**Prairie Wetland Loss is Associated with Substantial Economic Costs to Society**

**Abstract**

1. **Introduction**

The world has lost more than 50 percent of its original wetland area at a faster rate than other ecosystems in the world (Millennium Ecosystem Assessment, 2005; Mitsch and Gosselink, 2007). Canada has approximately 1.5 million km2 of wetlands which is about 28% of total wetlands in the world (Reimer, 2009). However, it has been estimated that up 20 million acres of wetlands have been loss since 1800 in Canada (Environment Canada, 2009), mainly through agricultural development (Badiou et al. 2011; Watmough and Schmoll, 2007). Other drivers of wetland loss in Canada include urban development, transportation, resource extraction and mining, recreational properties. About 40 to 71% of wetland acreage has been lost in the Canadian Prairies since European settlements (Kraus, 2019) at an annual rate of about 0.53% (Watmough and Schmoll, 2007).

Wetlands provide important ecosystem services to society but understanding the economic benefits of these services remain a challenge. Some of the ecosystem services of wetlands are carbon sequestration, recreation, tourism, human and livestock foods, habitat to support diverse biotic communities (Davies et al. 2008; Badiou et al. 2011; Gleason et al. 2011; De Groot et al. 2012), regulating and recharging aquifers (Dixon and Wood 2003) and removal of excess nutrients and pesticides from agricultural lands (Vymazal 2017). The economic value of ecosystem services has been estimated in several regions of the world, including Nakivubo wetlands in Uganda (Schuijt, 2002), Muthurajawela wetland in Sri Lanka (Emerson and Kekulandala, 2003); flood plains of the Elbe river in Germany (Meyerhoff and Dehnhardt, 2004); and Upper Paraná River floodplain in Brazil (Carvalho, 2007). In Canada, the economic value of wetland ecosystem services has been estimated, but the empirical evidence is limited (Lloyd-Smith, et al., 2020). Need for policy-ready valuation tools as wetlands continue to be degraded.

The purpose of this study is to develop and apply a Canadian wetland economic valuation model using recent advances in meta-analysis modeling of environmental valuation data. To do so, we extend the modeling framework of Moeltner et al. (2019) to include Canadian studies and estimate a Canada-US wetland valuation model. The total number of observations for the combined dataset is 40 from 20 studies (13 and 7 US and Canadian observations, respectively) published between 1991 and 2020. Five studies in both US and Canadian studies produced multiple observations. All the willingness to pay to conserve freshwater wetland values per household per year were converted to 2017 Canadian dollars (Can$).

For the combined dataset, the chosen model (model 1: which had log WTP as the dependent variable and log baseline acreage and log quantity acre change as main independent variables) provided a better fit to the data compared to model (2: which had log WTP – Log quantity change as the dependent variable and log baseline acreage as the main independent variable). Again, Model 1 is consistent with the sensitivity to scope condition, which shows that a 1% increase in wetland acreage change would cause about 0.26% increase in willingness to pay to conserve the wetland acreage change. Moreover, it satisfies the law of diminishing marginal utility assumption which is an important condition in utility theory; a 1% increase in the baseline acreage would cause about 0.04% decrease in WTP. Also, the meta-regression transfer error when predicting Canadian wetland values with model 1 (in the case of combined US and Canada data) is about 59% and 10% less than using the US only dataset, for the root mean square error (RMSE) and mean absolute deviation error (MAD), respectively. Moreover, the mean value errors from the US-Canada data were about 28% and 58% higher (for the root mean squared error and mean absolute deviation error, respectively) than for the US only data model.

The policy application of our estimated model to value wetlands lost between 2001 and 2011 in the Canadian Prairie Habitat Joint Venture landscapes, shows that the mean willingness to pay to restore wetlands are $510/household/year, $115/household/year, and $279/household/year, in Saskatchewan, Alberta, and Manitoba, respectively. Also, there is a positive relationship between willingness to pay to restore wetlands loss and wetland acreage.

We contribute to policy debates on the need to provide reliable benefit estimates for wetland conservation in Canada. Currently, mean value unit value transfer has been the most popular approach to the valuation of wetlands in Canada, where $/ha is derived from prior research to value wetlands in new settings (Belcher et al. 2001; Dupras and Alam, 2015; Dupras et al. 2015). Although mean value unit value transfer is relatively inexpensive and faster to implement, it has a mean transfer error of about 45% (Rosenberger and Loomis, 2017) which is lower than the transfer error of the meta-analysis benefit function at 36% (Rosenberger and Loomis, 2017). Benefit estimates are used in benefit-cost calculations to justify the need to fund projects. Besides contributing to providing reliable benefit transfer values for wetland conservation policy in Canadian Prairies, our paper supports the observation in Johnson and Thomasin (2010) that, relying only on US wetland valuation studies to infer wetland values in Canada is not a best practice. Therefore, the paper agrees with the suggestion of Johnson and Thomasin (2010) for policymakers to adjust benefit transfer values, especially from US original studies to Canadian policy contexts to reduce transfer errors. Again, our paper will improve on the application of benefit transfer of wetland values in Canada, by providing the key factors or variables practitioners could use to control for differences between policy and original study sites.

This paper is structured into five sections. Section two compares and contrasts the few wetland valuations studies that have been conducted in Canada; it also provides background information on the Prairie Habitat Joint Venture landscapes in the Canadian Prairies, which is the policy application area for our proposed meta-transfer function. The data that will be used to estimate our model, and its descriptive statistics are discussed in section 3. The methodology of the study, including meta-data and meta-analysis econometric model, is described in section four. Next, the results of our estimated model, the in-sample meta-function transfer errors, and the policy application of the estimated Bayesian model to the valuation of wetlands in the Canadian Prairies (PHJV landscapes) are reported in section five. We discuss the model results in section 6. Lastly, the conclusion of the study and the limitations of the study, and suggestions for future research are provided in section 7.

