Valuing Sportfishing Harvest with the Demand for Boat Fuel

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ABSTRACT

This article presents a novel application of the essential input welfare measure to valuing sportfishing harvest. The approach was suggested 30 years ago and has only been applied two other times with market data and has never been applied in the recreation context. We model boat fuel as an essential input in the production of sportfish harvested offshore and trace the value of changes in harvest quality with shifts in the demand for boat fuel. To implement the model we generate the first estimate of the demand for sportfishing boat fuel using the infrequent-purchases model. The estimate of boat fuel price elasticity is more than six times larger than typical estimates for the household demand for automobile fuel. Our estimates of the value of fishing quality are similar to estimates using stated preference and travel cost methods, but have the advantage of being based on market purchases.

Key words: Boat fuel demand, essential input, recreational fishing, revealed preference, valuation.
JEL Codes: Q260, Q510, Q220.

INTRODUCTION

The value of sportfishing quality is needed in benefit-cost analysis of regulatory changes and resource allocation policy. There are many approaches available to estimate the value of sportfishing quality and a wide range of estimates in the literature (Johnston et al. 2006). Most estimates are generated via the travel cost method or stated preference techniques. Both approaches are subject to bias in practice (Randall 1994; Kling, Phaneuf, and Zhao 2012). Since the value of sportfishing quality cannot be measured directly and all existing approaches to valuation require strong assumptions, multiple valuation approaches are needed to triangulate its "true" value (Carson et al. 1996).

Several years ago we suggested one alternative strategy that uses variation in market prices for charter fishing trips to estimate the value of small changes in sportfishing quality measured as average harvest rates (Carter and Liese 2010). In this article we implement another approach using market data. It is based on Bockstael and McConnell's (1983) clever insight more than 30 years ago regarding an input that is essential in the production of a commodity valued by the household. The insight is often used to motivate welfare measures from the travel cost model with "travel" as the essential input. However, travel is also produced by the

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household and does not have an explicit market price. The analyst must assume that the marginal cost of travel is constant (or exogenously given), which is unlikely to hold in the context of wildlife recreation (Bockstael and McConnell 1999; Bockstael and McConnell 1981). The essential input approach has been attempted only a few times using an essential input *priced in the market* with mixed success (Dickie and Gerking 1991; Agee and Crocker 1996).

Our approach differs from the use of household production theory in the travel cost model in that the focus is on the production of fishing quality (harvest) rather than fishing days. Specifically, we follow Bockstael and McConnell (1983) and consider boat fuel as an essential input along with fishing quality into the production of offshore sportfishing harvest on each fishing day. This approach allows us to trace changes in the value of fishing quality via shifts in anglers' demand for boat fuel.

This article also reports on the first estimate of the demand for fuel on private recreational fishing boats. The storability of boat fuel across fishing days leads us to a novel application of the infrequency of purchases model (Deaton and Irish 1984) to estimate the fuel demand equation parameters. The results indicate, not surprisingly, that the demand for boat fuel is considerably more price elastic than the demand for automobile fuel.

Our estimate of angler willingness to pay (WTP) per fish is consistent with published estimates using stated preference and travel cost methods, but has the advantage of being based on market purchases. However, the mean estimate of angler WTP is not very precise, primarily due to data limitations. Therefore, we consider the application as a proof of the concept and a demonstration of how the approach can be applied.

We begin with a presentation of the valuation model and a discussion of the assumptions necessary to estimate the value of sportfishing quality using the estimated demand for boat fuel on private boat fishing days. Then, we describe the specification of the econometric model and the data. Finally, we present the results and summarize the conclusions. As part of the conclusions we describe the data elements necessary to improve the harvest value measure for other cases where boat fuel can be considered an essential input in the production of sportfishing quality.

