**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 41 from 22 studies (15 and 7 US and Canadian observations, respectively) published between 1991 and 2020. Five and 4 studies in the US and Canadian datasets, respectively, 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 0.42% increase in willingness to pay to conserve the wetland acreage change. Also, the root mean square meta-regression transfer error (hereafter called meta-regression error) is about 63% less than the root mean square mean value transfer error (hereafter called mean value error). Again, the meta-regression error when predicting Canadian wetland values with model 1 (in the case of combined US and Canada data) is about 93% less than using the US only dataset; however, the mean value error from the US-Canada data is about 12% more than that 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 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 higher 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 several 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 9 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; Ayokunle, 2003; 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 on freshwater wetlands, and those that had information on baseline wetland acreage, the extent of wetland area changes and methodological attributes. We could not include Dias and Belcher (2015) in this study because it did not include enough information on baseline wetland acreage and extent of wetland change. Also, we excluded Rudd et al. (2016) because it focused on saltwater wetlands.

Seven studies on freshwater wetlands were used for this study. 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 16 value observations for the Canadian meta-analysis dataset.

The contingent valuation method was used by all the 7 studies to value wetlands. He et al (2017) compared the accuracy and effectiveness of contingent valuation and choice experiment in valuing wetlands. All the studies were published in peer-reviewed journals except Tkac (2002) and Ayokunde (2003).. 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 Stated Preference Wetland Valuation Studies in Canada**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Study** | **Prov** | **Data Collection Year** | **Sample Size** | **Restoration/Retention** | **Valuation Format** | **Ecosystem Service** | **Ch. Acres** | **WTP** |
| Tkac (2002) | ON | 2001 | 339 | Retention | CV (One Time) | Reg & Prov | 4,200 | 196 |
| Ayokunle (2003) | SK | 2003 | 196 | Retention | CV (An Cont.) | Cul | 555,975 | 62 |
| Pattisson et al. (2011) | MB | 2008 | 1980 | Retention and Restoration | CV (An Cont.) | Reg & Prov | 94,918 | 337 |
| Pattisson et al. (2011) | MB | 2008 | 1980 | Restoration | CV (An Cont.) | Reg & Prov | 135,598 | 345 |
| Pattisson et al. (2011) | MB | 2008 | 1980 | Restoration | CV (An Cont.) | Reg & Prov | 176,277 | 352 |
| Pattisson et al. (2011) | MB | 2008 | 1980 | Restoration | CV (An Cont.) | Reg & Prov | 257,636 | 367 |
| Pattisson et al. (2011) | MB | 2008 | 1980 | Restoration | CV (An Cont.) | Reg & Prov | 406,793 | 398 |
| Lantz et al. (2013) | ON | 2009 | 1407 | Retention | CV (An Cont.) | Reg & Prov | 3,000 | 498 |
| Lantz et al. (2013) | ON | 2009 | 1407 | Retention | CV (An Cont.) | Reg & Prov | 4,000 | 492 |
| Trenholm et al. (2013) | NB | 2007 | 299 | Retention | CV (An Cont.) | Reg, Cul & Prov | 5,884 | 36.9 |
| Trenholm et al. (2013) | NB | 2007 | 299 | Retention | CV (An Cont.) | Reg, Cul & Prov | 11,300 | 22.7 |
| Trenholm et al. (2013) | NB | 2007 | 270 | Retention | CV (An Cont.) | Reg, Cul & Prov | 7,408 | 28.9 |
| Trenholm et al. (2013) | NB | 2007 | 256 | Retention | CV (An Cont.) | Reg, Cul & Prov | 14,318 | 17.2 |
| Dias & Belcher (2015) | SK | 2010 | 250 | Retention | CE (One Time) | Prov | - | 64.5 |
| Dias & Belcher (2015) | SK | 2010 | 250 | Retention | CE (One Time) | Reg | - | 117.2 |
| Dias & Belcher (2015) | SK | 2010 | 250 | Retention | CE (One Time) | Reg & Prov | - | 72.5 |
| 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 |
| 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 |
| Vossler et al. 2020 | QC | 2014 | 1048 | Retention | CV(One Time) | Reg | 62,271,300, | 871 |

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; 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$, except for the one-time payments.

**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. One 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 but rather to people. 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).