1. **Stated Preference Wetland Valuation Studies in Canada**

In many cases, environmental goods and services, such as wetland ecosystem services, have non-use values that are not observed in markets; this attribute makes the valuation of environmental amenities using traditional revealed preference or other market-based valuation methods impossible. Stated preference (SP) provides the only known method to estimate non-use values that are not observed in market conditions (Johnson et al. 2017). Moreover, they provide a means to estimate comparable and welfare consistent values from quantity and/or quality changes associated with environmental goods, such as wetland acreage changes (Vedogbeton and Johnson, 2020). Welfare consistent values from different multiple studies would allow for commodity and welfare consistent meta-regression models.

We searched for Canadian wetland valuation studies from a number of sources including i) existing wetland meta-analyses, ii) the Environmental Valuation Reference Inventory (EVRI), iii) key word searches of environmental and resource economics journals as well as online databases such as EconLit and Google Scholar, iv) as well as a recent comprehensive review of environmental valuation studies in Canada (Lloyd-Smith, 2020).

We identified 8 wetland valuation studies in Canada that used the stated preference method to estimate people’s willingness to pay to retain or restore wetlands (Tkac, 2002; Pattison et al. 2011; Lantz et al. 2013; Trenholm et al. 2013, Dias and Belcher, 2015; Vossler et al. 2020; Pattison et al. 2011; Rudd et al 2016; He et al. 2017). We retained studies that had information on baseline wetland acreage, the extent of wetland area changes and methodological attributes. If the wetland acreage change information was absent, the study must provide enough information to enable us to obtain it from secondary sources. For instance, we excluded Dias and Belcher (2015) from this study because it did not include enough information on baseline wetland acreage and extent of wetland change.

Some of the seven Canadian studies estimated multiple willingness to pay estimates for different wetland conservation scenarios. For example, Pattison et al (2011) considered four different wetland restoration scenarios at various percentages (80%, 83%, 89%, 100%) of 1968 wetland acreage and one wetland retention scenario. In total, we obtained 17 value observations for the Canadian meta-analysis dataset.

The contingent valuation method was used by 6 of the 7 studies to value wetlands (Tkac et al. 2002; Pattison et al. 2011; Lantz et al. 2013; Trenholm et al. 2013; He et al. 2017; Vossler et al. 2020). Het et al (2017) compared the accuracy and effectiveness of contingent valuation and choice experiment in valuing wetlands. Two studies (Rudd et al. 2016; He et al. 2017) used a choice experiment to value wetlands. Again, except Tkac (2002), all the studies were published in peer-reviewed journals. Moreover, the studies were different with regards to the sample sizes, location of the study, and data collection year (Table 1).

**Table 1. Comparison of Wetland Valuation Studies in Canada**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Study** | **Prov** | **Data Collection Year** | **Sample Size** | **Restoration/Retention** | **Valuation Format** | **Ecosystem Service** | **Ch. Acres** | **WTP** |
| Vossler et al. 2020 | QC | 2014 | 1048 | Retention | CV (ref) | Reg | 10,0295,714 | 871 |
| He et al. (2017) | QC | 2013 | 930 | Restoration | CE (An Cont) | Reg & Prov | 988,421 | 512 |
| He et al. (2017) | QC | 2013 | 858 | Restoration | CV (An Cont) | Reg & Prov | 988,421 | 498 |
| Rudd et al (2016) | ON | 2011 | 301 | Restoration | CE (An Cont) | Reg & Prov | 106,253 | 12.6 |
| Rudd et al (2016) | ON | 2011 | 301 | Restoration | CE (An Cont) | Reg & Prov | 308,875 | 25.5 |
| Dias & Belcher (2015) | SK | 2010 | 250 | Retention (riparian area) | CE(One Time) | Reg & Prov | - | 72.5 |
| Dias & Belcher (2015) | SK | 2010 | 250 | Retention (wildlife habitat) | CE(One Time) | Prov | - | 64.5 |
| Dias & Belcher (2015) | SK | 2010 | 250 | Retention (water quality) | CE(One Time) | Reg | - | 117.2 |
| Lantz et al. (2013) | ON | 2009 | 1407 | Retention | CV (An Cont) | Reg & Prov | 3000 | 498 |
| Lantz et al. (2013) | ON | 2009 | 1407 | Retention & 1000acres restoration | CV (An Cont) | Reg & Prov | 4000 | 492 |
| Trenholm et al. (2013) | NB | 2007 | 299 | Retention (30 m riparian buffer) | CV (An Cont) | Reg, Cul & Prov | 5884 | 36.9 |
| Trenholm et al. (2013) | NB | 2007 | 299 | Retention (60 m riparian buffer) | CV (An Cont) | Reg, Cul & Prov | 11300 | 22.7 |
| Trenholm et al. (2013) | NB | 2007 | 270 | Retention (30 m riparian buffer) | CV (An Cont) | Reg, Cul & Prov | 7408 | 28.9 |
| Trenholm et al. (2013) | NB | 2007 | 256 | Retention (60 m riparian buffer) | CV (An Cont) | Reg, Cul & Prov | 14318 | 17.2 |
| Pattisson et al. (2011) | MB | 2008 | 1980 | Retention and Restoration | CV (An Cont) | Reg & Prov | 94918 | 337 |
| Pattisson et al. (2011) | MB | 2008 | 1980 | Restoration (80% of 1968 WAL) | CV (An Cont) | Reg & Prov | 135598 | 345 |
| Pattisson et al. (2011) | MB | 2008 | 1980 | Restoration (83% of 1968 WAL) | CV (An Cont) | Reg & Prov | 176277 | 352 |
| Pattisson et al. (2011) | MB | 2008 | 1980 | Restoration (89% of 1968 WAL) | CV (An Cont) | Reg & Prov | 257636 | 367 |
| Pattisson et al. (2011) | MB | 2008 | 1980 | Restoration (100% of 1968 WAL) | CV (An Cont) | Reg & Prov | 406793 | 398 |
| Tkac (2002) | ON | 2001 | 339 | Retention | CV (An Cont) | Reg & Prov | 4200 | 196 |

Notes:

Prov: Province where study was conducted; QC: Quebec; ON: Ontario; NB: New Brunswick; MB: Manitoba

WAL: Wetland Acreage Area

Valuation Format: CV: Contingent valuation; Ce: Choice experiment; ref: referendum; An cont: Annual contribution, one time: one time contribution

Eco Serv: Ecosystem service affected; Reg: regulation services regulate environmental processes such as climate change, water quality and flood control; Prov: provision services

provide food and raw materials to society, such as fishing and hunting; Cul: cultural services provide existence value of wetlands (non-extractive recreation) to society.