DEMAND AND VALUATION MODEL

This section introduces a simple model of the input demand for fuel on private boat sportfishing days that can be used to estimate the value of changes in offshore fishing quality. The model is adapted from the general framework for welfare measurement in the household production framework (Bockstael and McConnell 1983). The adaptation differs slightly from the usual use of the household production framework in the context of recreation. Instead of modelling the production of recreation user days with a "travel" input, we focus on the production of (offshore) fishing quality with boat fuel. This limits the range of behaviour captured in the welfare measure. However, our approach has the advantage of being based on a purchased input, i.e., boat fuel, with a market price that avoids some of the issues associated with the nonlinear price problem in the household production model.

Assume that the angler has already decided on a marina or ramp from which to launch, the species to target, and how long to fish. All demand and welfare measures presented here are conditional on these decisions. This limited view of the angler choice problem is adopted because we do not have the necessary data in our application to parameterize a more complete model of angler behaviour. We have just enough data to model how anglers adjust their fuel usage given different levels of fishing quality available from the point of departure (marina or boat ramp). Most attempts to model on-water fishing destination choices have also used this restricted view of the angler decision problem (Milon 1988a,b). These studies, with the exception of Haab, Hamilton, and McConnell (2008), did not model the angler's choice of fishing launch sites. A more complete model that encompasses the broader consumer problem is left for future research.

Following Bockstael and McConnell (1981), the number of fish harvested per angler during a day of offshore fishing is given by:

$$z = f(x; h, k, q), \tag{1}$$

where x is the boat fuel used during the day, h is time on the water in hours, k is fishing capital (e.g., boat size), and q is the relative offshore fishing quality available when launching from a given marina or ramp site. It is important to emphasize that we are modelling the quality of fishing offshore for species that cannot be harvested from the shore. Furthermore, there are natural features (currents, bottom type, water depth, etc.) that differentiate the offshore fishing quality available to boats launching from different marinas or ramps.

Note that in the Bockstael and McConnell (1981) setup, z is the quality of the recreational fishing experience on any given day and annual catch is given by $t(w) \cdot z$, where $t(w)$ measures the production of days per year as a function of a set of inputs, w. They state "that when the catch rate is exogenous and marginal costs of w are constant the household production approach collapses to the travel cost method" (206). Our model takes the opposite approach in focusing on fishing quality while assuming that the number of fishing days is exogenous.

The angler problem on each fishing day is $\max_{x,r} [u(z, r) | y = px + r, z = f(x; h, k, q)]$, where $u(\cdot)$ is the angler utility function, y is angler income, p is the price per unit of boat fuel, and r is the quantity of a composite commodity with a price that has been normalized to one. The solution to the problem gives the demand for boat fuel on any given fishing day, $x(p, h, k, q)$, which can be used to measure the change in welfare per day as a result of changes in offshore fishing quality, q, if the following conditions hold: (1) offshore fishing quality, q, is weakly complementary to harvest, z, so that $du/dq = 0$ when $z = 0$, and (2) boat fuel, x, is essential to the production of harvest, z; i.e., $z = 0$ if $x = 0$ (Bockstael and McConnell 1983). Although untestable without further structural restrictions, these conditions are likely to hold in certain cases of sportfishing from a boat. The first condition could be invalidated if anglers have a conservation ethic. However, the latter condition is true for any species that cannot be harvested from the shore.

Under the two conditions, q is weakly complementary to x; i.e., the marginal utility of offshore fishing quality is zero when boat fuel is not purchased. Note that we could have started with this weak complementarity (WC) assumption, but the essential input argument is a more appealing link. In either case, the change in the area behind the compensated demand curve for boat fuel when fishing quality changes, measures the compensating variation for the change in q:

$$CV = \int_{p^0}^{p^*(q^1)} x^c(p, u^0, q^1, h, k)dp - \int_{p^0}^{p^*(q^0)} x^c(p, u^0, q^0, h, k)dp, \tag{2}$$