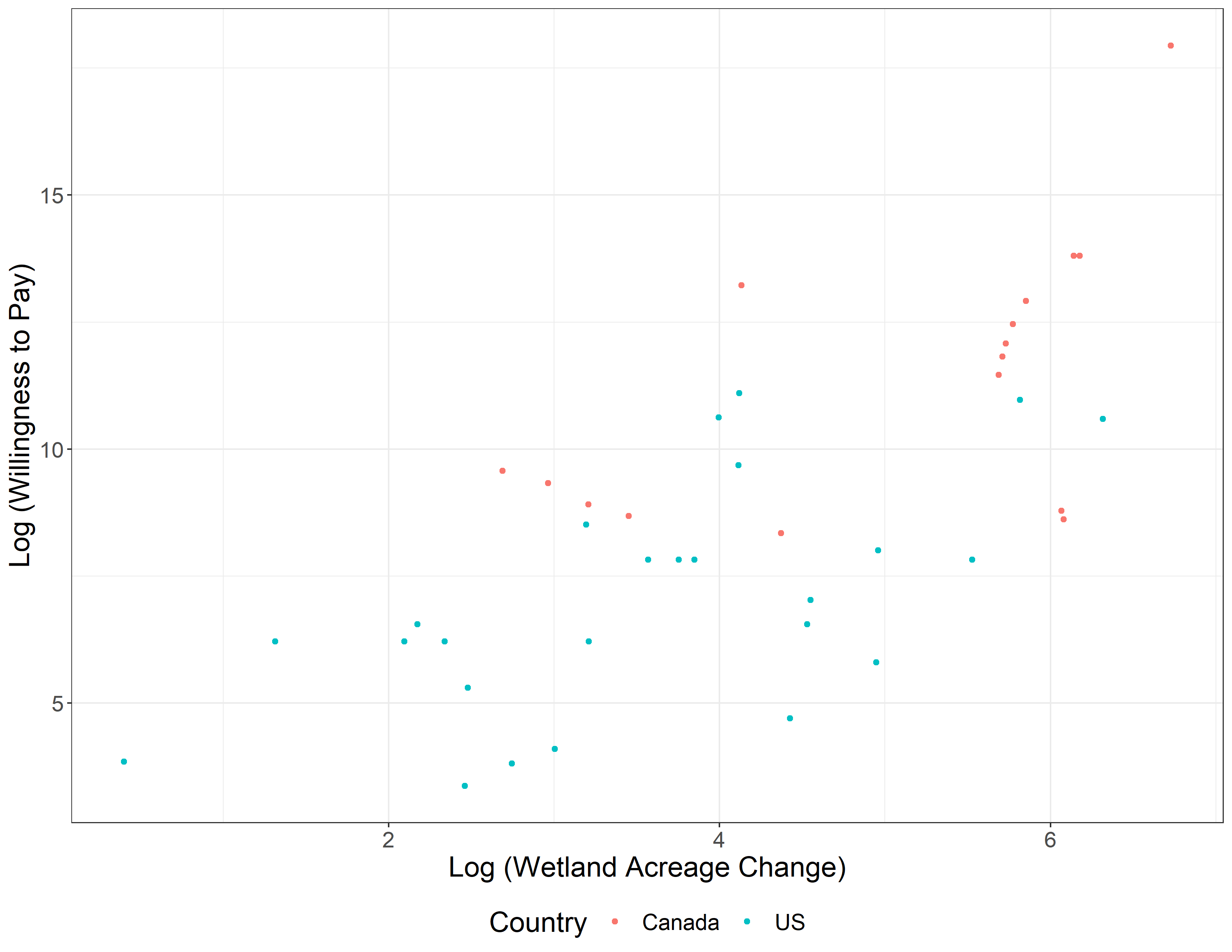
We satisfy the welfare consistency condition by collecting meta-data that used stated preference method to estimate the willingness to pay by households to conserve wetlands in US and Canada (Johnson and Bauer, 2019). For this study, we augment the 7 Canadian studies with a further 15 studies from the United States. From the 7 Canadian studies, we were able to obtain 16 observations, and 25 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). 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.