Ch. Acres: Difference between post improvement wetland acres and baseline wetland acres

WTP: willingness to pay to retain or restore wetlands per household per year in 2017 CAD$

**3.1. The Canada-United States Wetland Metadata**

Meta-regression involves the application of regression analysis to a pool of comparable empirical estimates (Nelson and Kennedy 2009; Richardson et al. 2015). The first generation of wetland valuation meta-analyses included hundreds of studies from around the world and specified a dollars per hectare value estimate as the dependent variable (Ghermandi et al. 2010; Brander, Florax, and Vermaat 2006; Woodward and Wui 2001; Brouwer et al. 1999).

The huge heterogeneity in value estimates across the world and valuation methods raises some concerns with these early applications. Another concern is with the use of dollar per hectare values as the dependent variable which may not be appropriate as social values are not linked to a specific surface area of a wetland. There are further concerns regarding the commensurability of including value estimates from many different valuation methods such as replacement cost and stated preference as well as studies from such disparate places as the United States and Cameroon which would violate the welfare consistency condition (Nelson and Kennedy 2009; Johnston and Rosenberger 2010; Rosenberger 2010; Boyle and Wooldridge 2018); another issue is the commodity inconsistency problem, which occurs when the commodity being valued is not the same across studies used for the meta-regression (Vedogbeton and Johnson, 2020). A final concern is that these models did not use frameworks that are consistent with economic theory (Moeltner et al., 2019) and key empirical conditions: commodity consistency, welfare consistency, sensitivity to scope and adding up condition (Kling and Phaneuf, 2018; Newbold and Walsh, 2018; Moeltner, 2019). Sensitivity to scope states that willingness to pay to conserve wetlands should increase with the change in wetland acres, while the adding up condition specifies that the WTP to achieve a target wetland acreage should be equal to or less than the sum of incremental WTP estimates from achieving the same wetland acreage target but in sequential steps (Kling and Phaneuf, 2018; Moeltner, 2019).

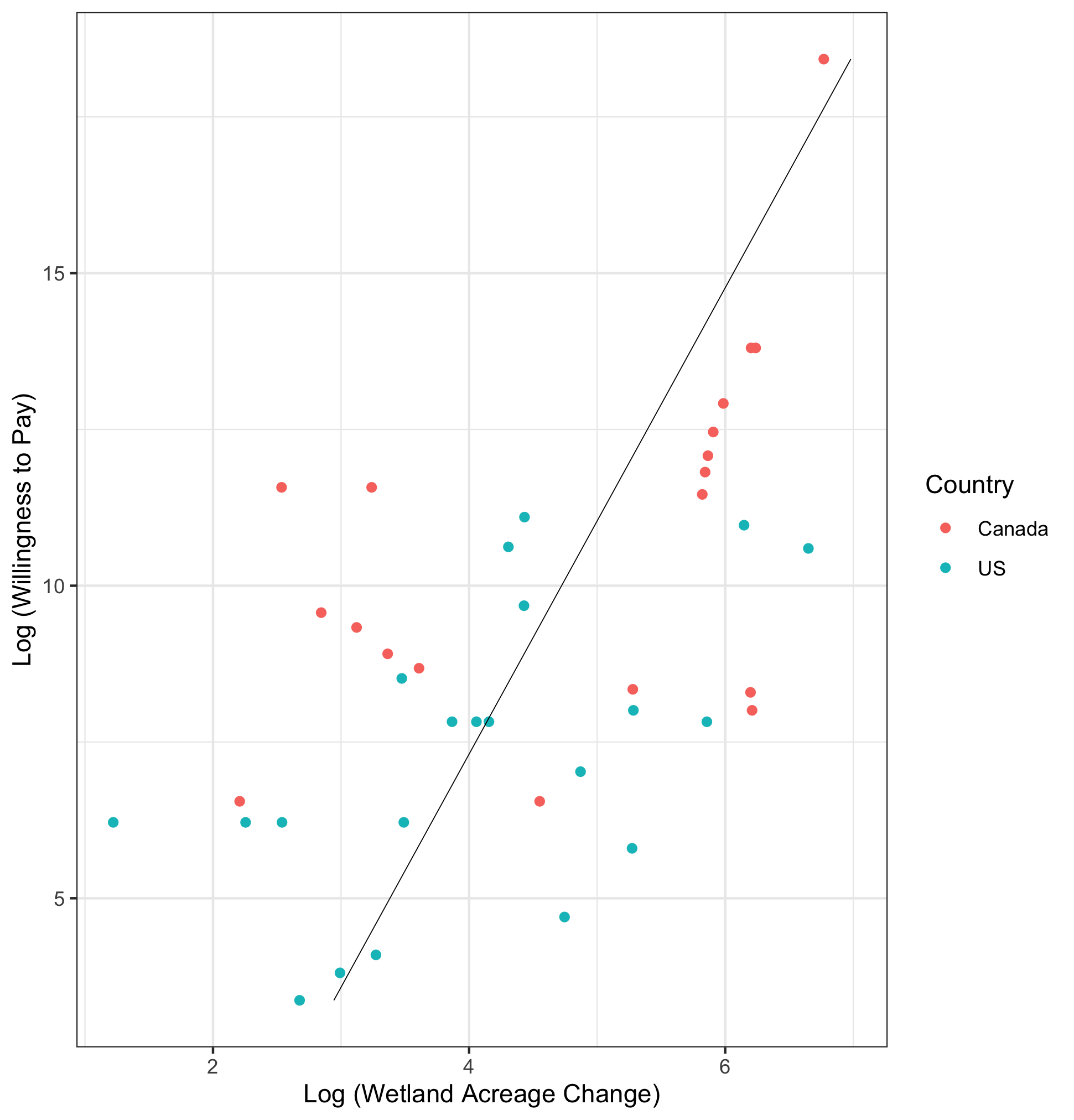
We satisfy the welfare consistency condition by collecting meta-data that used stated preference method to estimate the willingness to pay by households to conserve wetlands in US and Canada (Johnson and Bauer, 2019). For this study, we augment the data used in Moeltner et al. (2019) with 2 new US studies and 7 new Canadian studies. From the 7 Canadian studies, we were able to obtain 17 observations and 23 observations from the US studies. Detailed descriptions of the US and Canadian studies that we used in this study are provided in Tables A1 and A2, respectively (in appendix 1). We focused on freshwater wetlands since the Canadian wetland stated preference studies were conducted on freshwater wetlands. Also, to ensure that our model is compliant with the commodity consistency principle to produce valid and credible parameter estimates (Vedogbeton and Johnson, 2020) we included a dummy variable which equals 1 if the WTP is for specific ecosystem endpoints, including provisioning, regulating, and cultural ecosystem services. Further, following Kling and Phaneuf (2018) and Moeltner et al. (2019) we estimated our model with functional forms that have the best chance of satisfying the sensitivity to scope and adding up conditions.

