# The Option Price of Recreational Bag Limits and the Value of Harvest

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ABSTRACT

Daily harvest limits are a common form of regulation in consumptive recreation. We show that angler willingness to pay for a bag limit change is an option price and show how it relates to the value of harvest changes. Specifically, if expected utility theory holds, then option prices for one-fish bag limit increments along with catch distributions can be used to "recover" the compensating surplus (CS) for harvest increments. We also show that further assumptions (e.g., risk neutrality) are necessary to recover the CS for harvest from option prices for larger bag limit increments. We demonstrate our method using a choice experiment and catch data for Gulf of Mexico anglers. This work gives analysts a way to adapt the information at hand to the policy question. For example, when CS estimates are needed for an ex post analysis, but only option prices are available, our work shows how to obtain the required CS information.

**Key words:** Bag limit, option price, recreational fishing, stated preference, valuation.
**JEL codes:** Q220, Q260, Q510.

## INTRODUCTION

Natural resource managers need to understand the economic benefits and costs of changes in regulations to select policies that can improve the efficiency of resource use. This requires information on the economic value to resource users for changes in regulations. Most research focuses on the value of changes in regulations via associated changes in resource quality. The valuation of changes in water or air quality anticipated with proposed changes of ambient standards is a classic example (Freeman 1995; Viscusi, Huber, and Bell 2008). In fisheries, harvest rates serve as the pathway for regulations like bag limits to affect changes in angler welfare (Scrogin et al. 2004; McConnell, Strand, and Blake-Hedges 1995). Less work has been done to directly value changes in regulations, especially in the context of recreation.

Daily limits on harvest (i.e, creel or bag limits) are the most common form of regulation in consumptive recreation. A bag limit allows an angler to keep a prescribed number of fish each day in the event the fish are caught. However, there is no guarantee that the bag limit will be caught because catch is uncertain. In the parlance of choice under uncertainty, bag limits are a type of costless contingent claim, conditional on the distribution of catch per angler.

The main contribution of this paper is to show that angler willingness to pay (WTP) for an incremental change in the bag limit is an option price and to show how it relates to the value of

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changes in harvest.[1] The option price directly measures the value of bag limit change and therefore is immediately useful in policy analysis. That is, when using estimated values for changes in harvest for bag limit analyses, we must first determine how the bag limit change will affect harvest. If this is not possible, then a method to convert the estimated value for a change in harvest to the value for a change in a bag limit will be helpful. Similarly, if we are evaluating a change in harvest, for example, foregone because of an oil spill, and have only an option price value for a bag limit change, then it would be helpful to have a way to convert the option price to a value per fish harvested.

Whitehead (2006) derived expressions to compare the WTP for bag limits with the WTP for harvest in a deterministic setting. He shows generally that "since the marginal product of the bag limit may be zero, the WTP for a change in the bag limit is less than the WTP for a change in harvest" (1727). He did not, however, provide an operational model to go back and forth between the two expressions of WTP.[2]

Some research has focused on the amount of catch that exceeds the bag limit. Lew and Larson (2014) refer to the portion of the bag limit in excess of the actual catch as "potential catch" and found that WTP for potential catch was "generally positive" in their choice experiment. They suggested three reasons why the WTP for this unrealized catch would be positive: nonuse value, angler misperceptions, and "stochasticity." The last reason arises because Lew and Larson (2014) presented anglers with actual (*deterministic*) catch as an attribute in their stated choice questions. If anglers instead interpreted the actual catch attribute as *expected* catch, then they could have misunderstood the bag limit attribute as potentially acting on this catch attribute.

Carson, Hanemann, and Steinberg (1990) referred to the number of fish in the bag limit in excess of the number of fish the angler *expects* to catch as "insurance fish." They found that insurance catch either detracts from or has no effect on utility, suggesting that anglers "regard their own (expectations) as a reasonable limit on catch and feel that any license allowing more than (their expected harvest) will encourage over-harvesting of the fishery" or that anglers "put little or no value on an insurance that they might ultimately want to catch and keep more fish than they originally planned for" (Carson, Hanemann, and Steinberg 1990, 65).

In the next section we derive the relationship between the compensating surplus (CS) for changes in harvest and the option price for changes in the bag limit. Specifically, we show that, under certain assumptions, information on the option price for a bag limit increment and the distribution of catch can be used to recover the CS for the same increment in harvest. We also show how the relationship between CS and option price can be useful if we have only an estimate of CS for a harvest increment, but need to evaluate the option price for bag limit increment.

We then demonstrate the procedures using data from charter boat anglers fishing in the Gulf of Mexico during 2013. We use choice experiment survey data to estimate option prices for incremental changes in bag limits on key species and then use information on the distribution of catch in the Gulf of Mexico to recover estimates of the value of changes in expected harvest. The

1. We focus on how the uncertainty in the *supply* of fish affects anglers' preferences for bag limits. There is a rich literature on option prices in the context of supply uncertainty (e.g., Graham-Tomasi and Myers 1990). There can also be uncertainty in recreation participation or demand that is endogenous to the decision problem (Cameron and Englin 1997). Whitehead and Haab (2001) explicitly dealt with demand uncertainty in the target species in an option price model of fishing bag limits. Lastly, there can be uncertainty as to whether recreational opportunity will be available. Nguyen et al. (2007) derive an expression for the option price of a change in the *chance* of a recreation opportunity.

2. Other work estimates the welfare effects of changes in bag limits without acknowledging that the measures are in fact option prices (Whitehead et al. 2011; Lew and Larson 2015; Anderson and Lee 2013; Liese and Carter 2017).

choice experiment uses hypothetical, but realistic, choices between offshore charter fishing trips that vary in trip characteristics and regulations.

## OPTION PRICES FOR BAG LIMITS AND THE INCREMENTAL VALUE HARVEST

In this section we show how the option prices for bag limits can be used to "recover" the underlying value for ex post or known changes in the number of fish kept. We refer to the total number of fish caught per angler on a fishing trip as *catch* and the total number of fish kept per angler on a fishing trip as *harvest*. Catch and harvest levels can differ because of angler preferences and regulations, such as minimum size requirements and bag limits.