**3.2. 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.

Regarding the Canadian studies, the mean household willingness to pay for wetland conservation is $156 with a standard deviation of $3.82 . The mean wetland acreage change (the difference between policy wetland and baseline acres) is 85,819 acres with a standard deviation of 14.4 acres. Concerning the US studies, the mean willingness to pay is $36.6 with a standard deviation of $4.12 (exp (1.42)); the mean wetland acreage change is 1,119 acres with a standard deviation of 29 acres. The above results show that show that, on average, Canadian citizens in this study, would be willing to pay about $120 more for wetland conservation than US citizens; despite the observation that the mean household income of the Canadian studies ($68,871) is less than for the US only studies ($78,433). Also, the Canadian studies on average have greater changes in wetland areas compared US studies, which could suggest why they would be willing to pay more to conserve more wetlands areas; this is because, there seems to be a positive relation between the WTP and wetland acres (Figure 2).

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



Moreover, more Canadian studies (38%), on the average, informed respondents that the provisioning ecosystem service of wetlands under evaluation was affected than US studies (36%). This is also true for regulating ecosystem service which was 69% in the case of Canadian studies and 56% for the US studies. However, 72% of the US studies informed respondents that cultural ecosystem service was under evaluation compared to 13% of Canadian studies. Also, less wetlands in the Canadian studies were located on forested landscapes (38%) compared to the US studies (56%). Again, more of the Canadian studies were conducted at the local level (56%) than the for the US studies (44%).

In terms of the moderator variables, about 28% of the studies in the US used a choice experiment to value wetlands than for the Canadian studies (6%). Also, less studies in Canada used voluntary contribution payment mechanism and lump sum to elicit willingness to pay responses (19% and 6%, respectively) than in the US studies (36% in both cases). More studies in the US studies were published in peer reviewed journals (28%) compared to the Canadian studies (19%). 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. Variable description and sample statistics**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | **Canada (N=16)** | | | **USA (N=25)** | | |
|  |  | **Mean (SD)** | **Min** | **Max** | **Mean (SD)** | **Min** | **Max** |
| **Dependent Variable** | Log (WTP) | 5.05(1.34) | 2.69 | 6.73 | 3.60(1.42) | 0.40 | 6.32 |
| **Context** |  |  |  |  |  |  |  |
| Acreage change | Log (Difference between post improvement wetland acres and baseline wetland acres) | 11.36(2.67) | 8.34 | 17.95 | 7.07(2.29) | 3.37 | 11.10 |
| Baseline Acres | Log (Baseline wetland acres) | 8.82(6.52) | 0.00 | 17.54 | 9.10(2.34) | 0.00 | 12.30 |
| Income | Log (target population income in Canadian $) | 11.14(0.22) | 10.70 | 11.53 | 11.27(0.26) | 10.91 | 11.75 |
| Cultural | 1 = cultural function affected | 0.13(0.34) | 0.00 | 1.00 | 0.72(0.46) | 0.00 | 1.00 |
| Forest | 1 = forested wetland | 0.38(0.50) | 0.00 | 1.00 | 0.56(0.51) | 0.00 | 1.00 |
| Local | 1 = target population at sub-state level | 0.56(0.51) | 0.00 | 1.00 | 0.44(0.51) | 0.00 | 1.00 |
| Provision | 1 = provisioning function affected | 0.38(0.50) | 0.00 | 1.00 | 0.36(0.49) | 0.00 | 1.00 |
| regulation | 1 = regulating function affected | 0.69(0.40) | 0.00 | 1.00 | 0.56(0.51) | 0.00 | 1.00 |
| Year | Log (year of data collection - oldest year +1) | 2.88(0.19) | 2.40 | 3.18 | 2.18(1.86) | 0.00 | 7.61 |
| **Moderator** |  |  |  |  |  |  |  |
| CE | 1=elicitation method=choice experiment | 0.06(0.25) | 0.00 | 1.00 | 0.28(0.46) | 0.00 | 1.00 |
| Lumpsum | 1=payment frequency=lump sum (single payment) | 0.06(0.25) | 0.00 | 1.00 | 0.36(0.49) | 0.00 | 1.00 |
| Voluntary | 1=payment mechanism=voluntary contribution | 0.19(0.40) | 0.00 | 1.00 | 0.36(0.49) | 0.00 | 1.00 |
| Peer Review | 1=study was not peer-reviewed | 0.19(0.40) | 0.00 | 1.00 | 0.28(0.46) | 0.00 | 1.00 |

SD denotes standard deviation.

**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, to account for multiple observations per study, (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 2 models and choose the one that satisfies sensitivity to scope and consistent to the assumptions of utility theory, in particular, diminishing marginal utility that is associated with a wetland quality acreage change. Also, we will show if our chosen model satisfies the adding up condition.