**3.1.1. Descriptive Statistics Results of Study Variables**

We grouped the variables obtained from these studies into context-specific and moderator variables. The context-specific variables provide socio-economic and wetland attributes that could help context to the explanation of the willingness to pay values to conserve wetlands. The moderator variables describe how the study was conducted, including the valuation method that was employed to elicit willingness to pay responses and the payment characteristics. All the monetary variables from both the US and Canada data studies are converted to 2017 CAD$ per household per year.

The mean willingness to pay for wetland restoration or conservation for the combined US and Canada data is $197 with a standard deviation of $3.39. The mean willingness to pay (wtp) for Canadian only studies is $56 with a standard deviation of $1.8. The mean wtp for the Canadian studies is about $170 less than the US only studies (which is provided as Table A0 in the appendix); this show that, on average, US citizens in this study, could be willing to pay more for wetland conservation than Canadian citizens; despite the observation that the mean household income of the Canadian studies is higher than for the US only studies. The Canadian studies on average have much smaller changes in wetland areas (1,457 acres) compared US studies (75,969 acres, Table A0 in appendix). Also, overall, there seems to be a positive relation between the WTP and wetland acres; this would suggest that respondents are more likely or will be willing to pay more to conserve larger wetland acres, Figure 2 provides an overview of the relationship between the log of willingness to pay and the log of the difference between the baseline and policy wetland acreage (log acreage change).

**Figure 2. Relationship between the log of WTP and Log Wetland Acreage Change**



Moreover, proportionally, less Canadian studies (30%), on the average, informed respondents that the provisioning ecosystem service of wetlands under evaluation was affected than combined US-Canada studies (20%). This is also true for regulating ecosystem service which was 52% in the case of Canadian studies and 63% for the combined US-Canada studies. However, regarding cultural ecosystem service, on average more respondents (70%) informed respondents that the service was under evaluation than the combined US-Canada studies (48%). Also, more wetlands in the Canadian studies were located on forested landscapes than the combined Us-Canada studies (48%). Less studies in the Canada (39%) were conducted at the sub-provincial level compared to 45% in the case of US-Canada studies.

In terms of the moderator variables, about two percentage more studies in the Canadian studies used employed choice experiment value wetlands than in the combined US-Canadian studies. Also, more studies in Canada used voluntary contribution payment mechanism and lump sum to elicit willingness to pay responses (39% in both cases) than in the US studies (28% and 23%, respectively). Proportionally, more studies Canadian studies were published in peer reviewed journals (26%) compared to the US studies (23%). The summary statistics are provided in Table 2.

The summary statistic differences of the variables in the US and Canadian data suggest that using US only studies on willing to pay for wetland conservation by households to infer similar values in Canada through a benefit transfer approach, might produce unreliable estimates. In particular, wetland changes, on the average, in the Canadian studies are significantly smaller compared to the US studies which might mean that Canada only studies may not be appropriate in valuing big changes in wetland acreage. Therefore, it may be useful to combine US and Canadian studies to infer values of wetland acreage changes in Canada.

**Table 2. Summary statistics of the variables included in the Meta-regression**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  | **Canada-US Observation** | | **Canada Only Observation** | |
| **Model Variables** |  | **Mean**  **(SD)** | **Min**  **(Max)** | **Mean**  **(SD)** | **Min**  **(Max)** |
| Dependent Variable | Log (WTP in Can$2017) | 4.44 | 1.22 | 4.03 | 1.22 |
|  |  | 1.47 | 6.77 | 1.36 | 6.65 |
| **Context-specific** |  |  |  |  |  |
| Acreage change | Log (Difference between post improvement wetland acres and baseline wetland acres) | 8.96 | 3.37 | 7.28 | 3.37 |
|  |  | 3.12 | 18.42 | 2.25 | 11.10 |
| Baseline Acres | Log (Baseline wetland acres) | 9.51 | 0.00 | 9.18 | 0.00 |
|  |  | 4.31 | 17.21 | 2.43 | 12.30 |
| Income | Log (target population income in Canadian $) | 11.60 | 11.24 | 11.73 | 11.24 |
|  |  | 0.27 | 12.29 | 0.29 | 12.29 |
| Cultural | 1 = cultural function affected | 0.48 | 0.00 | 0.70 | 0.00 |
|  |  | 0.51 | 1.00 | 0.47 | 1.00 |
| Forest | 1 = forested wetland | 0.48 | 0.00 | 0.52 | 0.00 |
|  |  | 0.51 | 1.00 | 0.51 | 1.00 |
| US | 1=study country =US | 0.58 | 0.00 |  |  |
|  |  | 0.50 | 1.00 |  |  |
| Local | 1 = target population at sub-state level | 0.45 | 0.00 | 0.39 | 0.00 |
|  |  | 0.50 | 1.00 | 0.50 | 1.00 |
| Provision | 1 = provisioning function affected | 0.38 | 0.00 | 0.30 | 0.00 |
|  |  | 0.49 | 1.00 | 0.47 | 1.00 |
| regulation | 1 = regulating function affected | 0.63 | 0.00 | 0.52 | 0.00 |
|  |  | 0.49 | 1.00 | 0.51 | 1.00 |
| Year | Log (year of data collection - oldest year +1) | 2.63 | 0.00 | 1.71 | 0.00 |
|  |  | 1.29 | 4.14 | 0.93 | 3.26 |
| **Moderator** |  |  |  |  |  |
| CE | 1=elicitation method=choice experiment | 0.20 | 0.00 | 0.22 | 0.00 |
|  |  | 0.41 | 1.00 | 0.42 | 1.00 |
| Lumpsum | 1=payment frequency=lump sum (single payment) | 0.23 | 0.00 | 0.39 | 0.00 |
|  |  | 0.42 | 1.00 | 0.50 | 1.00 |
| Voluntary | 1=payment mechanism=voluntary contribution | 0.28 | 0.00 | 0.39 | 0.00 |
|  |  | 0.45 | 1.00 | 0.50 | 1.00 |
| Peer Review | 1=study was not peer-reviewed | 0.23 | 0.00 | 0.26 | 0.00 |
|  |  | 0.42 | 1.00 | 0.45 | 1.00 |

SD denotes standard deviation; Min denotes minimum; Max denotes maximum.

