APPENDIX C
ESTIMATED COMPENSATING VARIATIONS AND EXPECTED COMPENSATING VARIATIONS

C.1 INTRODUCTION

This appendix derives two lower-bound estimates of the aggregate compensating variation for different improvements in the characteristics of Green Bay. An estimate is "lower-bound" if it is an estimate of only a subset of the damages. One of these lower-bound estimates is smaller than the other because it is an estimate of a smaller subset of the damages.

The improvements considered will be for reductions in FCAs and increases in catch rates. Specifically, we estimate individual *i*'s compensating variation for an improvement in the characteristics of Green Bay for a *Green Bay fishing day*. In addition, we estimate individual *i*'s expected compensating variation for an improvement in the characteristics of Green Bay for a *fishing day*. Note that fishing days in the latter case include *all* open-water fishing days, including those to Green Bay and those to other sites.

Denote individual *i*'s expected compensating variation for a season for a change in the characteristics of Green Bay, $E\left(CV_i\right)$. Individual *i*'s $\mathrm{E}\left(CV_i\right)$ for the elimination of Green Bay FCAs is the expected value of the yearly damages to individual *i* from the FCAs. Aggregating these over all individuals, one obtains the expected value of total damages per year from Green Bay PCBs and the resulting FCAs. We do not estimate this; rather we report a lower-bound estimate of these total damages. It is a lower-bound estimate for two reasons: it does not include all of the potential components of each impacted individual's damages, and it does not include all potentially impacted individuals.

Denote individual *i*'s expected compensating variation for a fishing day for a change in the characteristics of Green Bay, $\mathrm{E}\left(CV_i^F\right)$, and denote individual *i*'s compensating variation for a Green Bay fishing day for a change in the characteristics of Green Bay, CV_i^G. The estimated CV_i^G and $\mathrm{E}\left(CV_i^F\right)$, along with estimates of the current number of fishing days and Green Bay fishing days by a subset of those who currently fish Green Bay, will be used to obtain two lower-bound estimates of WTP for the elimination of FCAs for this target population.

For an improvement in Green Bay, CV_i is how much the angler would pay per season (year) for the improvement, whereas CV_i^G is how much the angler would pay per Green Bay fishing day for the improvement, and CV_i^F is how much the angler would pay per fishing day. Note that for an improvement in Green Bay, $0 \leq CV_i^F \leq CV_i^G$, and for a deterioration in Green Bay,

$CV_i^G \leq CV_i^F \leq 0$. An angler will pay no more per fishing day to have the FCAs at Green Bay reduced than he would pay per Green Bay fishing day because all fishing days are not necessarily to Green Bay.

Explaining further, CV_i^G is individuals *i*'s compensating variation per Green Bay fishing day for an improvement in the conditions of Green Bay. There is no question as to where the angler will fish on a Green Bay fishing day: it is Green Bay. In contrast, CV_i^F is individuals *i*'s compensating variation per fishing day for an improvement in the conditions of Green Bay given that the individual can choose to fish either Green Bay or elsewhere.

For an improvement in Green Bay conditions:[1]

$$CV_i^G \times D_i^{G^0} \leq CV_i^F \times D_i^{F^0} \leq CV_i\,, \tag{1}$$

where $D_i^{G^0}$ is the number of days in a season individual *i* fishes Green Bay under current (injured) conditions, and $D_i^{F^0}$ is the number of days individual *i* fishes (all sites) under current conditions (Morey, 1994).

$(CV_i^G \times D_i^{G^0})$ would be individual *i*'s seasonal compensating variation if he were constrained to fish Green Bay the same number of days with the improvement as he did in the injured state. $CV_i^G \times D_i^{G^0} \leq CV_i$ because he has the ability to take greater advantage of the improvement by increasing the number of days he fishes Green Bay. $(CV_i^F \times D_i^{F^0})$ would be individual *i*'s compensating variation if he were constrained to fish the same total number of days with the improvement as he did in the injured state. $CV_i^F \times D_i^{F^0} \leq CV_i$ because he has the ability to take advantage of the improvement by increasing the number of days he fishes.

$CV_i^G \times D_i^{G^0} \leq CV_i^F \times D_i^{F^0}$ because an individual who is constrained to fish Green Bay the same number of days both before and after Green Bay is improved is more constrained in his ability to take advantage of the improvement than an individual constrained to fish the same number of total days both before and after Green Bay is improved. The latter constraint allows the individual to increase his days to Green Bay by reducing the days to other sites if this makes him better off, whereas the former constraint does not.

1. Given the model, CV^F and CV^G are constants independent of the individual's number of fishing days and Green Bay fishing days. This follows from the assumption that the utility from a fishing day (Green Bay fishing day) is not a function of the number of fishing days (Green Bay fishing days) — see Equations 1 and 3 in Appendix B. In this case, any quality increase can be represented by an equivalent price decrease, and Equation 1 (in this appendix) holds if the marginal utility of money is positive, which it is. That is, Equation 1 holds because the angler will not decrease fishing days if Green Bay improves in quality.