The first model (which we call 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. We expect the coefficient of log wetland acreage change in the main model (full model: equation 2) to be significant (at least at 10% level); when this is not the case, we will estimate two other versions of model 1: a) equation 1 will include only log baseline acreage and log wetland acreage change as independent variables (restricted), and b) equation 1 will exclude some of the independent variables that were not significant (at 10% level) in the main model (semi-restricted).

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. The independent variables include the log of baseline wetland acreage.

Also, the same procedure will be followed to estimate other versions of model 2 when the coefficient of log wetland acreage is not significant (at least 10% level).

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.

**4.2. Benefit Transfer Error**

A leave one out cross validation (LOOCV) method will be used to estimate the prediction error (root mean squared error) of our estimated models. The LOOCV, which is an n-fold cross validation (where n is the number of observations of the data) goes through the following steps: a) data would be divided into n folds or observations, b) In the ith iteration, a fold (one observation) is selected as the test data, and the model is estimated using the remaining n-1 folds. In this stage, since n =1, the root mean squared error (RMSE) statistic will be estimated using this equation: , c) the process is repeated for all the n observations. In the end, the number of estimated RMSE will be the same as number of observations of the data. For the US-Canada data (41 observations), after estimating the 41 RMSE statistics, we will use the 16 Canadian observations to estimate the mean RMSE statistic. For the US only data (25 observations) we will select one observation from the Canadian only data (16 observations) per iteration; however, to ensure we estimated 25 models for the US LOOCV exercise, we added 9 randomly selected 9 Canadian observations to the Canadian data to bring the total observations to 25. Also, we will estimate the mean value error for the models by replacing the predictions from the test data (for the ith iteration) with the mean logarithm willingness to pay to calculate the RMSE for that iteration. We will focus on the Canadian observations to calculate the mean RMSE because we want to compare the degree of benefit transfer error from using a US-Canada data and US only data meta-regression models.

* 1. **Meta-Regression Results**

The random coefficient model is appropriate for all the other models except model 2 using the US data because the null hypothesis that the observation level random error component of equation is significantly different from zero is rejected.

Table 3 presents the results of model 1 (with US-Canada data) which includes the restricted model (only includes information on wetland acreage as explanatory variables) and full model. We chose model 1, the full model (here after called best model), because it provided the best fit to the study data than model 2. The Akaike information criteria (AIC) for the best model, which is 110.8 (Table 3), is lower than that of all the 3 estimated versions of model 2 (A3 in appendix). The adjusted coefficient of determination of best model (0.93) shows that about 93% 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 (0.42) of the log (quantity acreage change) is positive and significant at the 1% level; it means that a 1% increase in acreage change would cause a 0.42% increase in willingness to pay to conserve the acreage change. Also, the model did not uphold the law of diminishing marginal utility in wetland acreage, because of the positive coefficient of the log of baseline acreage (-0.03), but it is not significant at the 10% level. Also, the model shows that the value of wetlands has decreased by about 25% (exp (-0.291) – 1= -0.25) since 1991. Also, the value of wetlands estimated at the local level context is more than those estimated at the province level context by a factor of 2.52 (exp (1.258) -1 = 2.52). Provisioning value of wetlands is less other wetland ecosystem values (regulation and cultural) by a factor of 0.7 (exp (-1.205) -1 = 0.7). The adding up condition was violated for the model for all scenarios (Table A5 in appendix).

**Table 3. Model 1 Meta-regression results (US-Canada Combined Data)**

|  |  |  |
| --- | --- | --- |
|  | | |
|  | **Model 1**  **(Restricted)** | **Model 1**  **(Full)** |
|  | | |
| Dependent Variable: Log (WTP) |  |  |
| **Context** |  |  |
| Log (Acreage) | 0.101\*\* (0.051) | 0.030 (0.051) |
| Log (Acreage Change) | 0.278\*\*\* (0.063) | 0.420\*\*\* (0.114) |
| Log (Year) |  | -0.291\*\* (0.136) |
| Local |  | 1.258\*\* (0.593) |
| US |  | 0.594 (0.735) |
| Provision |  | -1.205\*\* (0.478) |
| Regulation |  | 0.520 (0.506) |
| Cultural |  | -0.433 (0.582) |
| Forest |  | 0.271 (0.368) |
| Income |  | 1.399 (1.164) |
| **Moderator** |  |  |
| Voluntary |  | -0.272 (0.667) |
| Lumpsum |  | 0.351 (0.559) |
| Choice Experiment |  | -0.339 (0.460) |
| Peer Review |  | 0.945 (0.580) |
| Constant | 0.904 (0.727) | -15.642 (13.419) |
| Number of Observations | 41 | 41 |
| Log Likelihood | -59.791 | -38.394 |
| Akaike Inf. Crit. | 129.581 | 110.789 |
| Log-likelihood Test | 8.64\*\* | 6.68\*\* |
| Adjusted R-Square | 0.83 | 0.93 |
|  | | |