**4.1. Meta-Regression Econometric Model**

We used a random intercept meta-regression model to explain the variation in the willingness to pay to conserve wetlands in the US and Canada, because 5 (out of 13) and 5 (out of 7) US and Canadian studies, respectively, reported multiple observations (Nelson and Kennedy, 2008). The model is given as equation 1:

where: denotes the willingness to pay to conserve wetlands; is a vector of explanatory variables, including the baseline wetland acreage and quantity acreage change; is model parameters to be estimated; the stochastic error term for the ith observation, which is assumed to be normally distributed with mean 0 and a constant variance (: it accounts for variation in wetland values due to differences between individual observations; stochastic error term for the ith study, which is assumed to be normally distributed with mean 0 and a variance (: it accounts for variation in wetland values due to differences between study observations; is functional form.

We will test if the random intercept model is appropriate for our study or the null hypothesis that (in equation 1) is significantly different from zero using a likelihood ratio test (Dias and Belcher, 2015) with the “ranova” function in the “lmer” package in R statistical software; we will use an ordinary least squares if the null hypothesis is rejected. Also, we will use a heteroscedastic consistent estimator for equation 1 if we reject the null hypothesis that the observation level model error is homoscedastic or has constant variance; a non-constant error variance can affect the reliability of estimated standard errors of model parameters and, therefore, the credibility of model inferences. Again, even though multicollinearity will not affect the reliability of estimated standard errors of model parameters, they could inflate them; thus, variables that have variance inflation factors (VIF) of more than 10 will not be used to estimate the model. Variables with high VIF’s could be sources of multicollinearity in the model.

The choice of functional form for equation 1 will be instrumental in determining if the estimated model will conform to economic theory and/or whether the meta-regression value function can be useful for benefit transfer (Kling and Phaneuf, 2018; Moeltner, 2019). Our chosen functional form must be consistent to two theoretical constructs of sensitivity to scope and adding up, which are important in assessing the validity of benefit transfer applications (Kling and Phaneuf, 2018; Newbold and Walsh, 2018; Moeltner, 2019). However, according to Kling and Phaneuf (2018), the validity of sensibility scope could provide a better judgement of the usefulness of the meta-regression to benefit transfer compared to the adding up criteria; since it is “a conceptually difficult test to implement” and empirical tests conducted to date using real goods payments and private goods fail to show consistency with adding up (Kling and Phaneuf, 2018). Following, the above, we will estimate 3 models and choose the one that satisfies sensitivity to scope, closest to satisfying the adding up condition and consistent to the assumptions of utility theory, in particular, diminishing marginal utility that is associated with a wetland quality acreage change.

The first model, model 1, will use a log-log linear functional form which is given as equation 2:

where: is the natural logarithm of baseline wetland acreage for the ith observation and is the associated parameter to be estimated; is the natural logarithm of the quantity acreage change and is the associated parameter to be estimated; all the other variables and have already been defined in equation 1.

The coefficient of the log of baseline wetland acres, if negative, shows a diminishing marginal utility of additional improvements (or wetland acreage increase) which is expected from economic utility theory (Kling and Phaneuf, 2018). Moeltner et al. (2019), estimated this functional form in a meta-regression study and found severe departure from the adding up condition.

Like equation 2, the second model, model 2, will also follow a log-log functional form. However, unlike in equation 2, the dependent variable is the log of willingness to pay minus the log of quantity acreage change. Also, the independent variables include the log of baseline wetland acreage (but not the log wetland acres change).

The transformation in the dependent variable is necessary to convert the willingness to pay values into the same units because of the differing values in the quantity acreage change (Kling and Phaneuf, 2018). Moeltner et al. (2019) has estimated a meta-regression model with this function form and could not find serious violation of the adding up condition.

Lastly, for the third model (model 3) we will use a non-linear functional form (equation 3) that is, by definition, adding up compliant (Newbold and Walsh, 2018; Moeltner et al. 2019; Moeltner, 2019). This model is specified as equation 4. More details of this functional form including its derivation can be found in Moeltner (2019).

where q0 and q1 are baseline and target (policy) acreage and is the corresponding quantity parameter; all the other variables are already defined in equation 2.

The sensitivity to scope condition and the law of diminishing marginal utility are satisfied if coefficients of the log of quantity acreage change and the log of baseline acreage are positive and negative, respectively (Kling and Phaneuf (2018). Further, we will follow Moeltner et al. (2019) to test the validity of the adding up condition for the estimated models. Specifically, we will apply the estimated models to four wetland scenarios, namely a) wetlands located in forested landscapes and valuation study was at the sub-province or state level, b) wetlands located in forested landscape and valuation study was at the province or state level, c) wetlands located in non-forested landscape and valuation study was at the state level, and d) wetlands located in non-forested and valuation study was at the sub-province or state level. For each scenario, we calculated a) the total WTP to pay to conserve wetland given a hypothetical change from baseline (10000acres) to new state (10050acres), b) the incremental willing to pay to conserve wetlands from baseline (10000acres) to new state (10030acres), and c) incremental willing to pay to conserve wetlands from baseline (10030acres) to new state (10050acres). We defined Lnyear as (log (2017-1991 +1)), lumpsum = 0 (so that we can interpret WTP in per year units), Lninc was defined at the sample mean, volunt =1, choice experiment = 1, peer review = 1; the variables are described in Table 2.

