reduced species threats in Table 1 are measured in dollars and express households' annual WTP, on average, per 1-percentage point of improvement. The program cost coefficient is estimated as a log-normal coefficient in all models, so it needs to be exponentiated to obtain its absolute value.<sup>3</sup> The Status Quo coefficient is also estimated directly in U.S. dollars. It denotes the value respondents attach to maintaining

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<sup>3</sup>A log-normal coefficient takes only positive values so we enter the program cost coefficient as its negative in the WTP estimation routine. In addition, we scale program cost by dividing it by 100 to facilitate estimation. .

**Table 1.** Estimation results from a mixed logit model to predict WTP. The model is estimated using data on all respondents (1,373 respondents), predicting the joint probability of the five choice made by each individual (total 6,865 choices). Note that both models also incorporate observed heterogeneity in the program cost coefficient and control for program misconceptions; see Supporting Information for full estimation results.

| Variable   |           | Model 1: Mixed Logit with Correlated Random Parameters |         |         | Model 2: Model 1 + Controls for Program Misconceptions |         |         |
|--|-----------|--|---------|---------|--|---------|---------|
|  |           | Est.   | t-value | p-value | Est.   | t-value | p-value |
| Avoided forest loss, WTP in \$ per 1 % point     | Mean      | 5.27   | 7.39    | 0.00    | 4.97   | 6.78    | 0.00    |
|  | Std. dev. | 8.67   | 2.95    | 0.00    | 8.57   | 3.03    | 0.00    |
| Reduced species threats, WTP in \$ per 1 % point | Mean      | 3.03   | 2.07    | 0.00    | 3.19   | 2.18    | 0.03    |
|  | Std. dev. | 16.30  | 3.68    | 0.00    | 15.19  | 3.73    | 0.00    |
| L <sub>F,S</sub>                                 |           | -3.72  | -3.95   | 0.00    | -3.47  | -3.63   | 0.00    |
| Program cost                                     | Mean      | -1.06  | -4.14   | 0.00    | -1.13  | -4.45   | 0.00    |
|  | Std. dev. | -0.46  | -4.87   | 0.00    | 0.44   | 5.05    | 0.00    |
| Status Quo, WTP in \$                            |           | -95.81   | -3.75   | 0.00    | -134.96  | -4.70   | 0.00    |
| $\sigma_{SQ+1}$                                  |           | 1.08   | 4.72    | 0.00    | 1.01   | 4.28    | 0.00    |
| Log-likelihood                                   |           | -6382.01   |         |         | -6372.08   |         |         |

versus removing the status quo, regardless of the attributes of new conservation program options, and it could also pick up possible non-linearities in preferences.

The estimation results show patterns consistent with both economic theory and common sense. For example, the mean WTP for avoided forest losses and reduced species threats is positive and statistically significant. This shows that additional WTP for increased protection is positive and sensitive to the scope of benefit achieved. The coefficient for program costs is also consistently statistically significant, indicating that the costlier program options, keeping everything else constant, are less likely to be selected, as one would expect.

Estimated WTP for increased protection in the Amazon ranges between \$4.97 (Model 2) and \$5.27 (Model 1) for avoided forest loss and between \$3.03 (Model 1) and \$3.19 (Model (1) for fewer threatened species, with each estimate denoting WTP per 1-percentage point improvement. The estimation results show considerable preference heterogeneity, including statistically significant random terms for the program cost, avoided forest and species loss coefficients. When examining preference correlation, we find a negative relationship between WTP to avoid forest loss versus species loss. This is seen in the negative covariance coefficient  $L_{F,S}$  estimated at -0.37 in Model 1 and -0.35 in Model 2. Combined with the estimated variance terms, these coefficients show that the correlation between WTP for avoided forest and species loss are -0.38 and -0.39, respectively. This indicates that people's preferences focus more on either forest or species loss, with high WTP for either attribute suggesting a somewhat lower WTP for the other. In other words, those respondents who care particularly strongly about species are not equally strongly concerned about forest area, and vice versa. However, the negative correlation of WTP for different attributes is not very strong.

Variation of WTP estimates between different model results is not large, but which estimate should one use for policy assessment? Although both models estimate similar WTP measures, we prefer Model 2, as its purpose is to control for biased program perceptions to make the estimated WTP match the program described in the survey. Using Model 2 as our preferred model, we therefore estimate that WTP for avoided forest losses and reduced species losses equals \$4.97 (+/- \$1.44) and \$3.19 (+/- \$2.86), respectively, per 1-percentage point improvement, with the numbers in parentheses denoting the 95% confidence interval (Table 1). Note that Model 2 includes a dummy for respondents who indicated that their choices were influenced by the goal of reducing CO<sub>2</sub>

emissions, so these estimates should be interpreted as referring to benefits other than climate change mitigation.