\*\*\*, \*\*, \* denotes significance at 1%, 5% and 10%, respectively; WTP denotes willingness to pay; values in parenthesis are standard errors.

Regarding the US only model, we chose model 1 because the AIC of all the all the estimated models (Table 4) are lower than that of model 2 (Table A4 in appendix). Also, the preferred model among the estimated versions of model 1 is the semi-restricted model; this is because the coefficient of the logarithm of wetland acreage change is significant at the 5%, and the model’s AIC value is less than that of the restricted model (Table 4). We did not consider the full model (even though, it has the lowest AIC value) because the coefficient of logarithm of wetland acreage change is not significant even at the 10% level.

**Table 4.** **Model 2 Metal-regression results (US Data)**

|  |  |  |  |
| --- | --- | --- | --- |
|  | | | |
|  | **Model 1**  **(Restricted)** | **Model 1**  **(Semi-Restricted)** | **Model 1**  **(Full)** |
|  | | | |
| Dependent Variable: Log (WTP) |  |  |  |
| **Context-specific** |  |  |  |
| Log (Acreage) | -0.041 (0.093) | -0.151 (0.094) | -0.159\* (0.084) |
| Log (Acreage Change) | 0.374\*\* (0.150) | 0.393\*\* (0.199) | 0.161 (0.213) |
| Log (Year) |  |  | -0.396 (0.291) |
| Local |  |  | 1.847\* (1.088) |
| Provision |  | -1.450 (1.040) | -1.903 (1.381) |
| Regulation |  | 0.263 (1.123) | 0.378 (1.105) |
| Cultural |  | -0.647 (1.275) | 0.731 (2.282) |
| Income |  | -0.726 (2.638) | 1.292\*\*\* (0.348) |
| Forest |  | 1.107\*\*\* (0.387) |  |
| **Moderator** |  |  |  |
| Voluntary |  | -0.957 (1.366) | -0.668 (1.227) |
| Lumpsum |  | 1.041 (1.014) | -1.550 (1.235) |
| Choice Experiment |  |  | -2.519\* (1.458) |
| Peer Review |  |  | 3.279\*\* (1.522) |
| Constant | 1.518 (1.372) | 10.878 (30.418) | -3.125 (25.749) |
| N | 25 | 25 | 25 |
| Log Likelihood | -35.859 | -26.198 | -18.168 |
| Akaike Inf. Crit. | 81.718 | 76.396 | 68.337 |
| Loglikelihood Test | 10.46\*\* | 9.09\*\* | 5.82\* |
| Adjusted R-Square | 0.89 | 0.97 | 0.97 |
|  | | | |

\*\*\*, \*\*, \* denotes significance at 1%, 5% and 10%, respectively; WTP denotes willingness to pay; values in parenthesis are standard errors.

The model explained about 97% of the variation in the natural log of 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 0.39% 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 -0.151 suggest that the law of diminishing marginal returns is validated in this model; even though this effect is not significant even at the 10% level, it shows that a 1% increase in the acreage of wetland will cause about 0.15% decrease in willingness to pay to conserve the wetland. The results show that wetlands in forested landscapes are more valuable than those in other landscapes by a factor of 2.03 (exp (1.107) -1); this result is significant at the 10% level. The adding up condition was not violated for the model for all scenarios (Table A5 in appendix).

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

We performed a Leave One Out Cross Validation (LOOCV) to estimate the root mean square error of meta-regression models (US-Canada and US only data models) when applied to estimate the value of Canadian wetlands (in-sample). Full details of the LOOCV are provided in section 4.2.

The results show that the meta-regression error (root mean squared error) is about 76% lower than the mean value error when predicting the values of Canadian wetlands using the US-Canada model. Also, the meta-regression error when predicting Canadian wetland values is about 93% lower for the US-Canada model compared to the US only model. The results are shown in Table 5.