* 1. **Meta-Regression Results**

The random coefficient model is appropriate for the models that were estimated with the combined US-Canada data, because the null hypothesis that the observation level random error component of equation is significantly different from zero is rejected in all the estimated models (the likelihood ratio test statistics are all significant at the1 percent level (Table 4). However, model 1 is the best fit to our study data; it has the lowest Akaike Information Criteria value of 108 compared to the model 2 (125). The results of model 2 are provided in Table A3 in appendix. However, we chose the version of model 1 where the coefficient of log acreage change was significant (Model 1b in Table 4); the results of that model are reported in this section.

The model has an adjusted coefficient of determination of 0.92; it shows that about 92% of the variation in the dependent variable is explained by the model. This is a very high adjusted R square; but Vedogbeton and Johnson (2020) also estimated an adjusted R square of about 95% in their estimated meta-regression model. The null hypothesis of constant variance of the model error term (homoscedasticity) was not rejected even at the 10% level. The sensitivity of scope criteria is not rejected in this model because the coefficient (0.26) of the log (quantity acreage change) is positive and significant at the 5% level; it means that a 1% increase in acreage change would cause a 0.26% increase in willingness to pay to conserve the acreage change. Also, the model upheld the law of diminishing marginal utility in wetland acreage, because of the negative coefficient of the log of baseline acreage (-0.04) but not significant at the 10% level; this estimated coefficient means that a 1 percent increase in base line wetland acres will cause a decrease of 0.14% in wetland values.

**Table 4. Model 1 Meta-regression results (US-Canada Combined Data)**

|  |  |  |  |
| --- | --- | --- | --- |
|  | | | |
|  |  | | |
|  | **Model 1** | **Model 1b** | **Model 1c** | |
|  | | | |
| Dependent Variable: Log (WTP) |  |  |  | |
| **Context-specific** |  |  |  | |
| Log (Acreage) | 0.001 (0.067) | -0.042 (0.071) | -0.092 (0.079) | |
| Log (Acreage Change) | 0.181\*\* (0.089) | 0.263\*\* (0.124) | 0.190 (0.144) | |
| Log (Year) |  |  | -0.250 (0.703) | |
| Local |  |  | 1.171 (1.185) | |
| US |  | 0.192 (0.873) | -0.956 (1.809) | |
| Provision |  | -1.196\* (0.620) | -2.030\* (1.135) | |
| Regulation |  | 0.796 (0.668) | 0.177 (1.240) | |
| Cultural |  | -0.609 (0.746) | -0.413 (1.283) | |
| Log (Income) |  |  | 1.679 (2.418) | |
| Forest |  |  | 1.352\*\*\* (0.359) | |
| **Moderator** |  |  |  | |
| Voluntary |  | -0.094 (0.731) | 0.300 (1.188) | |
| Lumpsum |  | 0.669 (0.807) | -1.162 (1.456) | |
| Choice Experiment |  |  | -0.067 (0.433) | |
| Peer Review |  |  | 2.086 (1.388) | |
| Constant | 3.024\*\*\* (0.853) | 2.785\* (1.466) | -15.034 (28.439) | |
| N | 40 | 40 | 40 | |
| Log Likelihood | -52.451 | -46.212 | -37.147 | |
| Akaike Inf. Crit. | 114.902 | 114.425 | 108.295 | |
| Likelihood Ratio Test | 30.65\*\*\* | 26.78\*\*\* | 9.98\*\* | |
| Adjusted R-square | 0.91 | 0.92 | 0.98 | |

\*\*\*, \*\*, \* denotes significance at 1%, 5% and 10%, respectively; WTP denotes willingness to pay.

The random coefficient model was appropriate for the US data only model (Table 5). Model 1 provided a better fit to the US only data with a lower Akaike Information Criteria of 66.75 compared to that of model 2 (69.05); the results of model 2 are provided in Table A4 in the appendix. Moreover, we settled on a version of Model 1 which had a significant coefficient of log acreage change and a negative coefficient of log acreage (Model 1b in Table 5).

The model explained about 87% of the variation in the dependent variable (the log WTP). Also, the null hypothesis of homoscedasticity of the error term was not rejected even at the 10% level. The results showed that a 1% increase in the acreage change will cause about 0.37% increase in willingness to pay to conserve that acreage change; the positive slope of log acreage change means the sensitivity to scope condition is satisfied by this model. Again, the coefficient of the log of acreage of -0.03 suggest that the law of diminishing marginal returns is validated in this model; it means that a 1% increase in the acreage of wetland will cause about 0.02% decrease in willingness to pay to conserve the wetland. The adding up condition was not satisfied all estimated models (1 and 2) for both the combined US-Canada data and the US only data. The adding up test results are provided in Table A5 in the appendix.

**Table 5.** **Model 2 Metal-regression results (US Data)**

|  |  |  |  |
| --- | --- | --- | --- |
|  | | | |
|  | **Model 1** | **Model 1b** | **Model 1c** |
|  | | | |
| Dependent Variable: Log (WTP) |  |  |  |
| **Context-specific** |  |  |  |
| Log (Acreage) | -0.048 (0.097) | -0.028 (0.112) | -0.178\* (0.097) |
| Log (Acreage Change) | 0.257 (0.163) | 0.369\* (0.194) | 0.166 (0.267) |
| Log (Year) |  |  | -0.137 (1.220) |
| Local |  |  | 1.399 (2.127) |
| Provision |  | -0.916 (0.833) | 0.031 (1.767) |
| Regulation |  | 0.666 (0.851) | -0.430 (1.557) |
| Cultural |  | 0.092 (1.026) | -0.329 (1.872) |
| Forest |  |  | 1.626\*\*\* (0.381) |
| **Moderator** |  |  |  |
| Voluntary |  | -1.271 (0.967) | -1.877 (1.731) |
| Lumpsum |  | 0.798 (0.882) | 0.218 (1.455) |
| Choice Experiment |  |  | -3.326 (2.264) |
| Constant | 2.887\* (1.532) | 1.921 (1.886) | 5.217 (3.203) |
| N | 23 | 23 | 23 |
| Log Likelihood | -33.204 | -27.467 | -19.377 |
| Akaike Inf. Crit. | 76.408 | 74.933 | 66.753 |
| Likelihood Ratio Test | 9.98\*\* | 8.38\*\* | 11.07\*\*\* |
| Adjusted R-square | 0.84 | 0.87 | 0.98 |
|  | | | |