On any given choice occasion, an angler may choose a single fishing trip among $j \in 1, \cdots, J$ alternative trips. However, before the angler selects the preferred trip, the number of fish caught, $c_j$, and therefore the number of fish available to keep (harvest), $h_j$, are unknown. We assume that the angler has prior information about the catch distribution and denote $f(c)$ as the discrete probability density defined over integers ranging from 0 to $\bar{c}$, an upper limit on catch governed by the unknown stock size. The catch probability distribution is the same among all trips and the daily bag limit, $b_j$, on trip $j$ limits the number of fish kept according to the minimum function, that is, $h_j = min(c_j, b_j)$.[3]

The indirect utility on trip $j$ conditional on a harvest level is given by $u(y - p_j, x_j, h_j)$ where $y$ is income, $p_j$ is trip cost, and $x_j$ is a vector of other trip attributes. The prices of other goods are assumed constant over all trip alternatives, so we omit them as an argument in the indirect utility function. In addition, we assume that income and all prices are known with certainty and that preferences are independent of the realized catch. These assumptions eliminate demand uncertainty. Also, utility depends on only the number of fish kept, which rules out preferences for catch and release fishing but is a reasonable assumption given our focus on bag limits.

Following Holzer and McConnell (2017), we assume that the indirect utility function is linear in income and separable so that expected indirect utility can be written as the following:

$$
\begin{aligned}
EU(y - p_j, x_j, b_j) &= \sum_{c=0}^{\bar{c}} u(y - p_j, x_j, h_j) w(f(c)) \\
&= \alpha(y - p_j) + u_x(x_j) + \sum_{c=0}^{\bar{c}} u_h(min(c_j, b_j)) w(f(c)),
\end{aligned}
\tag{1}
$$

where $\alpha$ is the marginal utility of income, $u_x(\cdot)$ and $u_h(\cdot)$ are subutility functions for other trip attributes and harvest, respectively, and $w(\cdot)$ is a probability weighting function. Assuming that preferences for harvest are separable from preferences for consumption of other goods allows anglers to first optimally allocate income between harvest and consumption of other goods, and then determine the demands for individual goods. In this case, preferences given uncertainty in catch "can be investigated without concerns regarding background risk in income" (Holzer and McConnell 2017, 10). However, assuming that the marginal utility of income is constant and state independent does not allow us to distinguish between compensating and equivalent welfare measures (Graham-Tomasi and Myers 1990). Allowing for more complex income effects would complicate the welfare calculations (Herriges and Kling 1999; Cameron 2005) without generally changing the conclusions of the model.

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3. Lew and Larson (2014) also use the minimum function to characterize harvest when bag limits are present.

There are several ways to empirically model the behavior implied by the harvest component of equation 1. The most direct way is to explicitly model each part of the last term. This approach models preferences over risk and probability with functional forms for $u(\cdot)$ and $w(\cdot)$ (Glenk and Colombo 2013; Hensher, Li, and Rose 2013). A rich set of data on choices where the probabilities of catch outcomes is explicit are necessary to parameterize such a model. Even with such data, it is convenient to assume that the expected utility theory holds, such that all probabilities carry equal weight, that is, $w(f(c)) = f(c)$. Holzer and McConnell (2017) take this approach in their study of the risk preferences of recreational anglers. Alternatively, you can assume a simple form for $u_h(\cdot)$ (e.g., linear) and use a more complex probability weighting function (Roberts, Boyer, and Lusk 2008).

The most common approach in the recreational fishing demand literature to modeling the harvest term in equation 1 is to assume anglers are risk neutral in harvest (and income) and then reduce the expected utility expression further, to a function of the first moment of the harvest distribution. In this case the utility of *expected* harvest enters linearly as $\beta\Sigma_{c=0}^{\bar{c}}\, min(c_j, b_j)f(c)$, and equation 1 can be reduced to the specification commonly used in discrete choice recreation demand models, that is, $\alpha(y - p_j) + u_x(x_j) + \beta\, E[h(b_j)]$, where $\beta$ is a parameter measuring the constant marginal utility of expected harvest conditional on the bag limit. We explicitly write expected harvest as a function of the bag limit to highlight the influence of this regulation on expected harvest.[4] In most cases, especially where revealed preference data are used, the conditional expected harvest, $E[h(b_j)]$, is calculated as an average historical harvest or modeled assuming a distribution (e.g., Poisson). Scrogin et al. (2004) used spatial variation in regulations to model the effect of bag limits on expected harvest. In the absence of variation to identify the effect of regulations on expected harvest, McConnell, Strand, and Blake-Hedges (1995) demonstrated how a bag limit acts to truncate the harvest distribution and change the expected harvest.

If we have information about trip choices with different bag limit levels, then there is another approach to modeling the harvest component of equation 1. Specifically, we can use a set of dummy variables to recover the harvest term without making any assumptions about the shape of the utility function, $u_h(\cdot)$, the distribution of catch, $f(c)$, or how anglers weight probabilities, $w(\cdot)$. The utility function for zero to $M$ fish can be written as the following:

$$EU(y - p_j, x_j, b_j) = \alpha(y - p_j) + u_x(x_j) + \sum_{m=1}^{M} \delta_m D_{j,m}, \tag{2}$$

where $D_{j,m}$ equals 1 if trip $j$ has a bag limit of $m$ and 0 otherwise. In this case the parameter on each dummy variable represents the expected utility of a given bag limit, for example, $\delta_k = \Sigma_{c=0}^{\bar{c}} u_h(min(c_j, k))w(f(c))$ for the $k$th bag limit. The dummy or effects coding approach is common when using data from stated preferences studies that have anglers choosing over hypothetical trips with different bag limits (Whitehead et al. 2011; Lew and Larson 2014, 2015; Anderson and Lee 2013; Liese and Carter 2017). In these studies, and in our choice experiment described below, anglers are provided information on the bag limits active during each trip and are left to form their own expectations regarding catch and harvest. Thus we are directly modeling the effect of bag limits on utility.