**Table 5. Cross Validation Transfer Errors Results**

|  |  |  |  |
| --- | --- | --- | --- |
| **Transfer Error** | **RMSE**  **US-Canada Model** | **RMSE**  **US only Model** | **Difference** |
| Meta-regression | 0.94 | 1.88 | 0.93 |
| Mean Value | 1.70 | 1.96 | -0.26 |

RMSE denotes root mean squared error.

The above results show that, for this study, meta-regression is superior to mean-value transfer when conducting benefit transfers. Again, we have shown that using combined datasets from US and Canada is better (in terms of transfer errors) than using US only datasets to predict Canadian wetland values.

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

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**Appendix**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Author | | Year | | Type | | Target Population | | Wetland type | | BA | PA | | WTP | |
| Whitehead & Blomquist | | 1991 | | J | | All KY HHs | | Freshwater, forested | | 36,000.00 | 41,000.00 | | 19.00 | |
| 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 | |
| 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 | |
| deZoysa | | 1995 | | D | | Selected MSAs, OH | | Freshwater, unspec. | | 10,000.00 | 13,000.00 | | 109.00 | |
| 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 | |
| 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 | |
| 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 |
| Awondo et al. | | 2011 | | J | | Maumee Bay SP, OH, visitors | | Freshwater, unspec. | | 0.00 | 2,499.00 | | 193.00 | |
| 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 |
| Johnson et al | 2015 | | TR | | Maine | | Freshwater, unspec. | | 4000 | | | 4700 | | 8.8 |
| Johnson et al | 2016 | | J | | Maine | | Freshwater, unspec. | | 4000 | | | 4700 | | 92.7 |

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

Notes: BA is base wetland acreage; PA is policy wetland acreage; WTP is willingness to pay; j is journal article; BC is book chapter; CP is conference paper; TR is technical report; D is dissertation

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

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Author | Year | Type | Target Population | Wetland type | BA | PA | WTP |
| Tkac | 2002 | D | Southern Ontario | Saltwater, unspec | 4200 | 8400 | 79.22 |
| Ayokunle | 2003 | D | Saskatchewan | Saltwater, unspec | 0 | 555975 | 62.4 |
| Pattisson et al | 2011 | J | Manitoba | Freshwater, unspec | 945184 | 1044702 | 295.1 |
| Pattisson et al | 2011 | J | Manitoba | Freshwater, unspec | 945189 | 1084782 | 301.65 |
| Pattisson et al | 2011 | J | Manitoba | Freshwater, unspec | 945189 | 1125461 | 308.31 |
| Pattisson et al | 2011 | J | Manitoba | Freshwater, unspec | 945189 | 1206820 | 321.46 |
| Pattisson et al | 2011 | J | Manitoba | Freshwater, unspec | 945189 | 1355977 | 347.8 |
| 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 |
| 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 | 18520 | 431.3 |
| Lantz et al. | 2013 | J | Greater Toronto Area | Freshwater, unspec | 11997 | 17520 | 436.7 |
| Rudd et al | 2016 | J | Southern Ontario | Freshwater, forested | 1307159 | 1616034 | 24.3 |
| Rudd et al | 2016 | J | Southern Ontario | Freshwater, forested | 1307159 | 1413412 | 11.5 |
| He et al | 2017 | J | Southern Quebec | Freshwater, unspec | 988422 | 1976843 | 482 |
| He et al | 2017 | J | Southern Quebec | Freshwater, unspec | 988422 | 1976843 | 465 |
| Vossler et al. | 2020 | J | Quebec | Freshwater, unspec | 41514200 | 103785500 | 836 |

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;

j is journal article; BC is book chapter; CP is conference paper; TR is technical report; D is dissertation.