When examining socioeconomic and geographic differences in WTP (estimation results are not shown here but are included in Supporting Information), we found a consistent and statistically significant positive relationship between WTP and income. WTP for avoided forest loss increases by about \$0.38 (per 1-percentage point avoided loss) for each \$10,000 increase in household income (Supporting Information). The corresponding increase is greater, \$1.21, for reduced species threats.

WTP also varies by ethnic background, gender, and other socioeconomic characteristics. Among the socioeconomic variables included, we find that respondents with at most high school education, keeping everything else constant, are willing to pay less than those with more extensive educational background. We also find variation in WTP by the ethnic background of the respondent. For example, Hispanics' WTP to avoid forest loss is not statistically significantly different from that of groups of any other background, but Hispanics stand out as the group with the lowest WTP for reduced species loss. Considering gender differences, we find that women are willing to pay more than men for reduced species threats (\$6.48 more per year for each 1-percentage of threats reduced).

We find regional differences in WTP. Using New England as the baseline, WTP to avoid forest losses is (statistically) significantly greater in Canada but not in the eight other U.S. regions considered. More specifically, Canadians' WTP to avoid forest losses is \$9.65 greater than in New England, per 1-percentage point of avoided forest loss, on average. However, Canadians' WTP for reduced species threats is not statistically significantly different from any of the U.S. regions. We also find, as expected,

that environmentalists are willing to pay more than others, with the WTP of strong environmentalists particularly high.

**Table 2.** Willingness to pay (WTP) by U.S. and Canadian households for the improved protection of the Amazon rainforests, by benefit endpoint. All estimates are expressed per household per year (US\$ 2014), with 95-percent confidence intervals shown in parentheses.

| Benefit endpoint   | WTP household <sup>-1</sup> year <sup>-1</sup> (US\$ 2014) |
|--|--|
| A. Prevent losses projected by 2050 (12% loss of current forest area, 10% of species at high risk of extinction) | \$92<br>(\$60 - \$124)                                     |
| B. Each %-point reduction by 2050 in:  |  |
| (i) Percentage forest area deforested  | \$4.97<br>(\$3.53 - \$6.40)                                |
| (ii) Percentage of all species at high risk of extinction  | \$3.19<br>(\$0.32 - \$6.05)                                |

Note: The 95-percent confidence intervals of the WTP estimates were simulated using 10,000 draws from the estimated vector of WTP coefficients consistent with the estimated covariance matrix (Krinsky and Robb 1986).

Table 2 lists our primary estimates of marginal WTP for each percentage point reduction in forest loss and species threats (as estimated by Model 2 in Table 1). The table uses these estimates of marginal WTP to predict WTP for a large-scale international program to avoid forest losses and species extinction risks projected to take place between now and 2050 despite current forest protection policies (Soares-Filho, Nepstad et al. 2006). Adapting from Soares-Filho (Soares-



Filho, Nepstad et al. 2006), this program corresponds to preventing the loss of 12% of the remaining Amazon rainforest in 2014; equivalent to about 55.7 million hectares (138 million acres); and avoiding 10 percent of species facing a high risk of extinction. We estimated the current area of Amazon (in 2014) forests by deducting from the estimate of forest area in 2003 by Soares-Filho (Soares-Filho, Nepstad et al. 2006) deforestation documented in 2004-2014 (PRODES 2015). The area of avoided rainforest loss this scenario concerns, illustrated in yellow in Fig.2, is about 56 million hectares, or about 0.8 times the size of Texas. We find that households in the U.S. and Canada are willing to pay, on average, \$92 (95-percent confidence interval \$60-\$124), per household per year (Table 2), to help finance the program.

#### *4.2 Aggregate willingness to pay in the U.S. and Canada*

To estimate the total WTP in the U.S. and Canada for the above large-scale program under consideration, we used information from the U.S. Census (Bureau 2016) and Statistics Canada (Canada 2013) to determine that there were about 123.2 million households in the U.S. and about 13.9 million households in Canada in the year of the survey (2014), for a total of 137.1 million households. For Canada, the latest estimate of the number of households is from 2011; we assumed a linear trend in 2006-2011 prevailed when determining the 2014 estimate. Given the total number of households (137.1 million) and using our preferred WTP estimate of \$92 per household per year (95-percent confidence interval \$60-\$124), we estimate an aggregate North American WTP of about \$12.0 billion per year for the program discussed above. This estimate corresponds to avoiding the loss of 12% of the remaining Amazon rainforest in 2014; about 55.7 million hectares (138 million acres). We estimated the current area of Amazon (in 2014) forests by deducting from the estimate of forest area in 2003 by Soares-Filho's (Soares-Filho, Nepstad et al. 2006) deforestation documented in 2004-2014 (PRODES 2015).