In the remainder of the paper, we follow Holzer and McConnell (2017) and assume that expected utility theory holds for anglers' preferences over harvest levels, that is, $w(f(c)) = f(c)$, and

4. Note that $\Sigma_{c=0}^{\bar{c}}\, min(c_j, b_j)f(c) \neq \Sigma_{h=0}^{\bar{h}} hf(h)$ unless there is no bag limit or the bag limit is not binding. Therefore, the unconditional expected harvest, $E(h)$, will not necessarily equal expected harvest conditional on the bag limit, $E[h(b_j)]$.

save the investigation of more complex probability weighting functions for future research. Assuming expected utility theory holds in equation 1, it is straightforward to show the relationship between option price for an incremental bag limit change and the (compensating) surplus measure for the same increment in known harvest. First, for clarity, we write equation 1 assuming that expected utility holds such that $w(f(c)) = f(c)$:

$$\begin{aligned} EU(y-p_j, x_j, b_j) &= \sum_{c=0}^{\bar{c}} u(y-p_j, x_j, h_j) f(c) \\ &= \alpha(y-p_j) + u_x(x_j) + \sum_{c=0}^{\bar{c}} u_h(min(c_j, b_j)) f(c). \end{aligned} \tag{3}$$

Next, consider the option price, $OP_{k-1,k}$, for a trip that offers a bag limit of $k$ fish instead of a trip offering a bag limit of $k-1$ fish:[5]

$$\begin{aligned} EU(y-p_j-OP_{k-1,k}, x_j, k) &= EU(y-p_j, x_j, k-1), \\ \alpha(y-p_j-OP) + u_x(x_j) + \sum_{c=0}^{\bar{c}} u_h(min(c_j, k)) f(c) &= \alpha(y-p_j) + u_x(x_j) + \sum_{c=0}^{\bar{c}} u_h \\ &\quad (min(c_j, k-1)) f(c), \\ \alpha OP_{k-1,k} &= \sum_{c=0}^{\bar{c}} [u_h(min(c_j, k)) \\ &\quad - u_h(min(c_j, k-1))] f(c), \\ OP_{k-1,k} &= [u_h(k) - u_h(k-1)][1-F(k-1)] \,/\, \alpha, \end{aligned} \tag{4}$$

where $F$ is the cumulative density of catch. Essentially, the option price for each $k$th $-$ 1 to $k$th potential harvest increment is the dollar value for the actual harvest increment $((u_h(k) - u_h(k-1))/\alpha)$ weighted by the probability of catching at least $k$ fish.[6] Expression 4 is the discrete, stochastic version of Whitehead's (2006) expression (equation 9 on page 1727) for the marginal WTP for a bag limit as the product of the marginal WTP for harvest times the marginal productivity of the bag limit in the household production function for harvest. Given the harvest production function we defined earlier, $h_j = min(c_j, b_j)$, marginal productivity of the bag limit equals 1 when $c_j >= b_j$ and 0 otherwise. Therefore, as Whitehead (2006) says, "For those anglers for whom the bag limit is non-binding, willingness to pay for a change in the bag limit is equal to zero even if willingness to pay for harvest is positive" (1727). However, by making catch, $c$, random we are introducing a way to scale the WTP for harvest increments by the probability of catching (at least) the increment to obtain the WTP (option price) for the bag limit and vice versa.

Note that when the bag limits are dummy-coded in the utility function as shown in expression 2, the difference between two parameters on the bag limit dummy variables then gives the numerator in expression 4, that is, $\delta_k - \delta_{k-1} = [u_h(k) - u_h(k-1)][1-F(k-1)]/\alpha$. With this relationship in mind, we can use the estimated utility parameters in bag limit space along with information on the cumulative distribution of catch, $F(c)$, to recover the compensating surplus for harvest increments. Specifically, the CS for the $k-1$ to $k$th increment is defined as $CS_{k-1,k} = [u_h(k) - u_h(\mathrm{k}-1)]/\alpha$,

5. Our initial focus is on one-fish increments to ease the exposition. The results for larger increments involve more complex expressions, as we show at the end of this section.

6. We specify compensating welfare measures, but there is no difference between the compensating and equivalent welfare measures given the assumptions of the model.

which can be recovered from the dummy-coded specification as $CS_{k-1,k} = OP_{k-1,k}/[1 - F(k-1)] = (\delta_k - \delta_{k-1})/[1 - F(k-1)]\alpha$. If we only have information on the CS for harvest increments, but we need option prices for policy analysis, then we can also use (4) to obtain the option price as $OP_{k-1,k} = CS_{k-1,k}\ [1 - F(k-1)]$.

It is important to note that while expression 4 enables us to go back and forth from *OP* to *CS*, we cannot identify the source of differences between these two welfare measures without further assumptions: the differences between *OP* and *CS* could be due to the shape of the utility function, the catch distribution, or both. Differences could also be due to the shape of the probability weighting function, but we have assumed this away by maintaining the expected utility hypothesis.

Interestingly, if we assume risk neutrality in harvest so that utility is linear in expected harvest, that is, $\alpha(y - p_j) + \beta\Sigma_{c=0}^{\bar{c}}\ min(c_j, b_j)f(c)$, then there are multiple ways to recover the same underlying preference parameter, $\beta$. Each way is based on each of the bag limit parameter increments and the corresponding cumulative catch distribution function. That is, with risk neutrality, application of expression 4 over any increment should yield the same number for $\beta$. Otherwise, some other preference structure (e.g., risk aversion) applies, assuming the cumulative distribution of catch, $F(c)$, is measured correctly.

The assumption of risk neutrality in harvest (i.e., utility linear in harvest) is actually required to say anything at all about the relationship between bag limit option prices and the CS for harvest when bag limit *increments larger than one* are considered. For example, solving a version of equation 4 for the option price to go from a two- to four-fish bag limit gives

$$OP_{2,4} = [f(3)[u_h(3) - u_h(2)] + [1 - F(3)][u_h(4) - u_h(2)]] / \alpha, \quad (5)$$

which is based on the composite of two different option prices that cannot be separated without further assumptions. If we assume risk neutrality in harvest (i.e., utility linear in harvest), then expression 5 can be generalized for any two-fish bag limit increment as the following:

$$OP_{k-2,k} = (\beta / \alpha)[f(k-1) + 2[1 - F(k-1)]], \quad (6)$$

which can be solved for a constant CS per harvest, $\beta/\alpha$, given information on the catch distribution and the option price to go from two to four fish.

## EXAMPLE APPLICATION

### CHOICE EXPERIMENT DATA

In 2013 the National Marine Fisheries Service and the Gulf States Marine Fisheries Commission collaborated on a mail survey of recreational anglers fishing in the Gulf of Mexico (GOM). The primary purpose of the survey was to measure preferences for offshore charter fishing for key species such as red snapper, grouper, dolphinfish, king mackerel, and other snappers (aggregate snapper). Anglers fishing from charter boats in the GOM took nearly 260,000 angler trips targeting these species in 2013.[7] These target trips accounted for 28% of the charter fishing angler trips in the GOM during 2013.