C.2 ESTIMATED COMPENSATING VARIATION PER GREEN BAY FISHING DAY

Typically when estimating compensating variations, the expected value of the compensating variation is estimated rather than the compensating variation itself, because the compensating variation depends on unobservable stochastic terms, so it is a random variable. However, if there is only one alternative in each state of the world, the compensating variation is not a random variable. Since CV_i^G is per Green Bay fishing day and since the only alternative is Green Bay, CV_i^G is not a random variable and can be estimated as $CV_i^G = \mathrm{E}(CV_i^G)$.[2] This is because the random component(s) cancel out of the *CV* formula when the individual chooses the same alternative in each state.[3] In discrete choice models without income effects, the compensating variation can be written as the difference between the maximum utility in the two states multiplied by the inverse of the constant marginal utility of money (see Hanemann, 1984; and Morey, 1999):

$$\begin{aligned} CV_i^G &= \frac{1}{b_y}\left(U_i^{G^1} - U_i^{G^0}\right) = \frac{1}{b_y}\left[\left(b'x_i^{G^1} + e_{id}^G\right) - \left(b'x_i^{G^1} + e_{id}^G\right)\right] \\ &= \frac{1}{b_y}\left(b'x_i^{G^1} - b'x_i^{G^1}\right) \end{aligned} \tag{2}$$

where $U_i^{G^1}$ is the utility from a Green Bay fishing day in the improved state, and $U_i^{G^0}$ is the utility in the current state; that is, G^1 denotes Green Bay under improved conditions and G^0 denotes Green Bay under current conditions.[4]

In addition, $x_i^G = x^G \ \forall \ i$, so:

$$CV_i^G = CV^G \ \forall \ i \tag{3}$$

That is, everyone one has the same CV^G, which we can calculate.[5] The estimate is reported in Chapter 8.

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2. Estimated CV_i^F is a random variable.

3. For details, see Morey (1999), p. 103.

4. Note that any scaling of b in estimation will cancel out of Equation 2.

5. In Appendix D, we consider preference heterogeneity.

C.3 A LOWER-BOUND ESTIMATE OF DAMAGES

Equations 1 and 3 imply:

$$CV^{G} \times D^{G^0} \leq N \times CV \tag{4}$$

where N is the number of individuals in the target population and D^{G^0} is the number of Green Bay fishing days by the target population under current conditions, so $(CV^{G} \times D^{G^0})$ is a lower-bound estimate of the recreational fishing damages to the target population. The 1998 estimate is reported in Chapter 8.

C.4 EXPECTED COMPENSATING VARIATION PER FISHING DAY

Since CV_i^F is per fishing day and on each fishing day the angler has the choice of two sites: Green Bay or elsewhere, CV_i^F is a function of unobservable stochastic components, and so cannot be estimated. Instead we estimate its expectation:

$$\mathrm{E}\left(CV_i^F\right) = \frac{1}{b_y}\left[\mathrm{E}(\max(U_i^{G^1}, U_i^{O})) - \mathrm{E}(\max(U_i^{G^0}, U_i^{O}))\right] \tag{5}$$

where U_i^o is the utility from fishing at another site. Given that U_i^G and U_i^o are bivariate normal:

$$\mathrm{E}\left(\max(U_i^G, U_i^O)\right) = g_0 + (b' x_i^G - g_0)\Phi\left(\frac{b' x_i^G}{s_{0-G}} - \frac{g_0}{s_{0-G}}\right) + s_{0-G} f\left(\frac{b' x_i^G}{s_{0-G}} - \frac{g_0}{s_{0-G}}\right) \tag{6}$$

where $\Phi(\cdot)$ is the univariate standard normal cumulative distribution function, $f(\cdot)$ is the standard normal density function (Maddala, 1983, p. 370), and $s_{0-G}^2 = \mathrm{Var}[e_{ij}^0 - e_{ij}^G] = s_0^2 + s_G^2 - 2s_{G0}$ (see Appendix A).

Substituting Equation 6 into 5, and simplifying it one obtains:

$$\begin{aligned} &\mathrm{E}(CV_i^F) \\ &= \frac{1}{b_y}\Big[(b' x_i^{G^1} - g_0) F\left(\frac{b' x_i^{G^1} - g_0}{s_{0-G}}\right) + s_{0-G} f\left(\frac{b' x_i^{G^1} - g_0}{s_{0-G}}\right) \\ &\quad - (b' x_i^{G^0} - g_0) F\left(\frac{b' x_i^{G^0} - g_0}{s_{0-G}}\right) - s_{0-G} f\left(\frac{b' x_i^{G^0} - g_0}{s_{0-G}}\right)\Big] \end{aligned} \tag{7}$$

Since, in this model, $x_i^G = x^G \; \forall \; i$, $E\left(CV_i^F\right) = E(CV^F) \; \forall \; i$. The estimate of $\mathrm{E}(CV^F)$ is reported in Chapter 8.

C.5 A SECOND LOWER-BOUND ESTIMATE OF DAMAGES

Returning to Equation 1, consider the inequality $CV_i^F \times D_i^{F^0} \leq CV_i$.

Taking the expectation of both sides and noting that $D_i^{F^0}$ is exogenous:

$$\mathrm{E}(CV_i^F) \times D_i^{F^0} \leq \mathrm{E}(CV_i)\,. \tag{8}$$

Since $E(CV_i^F) = E(CV^F) \; \forall \; i$,this simplifies to $\mathrm{E}(CV^F) \times D_i^{F^0} \leq \mathrm{E}(CV_i)$. Summing over individuals, one obtains:

$$\mathrm{E}(CV^F) \times D^{F^0} \leq \sum_{i=1}^{N} \mathrm{E}(CV_i)\;, \tag{9}$$

where D^{F^0} is the number of Green Bay fishing days by the target population under current conditions, so $\left[\mathrm{E}(CV^F) \times D^{F^0}\right]$is a second lower-bound estimate of the recreational fishing damages to the target population. It is less constrained than the first estimate, so it is expected to be larger than the first lower-bound damage estimate. Anglers value improvements in Green Bay more highly when they can fish it more. The 1998 estimate is reported in Chapter 8.