Dividing the aggregate estimate of WTP (\$12.0 billion) by the area of forest it concerns (55.7 million hectares), our estimate corresponds to aggregate WTP of about \$225 (95-percent confidence interval \$112-\$337), per hectare of losses avoided, annually. Discounting at 5% and considering a 25-year horizon, the present value of those benefits is \$3,168 per hectare (95-percent confidence interval \$1,580-\$4,756). Assuming a lower discount rate and longer time horizon could be justifiable in the context of evaluation of societal benefits. Doing so would increase the present value estimate of benefits. This estimate corresponds to the economic benefit from the protection of the Amazon rainforest, on average per hectare, for its existence value to the households in the U.S. and Canada.

#### *5. Discussion*

Our results point to a substantial value to the international community from the protection of the Amazon rainforest. When considering marginal improvements in Amazon protection, we find that households in the U.S. and Canada are willing to pay, on average, \$4.97 (+/- \$1.44) per year for each 1-percentage point of avoided forest loss (relative to the baseline projection by 2050). We find slightly lower average WTP for similarly reduced species threats, \$3.19 (+/- \$2.86). When considering WTP for a large-scale program to avoid forest losses and species extinction risks projected to take place between now and 2050 despite current forest protection policies, we find that households in the U.S. and Canada are willing to pay, on average, \$92 (95-percent confidence interval \$60-\$124), per household per year, to help finance the program. Aggregating over all households in the U.S. and Canada, this estimate indicates total WTP of about \$12 billion per year. On a per hectare basis, this estimate suggests that the existence value of the Amazon rainforest is \$3,168 per hectare.

We note that our estimates concern only the U.S. and Canada, thus, providing a partial estimate of the total global value of the Amazon rainforest. These two countries represent about 28% of the total population of the OECD countries (comprising the vast majority of high-income nations) and a much smaller fraction of the global population. If one assumes that our estimates are representative of OECD countries, then the global total intrinsic value of protecting the Amazon rainforest would be approximately \$11,000 per hectare. In addition, previous research suggests that preservation of rainforests in developing countries is valued also by their domestic populations (Vincent, Carson et al. 2014), adding yet another source of benefits to consider when evaluating Amazon conservation options.

To estimate the total economic value of Amazon rainforest protection, several other categories of benefits, domestic and international, also need to be considered, including global climate benefits from reduced carbon emissions. Our intrinsic-value estimate for the U.S. and Canada specifically sets aside carbon benefits from avoided deforestation in the Amazon (Supporting Information). Climate benefits are best assessed using carbon emission damage estimates (the social cost of carbon) from global integrated assessment models (Tol 2005; Council 2013), multiplied by net amounts of avoided carbon emissions resulting from Amazon protection programs, about 130 t C ha<sup>-1</sup> (Song, Huang et al. 2015). Using a recent (conservative) estimate of the social cost of carbon, \$100 t<sup>-1</sup>C (Council 2013), average expected carbon benefits of avoided rainforest losses in the Amazon are \$13,000 per hectare. Therefore, our results suggest that global intrinsic values, likely adding up to some \$11,000 per hectare when accounted for in countries beyond just the U.S. and Canada, could be of comparable magnitude to carbon benefits from the protection of the Amazon rainforest.

A commonly raised concern with using survey-based methods necessary to measure non-use values (Freeman III, Herriges et al. 2014) is that people's stated choices may differ from actual decisions, although studies examining this issue typically find only small, if any, differences (Carson, Flores et al. 1996; Taylor, Morrison et al. 2010; Bernheim, Bjorkegren et al. 2013). Besides adhering to general guidelines for robust survey design, testing, and implementation (Arrow, Solow et al. 1993; Dillman 2000; Louviere, Hensher et al. 2000; Bateman and Transport 2002; Hensher, Rose et al. 2015), we addressed these concerns by statistically controlling for confounded perceptions and interpretations of the survey; considering various estimation approaches; and dropping problem cases from the analysis as a robustness check. When examining a broad range of alternative estimation approaches, we found that they produce higher estimates of WTP than the preferred estimates presented here.

Our findings lend further support to international efforts to reduce deforestation in the Amazon and could serve to inform benefit-cost assessments of programs to protect the Amazon rainforest and to guide its land use policies. They also show that focusing on only the carbon benefits from Amazon conservation is likely to considerably underestimate its total economic value.

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