Anglers fishing in the GOM must be cognizant of a variety of harvest regulations, such as seasonal closures, size limits, bag limits, and area closures, that can vary depending on the

7. Data are from the Marine Recreational Information Program for anglers fishing from Florida to Louisiana (Texas is not part of the program). See https://www.countmyfish.noaa.gov.

distance from shore (i.e., state versus federal marine waters) and among states. Regulations on the recreational catch of red snapper have been particularly strict. For example, federal regulations limited the red snapper season to only 28 days during the summer of 2013 for all federal waters in the Gulf of Mexico.[8]

The intended population for the survey was anglers who had previously fished or were likely to fish offshore in the Gulf of Mexico by charter boat. We used two complementary sample frames. The first frame comprised anglers who purchased a three-day license to saltwater fish from a charter boat departing from Louisiana. Other GOM states did not require a special license to fish in marine waters from a charter boat, so another approach was used to assemble a frame of charter boat anglers in these states. This second frame consisted of anglers who were intercepted as part of the Marine Recreational Information Program (MRIP) Access Point Angler Intercept Survey in Florida, Alabama, and Mississippi between March 2013 and November 2013. Any angler who had been on a charter trip in the previous year was asked to participate in the mail survey.

A modified Dillman mail survey protocol was used. Anglers from each frame first received a postcard alerting them that they would be receiving a survey in the mail asking about their recreational fishing preferences. A few days later, a full survey packet was sent out to all anglers; the packet included a cover letter, the 16-page survey, and a business-reply envelope. After a week, a postcard reminder was mailed out to any angler who had not yet returned the survey. After three weeks, another survey packet and cover letter was mailed to any nonresponding anglers. Mailings were conducted in three stages, in June 2013, September 2013, and January 2014. For each mailing, all charter angler addresses collected via the MRIP intercept survey for the months prior to the mailing were included.

There were 1,237 anglers sampled from the Louisiana charter angler license frame and the MRIP intercept frame combined. A total of 401 of these anglers returned a usable survey. This 32% response rate is slightly better than response rates for angler mail surveys based on fishing license databases. For example, Shideler et al. (2015) encountered a relatively low response rate to a mail survey drawn from licensed Florida anglers. However, they found no evidence of sample selection bias.

The main part of the questionnaire was the stated preference choice experiment, in which anglers were presented with a series of six choice questions. Each choice question asked the angler to select their preferred trip between two types of offshore charter fishing trips (trip A and trip B), each of which varied on nine trip attributes. The attributes were based on experience with a 2009 survey of anglers fishing from North Carolina, South Carolina, Georgia, and the east coast of Florida (Liese and Carter 2017). We tested and tailored the attributes for the Gulf of Mexico using three focus groups covering the geographic range of the study area.

In a follow-up question, we asked respondents whether they would actually take their preferred trip if it was the only option available on their next trip (Brazell et al. 2006). An example of the choice question is given in figure 1. Before estimation we created a third "no-trip alternative" based on the follow-up question: the choice outcome for any respondent who stated that they would not take their preferred trip was set to the no-trip alternative.

The first four trip attributes included the length of the charter trip (full-day, half-day), the size of the boat (40 ft, 50 ft), the captain's reputation (known, unknown), and the cost of the trip (half day:

8. https://www.fisheries.noaa.gov/history-management-gulf-mexico-red-snapper. Accessed November 12, 2021.

**C1** Please compare the features of Gulf of Mexico offshore charter fishing trips A and B and answer the questions below. Please keep in mind that:

- You can take up to **6 passengers**
- You **might catch** various types of fish, but **catch is not guaranteed**
- Trips A and B are **exactly the same** except for differences shown

| Trip Features | | Trip A | Trip B |
|---|---|---|---|
| Length of trip | | Full-day | Full-day |
| Vessel size | | 50 ft | 40 ft |
| Captain's reputation | | Unknown | Known |
| Charter fee (excluding tip) | | $1,000 | $1,200 |
| Regulations in effect at the place and time of trip | Dolphin fish | 10 bag | 5 bag |
| | All snappers / Red snapper | 10 bag / 2 bag | 5 bag / 1 bag |
| | All groupers | 6 bag | closed |
| | King mackerel | closed | 3 bag |
| | Other regulations | As in 2013 | As in 2013 |

**C1** a) Which of these two trips do you **prefer**? ☐ Trip A ☐ Trip B ☐ I don't know

**C1** b) Please **circle** one trip feature in the table above which **most influenced** your preference of one trip over the other.

**C1** c) If your **preferred trip** was the only option available for your next saltwater charter fishing trip, then what would you choose to do?

☐ Take my preferred trip
☐ Do something else, but not take a saltwater charter fishing trip
☐ I don't know

Figure 1. Example Choice Question in Charter Boat Survey

400, 600, 800; and full day: 1,000, 1,200, 1,400).[9] Note that the price of the charter trip is nested according to the length of the trip to make the prices more realistic. Also, the price of the trip is shown for the boat, as is customary for charter trips. The instructions indicated that up to six people could be taken on each trip, but did not specify number of passengers. To model behavior at the individual angler level, we defined the price of each as the fee for the boat shown in the experiment question divided by an assumed number of passengers on the boat. We assume that, on average, the charter fee for the boat is split evenly among the number of passengers. Eighty-three of the completed charter trip surveys were based on addresses collected from anglers intercepted on charter trips. The average number of passengers on these intercepted charter trips was 4.81. By comparison, the average number of passengers on all charter trips in the Gulf of Mexico between 2011 and 2013

9. All monetary values in this paper are in 2013 US dollars.

from the Marine Recreational Information Program was 5.02. Therefore, we assume that party equals five for all of the hypothetical trip options.

The remaining five attributes referred to the regulations in place at the time and location of the trip; regulations specified the total bag limit and whether the season was open or closed (zero bag limit). The bag limit attribute levels (numbers of fish) were as follows: dolphinfish (5, 10), aggregate snapper (5, 10), red snapper (0, 1, 2, 3), grouper (0, 2, 4, 6), and king mackerel (0, 1, 2, 3), where the numbers in parentheses refer to the number of fish in the daily bag limit. The final attribute was fixed across all versions to read that all other regulations (including regulations for other species, other closed seasons, etc.) were as in 2013.