* 1. **Freshwater Bayesian Meta-Function Benefit Transfer Errors**

A 10-fold cross-validation method was used to test the predictive power of our estimated meta-regression models. A traditional k-fold cross validation will go through the following steps: a) data would be divided into k groups or folds, b) 1 fold will be will be chosen as test data, and the model will be estimated with the remaining k-1 folds; predictions from the model (using the same test data) will be used with the original test data to calculate prediction errors, in our case root mean squared error and mean absolute deviation, c) the process is repeated k times, and for the kth iteration a different set is set aside as a test data. However, to test how well our US-Canada data and US only models compared with each other in terms of predicting Canadian wetland values, 4 random samples (observations) from the Canadian data was used as a test data for the kth iteration in the 10-fold cross validation process. This process is expected to produce robust prediction error metrics (Table 6).

The results in show that the meta-regression root mean squared error and mean absolute deviations from the chosen model (Model 1b) using the US-Canada data is about 59% and 110%, respectively, lower than the errors from Model 1b using US only data (Table 6). However, the mean value errors from the US-Canada data were about 28% and 58% higher (for the root mean squared error and mean absolute deviation error, respectively) than for the US only data model. The heterogeneity in the values of the mean transfer error and mean value transfer error for the US-Canada data and US only data cases are presented in Figures 6 and 7.

**Table 6. Cross Validation Transfer Errors Results**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **US-Canada** | | **US only** | |
| **Transfer Error** | **RMSE** | **MAE** | **RMSE** | **MAE** |
| Meta-regression | 0.50 | 0.36 | 1.09 | 1.46 |
| Mean Value | 1.70 | 1.67 | 1.42 | 1.09 |

RMSE denotes root mean squared error; MAE denotes mean absolute deviation.

**Figure 6. Heterogeneities in Estimated Meta-regression Transfer Errors**

|  |  |
| --- | --- |
| **Meta-regression Transfer Error Comparison** | |
| **US-Canada data (Model 1b)** | **US Data (Model 1b)** |
|  | |

**Figure 7. Heterogeneities in Estimated Mean Value Transfer Errors**

|  |  |
| --- | --- |
| **Mean Value Transfer Error Comparison** | |
| **US-Canada Model** | **US-Only Model** |
|  | |

* 1. **Empirical Application**
  2. **Discussion and Conclusion**

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**Appendix**

**Table A1. Description of US studies used in this study**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Author | | Year | | Type | | Target Population | | Wetland type | | BA | PA | | WTP | |
| Awondo et al. | | 2011 | | J | | Maumee Bay SP, OH, visitors | | Freshwater, unspec. | | 0.00 | 2,499.00 | | 193.00 | |
| Beran, L.J. | | 1995 | | D | | All SC HHs | | Freshwater, forested | | 6,000.00 | 8,500.00 | | 36.00 | |
| Beran, L.J. | | 1995 | | D | | All SC HHs | | Freshwater, forested | | 6,000.00 | 8,500.00 | | 27.00 | |
| Beran, L.J. | | 1995 | | D | | All SC HHs | | Freshwater, forested | | 6,000.00 | 8,500.00 | | 33.00 | |
| Blomquist & Whitehead | | 1998 | | J | | All KY HHs | | Freshwater | | 3,468.00 | 3,968.00 | | 3.00 | |
| Blomquist & Whitehead | | 1998 | | J | | All KY HHs | | Freshwater, forested | | 69,580.00 | 70,080.00 | | 8.00 | |
| Blomquist & Whitehead | | 1998 | | J | | All KY HHs | | Freshwater, forested | | 21,716.00 | 22,216.00 | | 6.00 | |
| Blomquist & Whitehead | | 1998 | | J | | All KY HHs | | Freshwater, forested | | 908.00 | 1,408.00 | | 19.00 | |
| deZoysa | | 1995 | | D | | Selected MSAs, OH | | Freshwater, unspec. | | 10,000.00 | 13,000.00 | | 109.00 | |
| Loomis et al. | 1991 | | BC | | All CA HHs | | Freshwater, unspec. | | 27,000.00 | | | 85,000.00 | | 258.00 |
| Loomis et al. | 1991 | | BC | | All CA HHs | | Freshwater, unspec. | | 85,000.00 | | | 125,000.00 | | 426.00 |
| MacDonald et al. | 1998 | | J | | Atlanta region, GA | | Freshwater, unspec. | | 212,378.00 | | | 212,708.00 | | 108.00 |
| Mullarkey & Bishop | 1999 | | CP | | All WI HHs | | Freshwater, forested | | 219,890.00 | | | 220,000.00 | | 64.00 |
| Newell & Swallow | 2013 | | J | | Two townships, RI | | Freshwater, forested | | 5,838.00 | | | 5,867.00 | | 9.00 |
| Newell & Swallow | 2013 | | J | | Two townships, RI | | Freshwater, forested | | 5,822.00 | | | 5,867.00 | | 12.00 |
| Newell & Swallow | 2013 | | J | | Two townships, RI | | Freshwater, forested | | 5,807.00 | | | 5,867.00 | | 16.00 |
| Poor | 1999 | | J | | All NE HHs | | Freshwater, unspec. | | 34,000.00 | | | 50,000.00 | | 47.00 |
| Poor | 1999 | | J | | All NE HHs | | Freshwater, unspec. | | 34,000.00 | | | 75,000.00 | | 42.00 |
| Poor | 1999 | | J | | All NE HHs | | Freshwater, unspec. | | 34,000.00 | | | 100,000.00 | | 47.00 |
| Whitehead et al. | 2009 | | J | | Selected counties, MI | | Freshwater, unspec. | | 9,000.00 | | | 10,125.00 | | 73.00 |
| Whitehead & Blomquist | 1991 | | J | | All KY HHs | | Freshwater, forested | | 36,000.00 | | | 41,000.00 | | 19.00 |

Notes: BA is base wetland acreage; PA is policy wetland acreage; WTP is willingness to pay