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

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Model 1**  **(Restricted)** | **Model 1**  **(Restricted)** | **Model 1**  **(Full)** |
|  | | |
|  |  |  |  |
| **Context-specific** |  |  |  |
| Log (Acreage) | 0.312\*\*\* (0.108) | 0.012 (0.107) | -0.063 (0.072) |
| Log (Year) |  |  | -0.247 (0.204) |
| Local |  |  | 2.059\*\* (0.879) |
| US |  |  | 3.449\*\*\* (0.735) |
| Provision |  |  | -1.793\*\* (0.722) |
| Regulation |  |  | 1.317\* (0.754) |
| Cultural |  |  | -1.988\*\* (0.777) |
| Income |  |  | 3.311\* (1.704) |
| Forest |  | 0.244 (0.509) | 0.982\*\* (0.476) |
|  |  |  |  |
| volunt |  | -4.676\*\*\* (1.230) | 0.347 (1.024) |
| lumpsum |  | 3.214\*\* (1.475) | 1.553\* (0.795) |
| ce |  | 0.058 (0.570) | -0.132 (0.621) |
| nrev |  | 1.681 (1.268) | 0.300 (0.886) |
| Constant | -7.173\*\*\* (1.226) | -4.443\*\*\* (1.277) | -43.907\*\* (18.859) |
| N | 41 | 41 | 41 |
| Log Likelihood | -85.297 | -66.615 | -46.135 |
| Akaike Inf. Crit. | 178.594 | 151.229 | 124.269 |
| Loglikelihood Test | 18.87\*\*\* | 31.26\*\*\* | 27.70\*\*\* |
| Adjusted R-square | 0.93 | 0.98 | 0.96 |

Dependent Variable is Log (WTP) – Log (Acreage Change);

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

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

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | | | | | |
|  | **Model 1**  **(Restricted)** | **Model 1**  **(Semi-Restricted)** | | **Model 1**  **(Full)** | |
|  | | | | | |
|  |  |  | |  | |
| **Context-specific** |  |  | |  | |
| Log (Acreage) | -0.042 (0.120) | -0.083 (0.124) | | 0.119 (0.106) | |
| Log (Year) |  |  | | -0.345\* (0.194) | |
| Local |  |  | | 3.178\*\*\* (0.794) | |
| Provision |  | -1.498 (1.001) | | -2.776\*\*\* (0.737) | |
| Regulation |  | 0.977 (1.065) | | 1.327 (0.877) | |
| Cultural |  | -1.406 (1.201) | | -0.723 (0.708) | |
| Income |  | 2.518 (2.461) | | 2.483 (1.632) | |
| Forest |  | 1.017\* (0.523) | | 1.069\* (0.560) | |
| **Moderator** |  |  | |  | |
| Voluntary |  | -0.704 (1.320) | | 0.330 (0.817) | |
| Lumpsum |  | 1.727\* (0.946) | | 0.129 (0.812) | |
| Choice Experiment |  |  | | 0.212 (0.930) | |
| Peer Review |  |  | | 1.601 (1.049) | |
| Constant | -2.786\*\* (1.169) | -30.774 (28.012) | | -33.618\* (18.511) | |
| Number of Observations | 25 | | 25 | | 25 | |
| Log Likelihood | -41.448 | -33.141 | | -21.970 | |
| Akaike Inf. Crit. | 90.895 | 84.283 | | 73.939 | |
| Loglikelihood Test | 18.27\*\*\* | 14.8\*\*\* | | 0.88 | |
| Adjusted R-square | 0.89 | 0.95 | | 0.92 | |
|  | | | | | |

Dependent Variable is Log (WTP) – Log (Acreage Change);

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

**Table A5. Adding up test**

|  |  |  |
| --- | --- | --- |
| Scenario (acres, 1000s) | US-Canada Model  Predicted WTP | US Model  Predicted WTP |
|  |  |  |
|  | Forested, Local | |
| 10 to 10.3 | 13.32 | 2.53 |
| 10.3 to 10.5 | 11.26 | 1.53 |
| 10 to 10.5 | 16.18 | 4.16 |
| Adding-up error (%) | 51.94 | -2.14 |
|  | Forested, Province | |
| 10 to 10.3 | 1.35 | 2.50 |
| 10.3 to 10.5 | 1.14 | 1.58 |
| 10 to 10.5 | 1.73 | 3.59 |
| Adding-up error (%) | 101.27 | 193.90 |
|  | Non-forested, Local | |
| 10 to 10.3 | 9.95 | 0.07 |
| 10.3 to 10.5 | 8.84 | 0.07 |
| 10 to 10.5 | 12.65 | 0.06 |
| Adding-up error (%) | 48.49 | 113.01 |
|  | Non-forested, Local | |
| 10 to 10.3 | 1.32 | 0.02 |
| 10.3 to 10.5 | 1.16 | 0.02 |
| 10 to 10.5 | 1.60 | 0.01 |
| Adding-up error (%) | 54.60 | 157.80 |