With one 6-level attribute, four 2-level attributes, and three 4-level attributes, the total possible types of trips is $6 \times 16 \times 64 = 6{,}144$ types. We used SAS software to generate a fractional factorial choice design from these potential trip types (Kuhfeld 2010). Specifically, a computer algorithm was used to search over the 6,144 potential trip types for 96 pairs of trips (choice sets) that minimized the variance (D-efficiency) of the logit conditional based on an assumed parameter vector (Ferrini and Scarpa 2007). For the purposes of the experimental choice design algorithm, we used a linear angler utility function, including interactions between trip duration and the continuous versions of the non-cost attributes. The parameters on the first three binary attributes (length of trip, vessel size, and captain's reputation) were assumed to be 3, 0.5, and 1, respectively, and the parameter on cost was assumed to be –1. All other parameters were fixed at 0 in the experimental choice design algorithm. The 96 pairs of trips were separated into 16 six-choice set blocks, and each angler saw only one block. Another SAS software algorithm from Kuhfeld (2010) was used to create the blocking factor to be (nearly) uncorrelated with every attribute of both alternatives.

## SPECIFICATION AND ESTIMATION

The choice experiment questions involved a preference between trip A, trip B, and no trip based on the question shown in figure 1. Based on expression 2 we specify angler expected utility for trip alternative $j$ in each choice question as the following:

$$\begin{aligned} V_j &= EU(y - p_j, x_j, b_j) + \varepsilon_j \\ &= \lambda z_j - \alpha p_j + \gamma x_j + \sum_{s=1}^{S} \sum_{m=1}^{M_s} \delta_{s,m} D_{q,j,s,m} + \varepsilon_j, \end{aligned} \tag{7}$$

where $\varepsilon_j$ is the random portion of utility and $z_j$ is an indicator that equals 1 for the no-trip alternative and 0 for the other alternatives such that $\lambda$ is a constant for the no-trip alternative. In the second line we have dropped income because it does not vary among trip alternatives. The trip attributes in $x_j$ for the choice experiment are binary, so $u_x(\cdot)$ from equation 2 is shown as linear. Also, relative to expression 2, we have added a subscript, $s$, to denote species. As described in the previous section, there are five species in the choice experiment ($S = 5$): two species with two bag limit levels ($M_s = 2$) and three species in the experiment with three levels ($M_s = 3$). Recalling expression 1, there are two sources of uncertainty in equation 7: the uncertainty associated with the catch distribution and the uncertainty associated with the choice between trip alternatives (including no trip). The former, catch uncertainty, is random from the perspective of the angler and the researcher before the trip choice, whereas the latter, choice uncertainty, is random only from the perspective of the researcher.

Table 1. Non-price Attribute Names and Definitions

| Attribute Name | Active | Reference |
|---|---|---|
| Full day | Full-day trip | Half-day trip |
| 50 ft | 50 ft boat | 40 ft boat |
| Known reputation | Known captain reputation | Unknown captain reputation |
| Dolphinfish10 | 10 dolphinfish bag | 5 dolphinfish bag |
| Snapper10 | 10 snapper bag | 5 snapper bag |
| Red1 | 1 red snapper bag | 0 red snapper bag |
| Red2 | 2 red snapper bag | 1 red snapper bag |
| Red3 | 3 red snapper bag | 2 red snapper bag |
| Grouper2 | 2 grouper bag | 0 grouper bag |
| Grouper4 | 4 grouper bag | 2 grouper bag |
| Grouper6 | 6 grouper bag | 4 grouper bag |
| King1 | 1 king mackerel bag | 0 king mackerel bag |
| King2 | 2 king mackerel bag | 1 king mackerel bag |
| King3 | 3 king mackerel bag | 2 king mackerel bag |

Table 2. Red Snapper Bag Limit Backward Difference Coding

| Bag Limit | Red1<br>Bag Limit 1 v. 0 | Red2<br>Bag Limit 2 v. 1 | Red3<br>Bag Limit 3 v. 2 |
|---|---|---|---|
| 0 fish | –0.75 | –0.50 | –0.25 |
| 1 fish | 0.25 | –0.50 | –0.25 |
| 2 fish | 0.25 | 0.50 | –0.25 |
| 3 fish | 0.25 | 0.50 | 0.75 |

The non-price attributes from the choice experiment in $x_j$ and $D_{j,s,m}$ are defined in table 1, where the second and third columns indicate the meaning of the active and reference (or base) values of the attribute. The reference value for the bag limit attributes with more than two levels is the previous level, because we use backward difference effects coding. For example, the coefficient on the variable Red1 refers to the change in utility associated with going from zero-fish to one-fish bag limit for red snapper. The coding system used for the red snapper bag limit attributes is shown in table 2.[10] The coding system for the king mackerel and grouper bag limit attributes is identical to the system shown in table 2 for red snapper. However, the bag limits for grouper are in two-fish increments.

We assume that the random portion of utility, $\varepsilon_j$, for each angler is an identically distributed extreme value and estimate the conditional logit model parameters via maximum likelihood using `apollo` in *R* (Hess and Palma 2019). More complex error and parameter assumptions (e.g., mixed logit in WTP space) yielded comparable results for average angler preferences, so we chose to focus on the simpler conditional logit model for the purposes of this paper.[11]

10. Further details and the general formulation for the backward difference coding system are available at the UCLA Statistical Consulting Group website (UCLA Statistical Consulting Group 2019).

11. The results of more complex estimators are available upon request. Results from more complex estimators using a different sample from the same survey are also presented in a companion paper (Carter, Lovell, and Liese 2020).

## RESULTS

### PARAMETER ESTIMATES

The estimates of the expected utility model are shown in table 3. The second and third columns show the estimated utility parameters and the WTP for the trip attributes. For each trip attribute, we calculate the standard error of the WTP estimates (i.e., the negative of the ratio of a trip attribute utility parameter to the charter fee parameter) using the delta method with `apollo` in *R* (Hess and Palma 2019). Note that for the price and bag limit parameters and the WTP estimates we use one-sided *p*-values to represent statistical significance because, as specified, we expect the utility parameters and WTP estimates to be positive: the (negative of the) price parameter and option prices cannot be negative by definition.[12] We are specifically testing the null hypothesis that a parameter is less than or equal to zero versus the alternative hypothesis that the parameter is greater than zero. We use two-sided tests for the parameters and WTP for the other trip attributes.

Our main interest is the bag limit WTP results in the last column of table 3. However, a brief summary of the WTP results for the other trip attributes will provide some context. The mean WTP for a full-day over half-day trip is around $66 per angler. The size of the vessel does not appear to influence trip choices, at least for the two sizes considered in the choice experiment. The reputation of the captain is very important for anglers fishing on charter boats, whereby the value of a trip increases by $99 per angler when the reputation is known.

The WTP results in the last column for the bag limit attributes represent the bag limit option prices. Based on expression 4, each option price is a function of the underlying WTP for the bag limit increment and the probability of catching the bag limit.