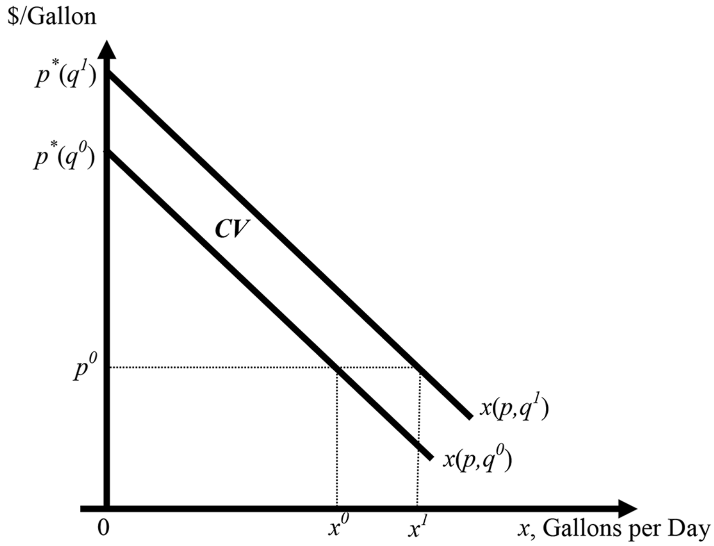

Figure 1. Compensating Variation (CV) per Day for a Change in the Harvest Rate Measured with Shifts in Weakly Complementary Boat Fuel Demand

where x^c is the compensated demand function, the zero and one superscripts indicate the state-of-the-world before and after the change in q, respectively, and p^* is the choke price of x^c conditional on the level q. This change is also illustrated in figure 1. The demand curves are shown as linear for ease of illustration. Other forms are possible in practice. The figure depicts the fuel demand curve shifting outward. However, in the essential input case, the direction of the shift in the demand curve is ambiguous due to the countervailing substitution and productivity effects of changes in q. An increase in offshore fishing quality, for example, will shift x^c outward when the fuel usage increase, due to the lower "effective price" of fish, is greater than the decrease in fuel usage, due to the improvement in fishing productivity. In any case, as noted by Bockstael and McConnell (2007, 255), the area between the two fuel demand equations measured at the different levels of q will equal the correct welfare measure as long as the two demand curves cross at some price greater than p^0, as required by the essential input argument.

SPECIFICATION AND ESTIMATION

We describe the data in detail in the next section. For now, it is important to note that our data has information on the amount of fuel *purchased* on each fishing day, but not the amount of fuel that was *consumed* on that day. This is because the data collection was designed with another purpose in mind. Consequently, it is possible to observe zero purchases, even though fuel is necessary to operate a power boat, because fuel is storable across trips and days. This situation is common in household surveys where the survey period is shorter than the frequency of purchase. Deaton and Irish (1984) developed an econometric model to deal with both purchases and consumption in what has become known as the "infrequent purchases model" (IPM). Blundell and Meghir (1987) extend the IPM to commodities (e.g., clothing) without corner solutions in consumption that is applicable to the case of fuel consumption when fishing from a power boat. Their model also fits with the notion of fuel as an essential input into the production of sportfishing harvest.

Specifically, we distinguish between fuel consumption, x_i, and purchases, $x_i^{'}$, per angler on fishing day i. Expected observed purchases are given by:

$$E(x_i^{'}) = E(x_i^{'}|D_i > 0)P_i + E(x_i^{'}|D_i \leq 0)(1 - P_i), \tag{3}$$

where P_i is the probability of purchasing fuel on day i, and D is a latent variable describing the decision to purchase (i.e., $D_i > 0$ if and only if $x_i^{'} > 0$). If, as is common in the IPM literature, consumption is interpreted as a long-term average rate of purchases that is predetermined when each purchase is made, then fuel purchases and consumption are equal, on average, $E(x_i^{'}) = E(x_i)$. Since the second term in (3) is zero, we can rewrite expected observed purchases in this case as:

$$E(x_i^{'}|D_i > 0)P_i = E(x_i). \tag{4}$$

For commodities (e.g., fuel) where consumption must occur in each period (day), Blundell and Meghir (1987) present a specification in which consumption is given in logarithms as:

$$\begin{gathered} \log x_i = g_i\beta + e_i \\ or \\ x_i = \exp(g_i\beta)\exp(e_i), \end{gathered} \tag{5}$$

where g_i is a vector of known factors (price, income, etc.) that determine boat fuel consumption, β is a vector of unknown parameters, and e_i may represent optimization errors and/or preference heterogeneity in consumption such that $E(\exp(e_i) \mid x_i) = 1$. Using expressions (4) and (5), the relationship between consumption and purchases on any given day can now be defined as:

$$\begin{aligned} x_i^{'}P_i &= x_i \exp(v_i) \\ &= \exp(g_i\beta)\exp(e_i)\exp(v_i) \\ &= \exp(g_i\beta)\exp(u_i), \end{aligned} \tag{6}$$

where v_i captures random discrepancies in the process linking the observable purchases dependent variable, $x_i^{'}$, with the corresponding latent consumption variable, x_i, such that $E(\exp(v_i) \mid x_i) = 1$. The term $u_i = e_i + v_i$ is a composite error. Blundell and Meghir (1987) also assume that P_i is determined by the following index equation:

$$D_i = z_i\theta + w_i, \tag{7}$$

where $w_i \sim N(0, 1)$ so that $P_i = \Phi(z_i\ \theta)$ with $\Phi(\cdot)$ as the standard normal cumulative function. The censoring rule generating fuel purchases, $x_i^{'}$, in any random sample can be written as:

$$x_i^{'} = \frac{\exp(g_i\beta)\exp(u_i)}{\Phi(z_i\theta)}\ if\ D > 0\ and\ 0\ otherwise. \tag{8}$$

Using equations (5) and (8), the positive observations can also be expressed as:

$$log\, x_i^{'} = \log\left[\frac{\exp(g_i\beta)\exp(u_i)}{\Phi(z_i\theta)}\right] = g_i\beta - \ln\Phi(z_i\theta) + u_i. \tag{9}$$

This expression highlights that, even if u_i and w_i are independent, using positive purchases to estimate the β parameters will "give rise to inconsistency of a similar nature to that arising when omitting a variable from a regression equation" (Blundell and Meghir 1987, 184). Therefore, we proceed with a maximum likelihood approach, but also estimate equation (9) via OLS (without the second term) for comparison. The sample log likelihood for the case where the terms u_i and w_i are distributed as a standard bivariate normal, BVN($g_i\beta/\sigma$, $z_i\theta$, ρ) is:

$$\ln L = \sum\nolimits_0 \ln(1-\Phi(z_i\theta)) + \sum\nolimits_+ \left[-\ln\sigma - \ln x_i' + \ln\Phi\left(\frac{\ln(\Phi(z_i\theta)x_i') - g_i\beta}{\sigma}\right) + \ln\left(\Phi\left(\frac{z_i\theta + \rho\frac{\ln(\Phi(z_i\theta)x_i') - g_i\beta}{\sigma}}{\sqrt{1-\rho^2}}\right)\right)\right], \tag{10}$$

where $\sum_+$ is the summation for days with positive purchases, $\sum_0$ is the summation for days with zeros, while $\Phi(\cdot)$ represents the standard normal density functions. We estimate the parameters using the BFGS algorithm in the maxLik package for R to minimize the negative log-likelihood (Henningsen and Toomet 2011).

DATA

The data used to estimate the demand for boat fuel is from an intercept survey of anglers fishing in the marine waters of North Carolina from March through December in 2009.[1] Interviews took place at a marina or ramp when anglers returned from fishing. Anglers were asked whether they fished in inland areas or offshore in areas that are either less than three miles from the shoreline or greater than three miles from the shoreline. We focus on the sample that fished in the offshore area greater than three miles, because this group was most likely to harvest species that are not available from the shore; i.e., without a power boat.