**Table A2. Description of Canadian studies used in this study**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Author | Year | Type | Target Population | Wetland type | BA | PA | WTP |
| Rudd et al | 2016 | J | Southern Ontario | Freshwater, forested | 1307159 | 1413412 | 11.5 |
| Trenholm et al | 2013 | J | Southern New Brunswick | Freshwater, forested | 0 | 14318 | 14.6 |
| Trenholm et al | 2013 | J | Southern New Brunswick | Freshwater, forested | 0 | 11300 | 19.38 |
| Rudd et al | 2016 | J | Southern Ontario | Freshwater, forested | 1307159 | 1616034 | 24.3 |
| Trenholm et al | 2013 | J | Southern New Brunswick | Freshwater, forested | 0 | 7408 | 24.7 |
| Trenholm et al | 2013 | J | Southern New Brunswick | Freshwater, forested | 0 | 5884 | 31.56 |
| Lantz et al. | 2013 | J | Greater Toronto Area | Freshwater, unspec | 11997 | 14520 | 36.2 |
| Tkac | 2002 | D | Southern Ontario | Freshwater, unspec | 4200 | 8400 | 146.98 |
| Pattisson et al | 2011 | J | Manitoba | Freshwater, unspec | 945184 | 1044702 | 318.33 |
| Pattisson et al | 2011 | J | Manitoba | Freshwater, unspec | 945189 | 1084782 | 325.36 |
| Pattisson et al | 2011 | J | Manitoba | Freshwater, unspec | 945189 | 1125461 | 332.37 |
| Pattisson et al | 2011 | J | Manitoba | Freshwater, unspec | 945189 | 1206820 | 346.76 |
| Pattisson et al | 2011 | J | Manitoba | Freshwater, unspec | 945189 | 1355977 | 375.6 |
| He et al | 2017 | J | Southern Quebec | Freshwater, unspec | 988422 | 1976843 | 483 |
| He et al | 2017 | J | Southern Quebec | Freshwater, unspec | 988422 | 1976843 | 506 |
| Vossler et al. | 2020 | J | Quebec | Freshwater, unspec | 29652646 | 129948360 | 887 |

Notes: BA is base wetland acreage; PA is policy wetland acreage; WTP is willingness to pay which is measured in C$ in the year of study per household per year

**Table A3. Model 2 Meta-regression results (US only Data)**

|  |  |  |  |
| --- | --- | --- | --- |
|  | | | |
|  | **Model 2** | **Model 2b** | **Model 2c** |
|  | | | |
| Dependent Variable: Log (WTP) – Log (Acreage Change) | | | |
| **Context-specific** |  |  |  |
| Log (Acreage) | -0.196\* (0.116) | -0.198\*\* (0.097) | -0.136 (0.101) |
| Log (Year) |  |  | -1.113 (0.688) |
| Local |  |  | 3.231\*\*\* (1.152) |
| US |  | 3.035\*\*\* (1.136) | 1.204 (1.782) |
| Provision |  | -1.497 (0.957) | -2.347\*\* (1.041) |
| Regulation |  | 1.064 (1.033) | 1.376 (1.199) |
| Cultural |  | -2.301\*\* (1.070) | -1.910\* (1.087) |
| Forest |  |  | 1.382\*\* (0.539) |
| **Moderator** |  |  |  |
| Voluntary |  | -0.004 (1.132) | -0.138 (1.168) |
| Lumpsum |  | 2.469\*\* (1.158) | 1.585 (1.317) |
| Choice Experiment |  |  | 0.120 (0.674) |
| Peer Review |  |  | 0.649 (1.353) |
| Constant | -2.245\* (1.280) | -3.681\*\* (1.534) | -2.566 (3.122) |
| N | 40 | 40 | 40 |
| Log Likelihood | -71.966 | -57.123 | -47.730 |
| Akaike Inf. Crit. | 151.932 | 134.246 | 125.460 |
| Likelihood Ratio Test | 16.27\*\*\* | 13.41\*\*\* | 8.09\*\* |
| Adjusted R-square | 0.89 | 0.91 | 0.95 |
|  |  |  |  |
|  | | | |

\*\*\*,\*\*,\*denotes significance at 1%, 5% and 10%, respectively; WTP denotes willingness to pay.

**Table A4. Model 2 Meta-regression results (US only Data)**

|  |  |  |  |
| --- | --- | --- | --- |
|  | | | |
|  |  | | |
|  | **Model 2** | **Model 2b** | **Model 2c** |
|  | | | |
| Dependent Variable: Log (WTP) – (Acreage Change) | | | |
| **Context-specific** |  |  |  |
| Log (Acreage) | -0.038 (0.133) | -0.064 (0.142) | -0.125 (0.140) |
| Log (Year) |  |  | -1.282 (0.888) |
| Local |  |  | 3.898\*\*\* (1.350) |
| Provision |  | -1.494 (1.141) | -2.572\*\* (1.061) |
| Regulation |  | 1.095 (1.170) | 1.580 (1.027) |
| Cultural |  | -0.980 (1.351) | -2.282\* (1.355) |
| Forest |  |  | 1.417\*\*\* (0.537) |
|  |  |  |  |
| **Moderator** |  |  |  |
| Voluntary |  | -1.041 (1.345) | -0.325 (1.152) |
| Lumpsum |  | 2.122\* (1.090) | 1.978\*\* (1.006) |
| Choice Experiment |  |  | 0.146 (1.434) |
| Constant | -2.571\* (1.312) | -2.250 (1.788) | -1.207 (2.775) |
| N | 23 | 23 | 23 |
| Log Likelihood | -39.353 | -30.823 | -21.527 |
| Akaike Inf. Crit. | 86.706 | 79.647 | 69.053 |
| Likelihood Ratio Test | 43.92\*\*\* | 30.82\*\*\* | 28.36\*\*\* |
| Adjusted R-square | 0.96 | 0.96 | 0.97 |
|  | | | |

\*\*\*,\*\*,\*denotes significance at 1%, 5% and 10%, respectively; WTP denotes willingness to pay.

**Table A5. Adding up test**

**UScan—uscand testdata**

|  |  |
| --- | --- |
|  |  |