The option prices for the 5- to 10-fish increment in the bag limit for dolphinfish and aggregate snapper are significantly different from zero at the 0.01 level and very close to each other at $23 and $25, respectively.

The option prices for red snapper bag limit increments appear to be decreasing, but the option price for the third bag limit increment is not significantly different from zero: on average anglers fishing on charter boats are willing to pay about $17 each for the option to open the red snapper season with a one-fish bag limit and $19 for the option to keep a second fish, but nothing more for the third bag limit increment. Red snapper is a popular fishery that, in the years leading up to the angler survey, was open for only a few weeks a year with a two-fish bag limit. Anglers on charter boats also might not be interested in keeping many fish if they are on vacation, away from home.

The option prices for the two-grouper increments exhibit decreasing marginal value, starting with $63 for the first two fish and $29 for the third and fourth fish. The marginal WTP for the fifth and sixth grouper is not greater than zero at any reasonable level of significance. This could be because the aggregate grouper bag limit in the Gulf of Mexico has been four fish since 2009 or because anglers are, again, not interested in keeping a lot of fish on a charter trip if they are away from home.

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12. We used the negative of the price in the estimation, but did not constrain the corresponding parameter to be positive. Similarly, we did not constrain the bag limit parameters (option prices) to be positive. We tried the approach suggested by Carson and Czajkowski (2019), but ran into estimation issues, likely related to the difficulty in identifying exponentiated parameters. These issues are highlighted in a recent working paper by Daly, Hess, and Dios Ortúzarc (2020). That said, while the parameters we estimated could have technically been negative, we used theory to inform the one-sided hypothesis tests.

Table 3. Conditional Logit Utility Parameter and WTP Estimates

| | Utility Parameters | WTP |
|---|---|---|
| Charter fee | 0.009*** | |
| | (0.002) | |
| Full day | 0.566*** | 65.712*** |
| | (0.197) | (13.256) |
| 50 ft | –0.071 | –8.245 |
| | (0.057) | (7.552) |
| Known reputation | 0.857*** | 99.473*** |
| | (0.086) | (15.098) |
| Dolphinfish10 | 0.202*** | 23.490*** |
| | (0.051) | (7.299) |
| Snapper10 | 0.211*** | 24.559*** |
| | (0.053) | (7.721) |
| Red1 | 0.145** | 16.798* |
| | (0.085) | (10.609) |
| Red2 | 0.160** | 18.545** |
| | (0.087) | (10.435) |
| Red3 | 0.007 | 0.821 |
| | (0.078) | (9.106) |
| Grouper2 | 0.540*** | 62.695*** |
| | (0.091) | (15.234) |
| Grouper4 | 0.248*** | 28.776*** |
| | (0.088) | (11.661) |
| Grouper6 | 0.078 | 9.073 |
| | (0.086) | (10.068) |
| King1 | 0.139* | 16.142* |
| | (0.086) | (10.043) |
| King2 | 0.092 | 10.648 |
| | (0.090) | (10.769) |
| King3 | 0.065 | 7.526 |
| | (0.083) | (9.724) |
| No trip | –1.806*** | –209.694*** |
| | (0.223) | (24.239) |
| Log likelihood | –2,037 | |
| Obs. | 2,253 | |
| Anglers | 401 | |

Note: Robust standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Only the option price for the first king mackerel bag limit is statistically greater than zero at \$16. These results could reflect preferences for catch and release among king mackerel anglers (Carter and Liese 2012). The bag limit for king mackerel in the Gulf of Mexico has been two fish since 2000.

**The value of harvest based on the estimated option prices.** The empirical distribution of catch per angler for each species is shown in table 4 as derived from the data reported in the Marine Recreational Information Program intercept interviews for the Gulf of Mexico from 2011 to 2013. We used the interviews for trips where anglers reported the species of interest (dolphinfish, aggregate snapper, red snapper, groupers, or king mackerel) as their primary or secondary target. The

Table 4. 2011–13 Distribution of Catch Per Angler in the Gulf of Mexico: Charter Boats

| No. Fish | Dolphinfish | Aggregate Snapper | Red Snapper | Grouper | King Mackerel |
|---|---|---|---|---|---|
| 0 | 0.556 (0.052) | 0.210 (0.072) | 0.173 (0.151) | 0.263 (0.063) | 0.673 (0.078) |
| 1 | 0.111 (0.017) | 0.135 (0.012) | 0.174 (0.047) | 0.101 (0.018) | 0.158 (0.028) |
| 2 | 0.072 (0.010) | 0.104 (0.013) | 0.159 (0.037) | 0.076 (0.012) | 0.076 (0.023) |
| 3 | 0.052 (0.007) | 0.083 (0.013) | 0.130 (0.026) | 0.062 (0.009) | 0.040 (0.014) |
| 4 | 0.039 (0.005) | 0.069 (0.012) | 0.101 (0.019) | 0.052 (0.007) | 0.022 (0.008) |
| 5 | 0.031 (0.004) | 0.057 (0.011) | 0.076 (0.015) | 0.045 (0.005) | 0.013 (0.005) |
| 6 | 0.024 (0.003) | 0.048 (0.009) | 0.055 (0.012) | 0.039 (0.004) | 0.007 (0.003) |
| 7 | 0.020 (0.003) | 0.041 (0.008) | 0.040 (0.010) | 0.034 (0.003) | 0.004 (0.002) |
| 8 | 0.016 (0.002) | 0.035 (0.006) | 0.028 (0.009) | 0.030 (0.003) | 0.003 (0.001) |
| 9 | 0.013 (0.002) | 0.030 (0.005) | 0.020 (0.007) | 0.027 (0.002) | 0.002 (0.001) |
| 10 | 0.011 (0.002) | 0.025 (0.004) | 0.014 (0.006) | 0.024 (0.002) | 0.001 (0.001) |
| 11 | 0.009 (0.002) | 0.022 (0.004) | 0.009 (0.005) | 0.022 (0.002) | 0.001 (0.000) |
| 12 | 0.007 (0.001) | 0.019 (0.003) | 0.006 (0.004) | 0.020 (0.002) | 0.000 (0.000) |
| 13 | 0.006 (0.001) | 0.016 (0.003) | 0.004 (0.003) | 0.018 (0.002) | 0.000 (0.000) |
| 14 | 0.005 (0.001) | 0.014 (0.002) | 0.003 (0.002) | 0.016 (0.002) | 0.000 (0.000) |
| 15 | 0.004 (0.001) | 0.012 (0.002) | 0.002 (0.002) | 0.015 (0.002) | 0.000 (0.000) |
| Mean | 1.760 (0.223) | 3.582 (0.508) | 3.126 (0.661) | 3.230 (0.271) | 0.717 (0.207) |

Note: Standard errors are in parentheses.

first 16 rows of table 4 show the distribution of catch per angler trip for each species up to 15 fish, and the last row shows the mean catch per angler trip. We use these distributions to recover the *CS* estimates from the option price estimates shown in the last column of table 3.