Anglers were also asked how much they spent on boat fuel and how much they paid per gallon of fuel. We aggregated the responses from anglers fishing from the same boat to calculate the total expenditure on fuel and the price paid per gallon.[2] The boat-level fuel expenditure was then divided by the reported price per gallon and the number of anglers on the boat to get the average quantity of fuel purchased per angler.

The anglers were asked about their household income, but very few anglers answered this question. Therefore, we used the average adjusted gross income in the angler's zip code of residence in 2008.[3] The income measure was aggregated to the boat level as the average income per angler. The fishing and boating duration and the length of the boat were recorded, and the later served as our proxy for fishing capital.

1. The economic survey questions were added to the Access-Point Angler Intercept Survey (APAIS) of the Marine Recreational Information Program of the National Marine Fisheries Service. The APAIS is a multi-stage, cluster sample (Breidt et al. 2010). All estimates reported herein use the sampling weights, and robust variance estimators are used to address the clustered nature of the sample.

2. We dropped cases in which every angler was not interviewed because it was not possible to calculate the total fuel expenditure.

3. Information about the zip code data from the Statistics and Income Division of the Internal Revenue Service is available at: http://www.irs.gov/uac/SOI-Tax-Stats-Individual-Income-Tax-Statistics-ZIP-Code-Data-(SOI).

We assume that the quality of fishing available from any given coastal NC interview site (i.e., marina or boat ramp) is proportional to the historical average number of dolphinfish and king mackerel harvested per angler, per hour in the "zone" containing that site. King mackerel and dolphinfish accounted for nearly half of all observed fish harvested from outside of three miles of the North Carolina coast in 2009. The interview sites were aggregated to zones and averaged across king mackerel and dolphinfish because there was not enough data to generate averages with low standard errors for individual species for each site where the anglers were interviewed. This approach parallels the methods commonly used in sportfishing site choice applications (Haab et al. 2012). Also, the harvest of these two popular pelagic species without a boat is extremely rare: less than 0.6% of the nearly 1.5 million king mackerel and dolphinfish harvested between 2004 and 2009 were estimated to be caught by anglers fishing from the shore or a man-made structure. This supports the characterization of boat fuel as an essential input in the production of harvest of these species.

A map of the eight zones along the North Carolina coast is shown in figure 2. These zones were created by aggregating interview sites with similar road access points and offshore fishing opportunities. The historical average number of fish harvested per angler per hour for each zone is calculated using data from 4,213 interviews of anglers fishing offshore during the months of March through December from 2004 to 2008. Each interview in our 2009 sample was assigned a historical average harvest rate based on the zone where the interview took place.