The *CS* calculation for the species (red snapper and king mackerel) with the one-fish bag limit increments is based on expression 4. For example, the *CS* to go from one to two harvest of red snapper is given by the option price from table 3, 18.5, divided by $1 - F(1) = 0.65$.

Recall that the option price for fish increments larger than one are more complex functions of the underlying *CS* and catch distribution as demonstrated in expression 5 for the option price to go from a two- to four-fish bag limit. However, if we assume that utility is linear in harvest (i.e., risk neutrality in harvest), then the underlying *CS* value can be recovered. We use the general expression for two-fish increments shown in equation 6 to recover the *CS* for grouper. For example, based on expression 6, the *CS* to go from two to four harvest of grouper is given by the option price from table 3, 28.8, divided by $f(k-1) + 2[1 - F(k-1)] = 1.06$. At first glance, dividing the option price by a factor larger than 1 seems to suggest that the underlying *CS* is smaller than the option price. However, the option price is actually for a two-fish increment, whereas the *CS* is for a one-fish harvest increment. To obtain the comparable *CS* for a two-fish increment, we have to multiply the recovered *CS* estimate by 2 or divide the option price for the two-fish increment by 2.

The option price expression for the 5- to 10-fish increments for dolphinfish and aggregate snapper, assuming that utility is linear in harvest, is $OP_{5,10} = (\beta/\alpha)\,[f(6) + 2f(7) + 3f(8) + 4f(9) + 5[1 - F(9)]]$. Again, the recovered *CS* estimate is for a one-fish increment. In this case, to obtain the comparable *CS* for the five-fish increments represented by the option prices, we would have to multiply the *CS* estimates by 5 or divide the option price estimates by 5.

The estimates of the *CS* for one-fish increments in actual harvest recovered for each species and bag limit combination are shown in the fourth column of table 5. The first column (Species) indicates the species for which the one-fish increment *CS* is calculated, and the second column (Basis)

Table 5. Compensating Surplus for a One-Fish Increment in Known Harvest Based on the Option Price for Different Bag Limit Increments

| Species | Basis | Linearity Required | Compensating Surplus | Lit. Range |
|---|---|---|---|---|
| Aggregate snapper | Snapper10 | Yes | 48 (18)*** | (12, 34) |
| Dolphinfish | Dolphin10 | Yes | 19 (7)*** | (15, 556) |
| Red snapper | Red1 | No | 20 (13)* | |
| Red snapper | Red2 | No | 28 (17)** | (9, 137) |
| Red snapper | Red3 | No | 2 (18) | |
| Grouper | Grouper2 | Yes | 46 (12)*** | |
| Grouper | Grouper4 | Yes | 27 (11)*** | (16, 137) |
| Grouper | Grouper6 | Yes | 11 (12) | |
| King mackerel | King1 | No | 49 (33)* | |
| King mackerel | King2 | No | 63 (67) | (–30, 99) |
| King mackerel | King3 | No | 81 (108) | |

Note: Standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

indicates the option price from the last column in table 3 that is used in the *CS* calculation. The third column (Linearity Required) indicates whether it was necessary to assume that utility is linear (i.e., anglers are risk neutral) in harvest in order to perform the *CS* calculation in the row. We are able to examine the shape of the relationship between *CS* and harvest increments for red snapper and king mackerel because we did not require the linearity assumption for these species. The standard errors for the estimates of *CS* in table 5 are calculated using the delta method for a ratio based on the option price standard errors in table 3 and the standard errors of the empirical distributions in table 4.

It is beyond the scope of this paper to conduct a thorough comparison of the derived *CS* per fish estimates shown in table 5 with estimates from previous research for the same species. However, in the last column we show the range of *CS* per fish for each species based on estimates in the literature. The range of estimates are based on the results and literature review in Carter and Liese (2012), Lovell and Carter (2014), and Haab et al. (2012). The calculated *CS* estimates in the fourth column for all species, except snapper, are within the range of estimates in the literature. Unfortunately, it is difficult to assess convergent validity given the very wide range of estimates in the literature.

For red snapper, the first two *CS* values calculated using the first two different option prices (Red1 and Red2) are relatively similar, though there is limited statistical evidence to suggest that either of these numbers is different from zero. This suggests that, on average, anglers may be risk neutral in harvest for red snapper.[13] We can use the delta method for that standard error of parameter differences to test the hypothesis that the *CS* for one-fish increments based on the different option prices are equal. We cannot reject the null hypothesis that the difference between the *CS* estimate for the one-fish increments is zero for red snapper based on the option prices for the first two red snapper ($p$-value $= 0.647$ comparing *CS* based on Red1 with *CS* based on Red2).

The *CS* estimates for king mackerel based on the first option price (King1) appear different from the *CS* estimates based on the second (King2) and third (King3) option prices. However, we cannot reject the null hypothesis that the *CS* estimates for king mackerel are greater than zero at any reasonable level. Given the large standard errors it is not surprising that we cannot reject

13. As noted earlier, if the utility function is linear in harvest (risk neutrality), then we would expect the derived *CS* estimates based on different option prices for the same species to be the same within species because each number is an estimate of the constant incremental value of (expected) harvest, that is, $[u_h(k) - u_h(k-1)]/\alpha = \beta/\alpha \quad \forall k$.

the null hypothesis that the difference between the *CS* estimate for the one-fish increments is zero for king mackerel ($p$-value = 0.573 comparing *CS* based on King1 with *CS* based on King2 and $p$-value = 0.555 comparing *CS* based on King2 with *CS* based on King3).

The results for red snapper and king mackerel might provide some evidence that the utility function is linear in harvest for these species. However, the evidence is weak given the relatively high standard errors on the derived *CS* estimates. Other shapes are possible for the utility function with respect to harvest.

For the species that required the linearity assumption (aggregate snapper, dolphinfish, and grouper), the *CS* for the one-fish increments based on different option prices should be equal by definition. However, only grouper has the multiple *CS* estimates necessary to evaluate the linearity assumption.[14] The *CS* for a one-fish increment based on the option price for the first two fish (Grouper2) is considerably larger than the *CS* for a one-fish increment based on the other two option prices (Grouper4 and Grouper6). Again, in this case, the *CS* estimates based on the different option prices should be equal by definition. We cannot reject the null hypothesis that the difference between the *CS* estimates for the one-fish increments is zero for grouper ($p$-value = 0.131 comparing *CS* based on Grouper2 with *CS* based on Grouper4 and $p$-value = 0.161 comparing *CS* based on Grouper2 with *CS* based on Grouper6).

In closing this section, we consider two hypothetical examples that seek to calculate the change in aggregate value associated with a a policy change. One example simply demonstrates how we would use the option price estimates presented in table 3 to calculate aggregate effect of a change in the bag limit. The other example illustrates a case in which we have the bag limit option price estimates, but actually need estimates of the value (*CS*) per kept fish to complete the analysis.

In the first case, we estimate the aggregate value of a hypothetical increase in the Gulf of Mexico gag grouper bag limit from two to four fish. Assuming, as is frequently done in applied policy analysis, that the aggregate number of fishing trips will not change when the bag limit changes, the change in aggregate value is given by the option price for the bag limit increment under consideration times the number of trips. In practice, it is challenging to identify the correct domain over which to aggregate trips. Do we use all trips, only trips that targeted the species of interest, only trips that caught the species of interest, or some other variation? In this case, we multiply the number of trips that targeted gag grouper, 19,937, by the option price to go from two to four fish in table 3, \$28.80, to get the aggregate change in value of \$573,715.[15]

In the second example, assume that we are evaluating a hypothetical decrease in the amount of the total allowable harvest of Gulf of Mexico red snapper that is allocated to the charter boat sector, but we only have information on the bag limit option prices. It would not be appropriate to apply a bag limit option price estimate to the proposed change in allowable harvest to calculate the aggregate value because the option prices are ex ante, per trip measures, not ex post, per fish estimates. In the example, we assume that the aggregate charter boat harvest of red snapper will decrease by 15% from 2013 levels (180,951 fish). In this case we multiply the expected change in harvest, 27,143, by the *CS* for red snapper in table 5. Based on our results, we could use either of the first two CS values for red snapper reported in the table, but we choose the one based on the option price to go from one to two fish, \$28.40, because the red snapper bag limit

14. We cannot test the assumption of constant incremental *CS* for aggregate snapper and dolphinfish because we have only one measured increment, 5 to 10 fish, for these species.

15. The estimate of the number of charter trips targeting gag grouper comes from the MRIP for 2013 in the Gulf of Mexico.

was two fish in 2013. Multiplying the change in harvest by the CS gives an estimate of the decrease in aggregate value of $771,533.[16]

## DISCUSSION

Bag limits are a type of costless contingent claim, conditional on the distribution of catch per angler. We show that angler willingness to pay for an incremental change in the bag limit is an option price and show how it relates to the value of changes in harvest. Conceptually, the option price for each $k$th – 1 to $k$th potential harvest increment is the dollar value for the harvest increment weighted by the probability of catching at least $k$ fish. Assuming that expected utility theory holds for anglers' preferences over harvest levels, the option prices for one-fish increments in bag limits can be used to "recover" the underlying value for ex post or known changes in one-fish increments of fish kept (harvest) or vice versa. For increments larger than one fish, we showed that more stringent assumptions (i.e., risk neutrality in harvest) are necessary to easily go back and forth between the option price for a bag limit increment and compensating surplus for the same increment.

Using data from a 2013 choice experiment survey of anglers fishing offshore in the Gulf of Mexico, we estimate option prices for incremental changes in bag limits on key species. We then use information on the distribution of catch to recover estimates of the value (*CS*) of changes in actual harvest. The option price directly measures the value of bag limit change and therefore is immediately useful in policy analysis. That is, when using estimated values for changes in harvest for bag limit analyses, we must first determine how the bag limit change will affect harvest. If this is not possible, then a method to convert the estimated value for a change in harvest to the value for a change in a bag limit will be helpful. The opposite case could also occur, whereby we need an estimate of the value of harvest but there is only an estimate for the bag limit option price available. We provided two examples of how the conversion process works given different sets of information.

Our approach would appear applicable to cases where the function for a household-produced commodity can be defined as the minimum of an uncertain input and a quantity constraint. We considered the production of harvest (fish kept) as the minimum of uncertain catch and the bag limit. A key working assumption is that catch is exogenous, that is, that expenditures during a trip cannot affect the catch for that trip. More work is necessary to determine whether the derivation applies more generally to cases where anglers can significantly affect the number of fish caught during a trip. The empirical model of the catch distributions could be modified to generate angler-specific probabilities that could accommodate the potential endogeneity of catch (McConnell, Strand, and Blake-Hedges 1995). Another potential application might be the production of days spent recreating as the minimum of the supply of uncertain recreation days (e.g., due to weather) and the season length. However, this case is complicated because angler effort is clearly endogenous to the problem.

The work presented in this paper could be extended in several directions. First, it would be helpful to apply the method to other estimates of option prices and *CS* to determine the validity of the conversion method and, therefore, the underlying assumptions of the utility model. It would be interesting to conduct a study that estimates option prices and *CS* for the same units from the same sample to more precisely determine how well the conversion method works. Such

16. The estimate of the charter boat gag grouper harvest comes from the MRIP for 2013 in the Gulf of Mexico.

a study could also elicit subjective catch probabilities. This suggests a related second extension that would aim to incorporate demand uncertainty, that is, cases where the angler is unsure that they will fish in the future or target a specific species (Cameron and Englin 1997). Demand uncertainty in the context of bag limits was introduced by Whitehead and Haab (2001).

Third, our derivations assumed that expected utility held. Future work could examine the relationship in practice between option prices and *CS* under different assumptions regarding the weighting of utility outcomes. We used risk neutrality to simplify the derivations, but other risk profiles (e.g., risk aversion) may be more applicable (Holzer and McConnell 2017). Furthermore, it appears that as long as the probability weighting function satisfies additivity and the weighted probabilities sum to 1, then our results could be extended to accommodate non-expected utility theory (Machina 2017).[17] Lastly, the work could be extended to more thoroughly investigate the results for increments larger than one fish.

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17. In terms of the notation of our model we would need $w(f(c_j)) + w(f(c_z)) = w(f(c_j) + f(c_z))$ for $j \neq z$ and $w(f(c_1)) + w(f(c_2)) + \ldots + w(f(\bar{c})) = 1$.

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