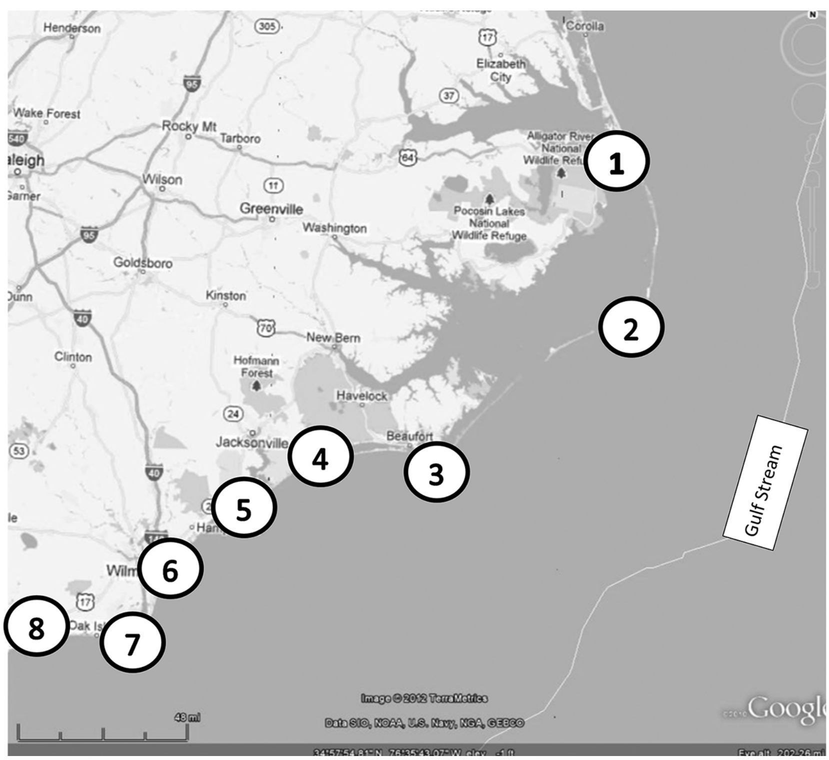

Figure 2. Selected Fishing Zones on the Coast of North Carolina

The final 2009 sample consisted of 205 boat-level observations based on 549 angler interviews with complete information. The variable definitions and the population mean estimates are presented in table 1 for the entire sample and for two sub-samples based on whether or not fuel was purchased. We split the sample according to the fuel purchase decision, because this is an important feature of the data. The theoretical model presented in the first section is for fuel consumed on each fishing day. However, as noted in the previous section, our data contains observations of fuel purchases, not consumption. Table 1 suggests that there is little difference in the main consumption/purchase model variables (price, income, boat length, duration, and historic harvest rates) between the days when fuel was purchased and the days when fuel was not purchased.

Several other variables available in our data are shown in table 1. There is an indicator for fishing in the two northernmost zones (figure 2, zones 1 and 2). These two zones are situated much closer to the Gulf Stream than the other zones and are important because the majority of fishing for offshore species, especially dolphinfish, occurs in the Gulf Stream. Consequently, all else equal, fishing in the Gulf Stream from the two northernmost zones will use relatively less fuel. We include this indicator in our specification to control for the geographic advantage of the northernmost zones. Note that a larger proportion of the sample respondents who purchased fuel originated from these zones than those who did not purchase fuel.

We averaged the number of days fished in the two months prior to the interview for anglers on each boat to get a measure of fishing avidity. There is little difference in the avidity of anglers between boats that purchased fuel and those who did not. Marinas are more likely to have fuel pumps than ramp-only launch sites. However, the fuel sold at marinas tends to be more expensive. In our sample, anglers who purchased fuel were about as likely to be interviewed at a marina as those who did not purchase fuel. There is a variable (daytrip) that takes a value of zero if the interview took place during a multi-day trip and a value of one if the angler returned home the same day of the interview. A much higher proportion of anglers purchasing fuel were on day trips than those not purchasing fuel. The average age of anglers on the boat does

Table 1. Means and Standard Errors of the 2009 NC Offshore Private Boat Sample

	All	Didn't Purchase Fuel	Purchased Fuel
Fuel purchases (gallons)	17.13 (2.11)	0.00 (0.00)	30.43 (2.76)
Fuel price ($/gallon)	2.50 (0.02)	2.50 (0.04)	2.49 (0.04)
Income ($000)	50.52 (0.81)	49.96 (0.99)	50.95 (1.21)
Boat length (ft.)	23.59 (0.37)	23.06 (0.34)	24.00 (0.57)
Duration (hours)	8.18 (0.22)	7.91 (0.33)	8.38 (0.30)
Historic harvest rate (fish/(angler*hours))	0.12 (0.01)	0.10 (0.01)	0.13 (0.01)
Zones 1 and 2 (1=yes, 0=no)	0.45 (0.08)	0.34 (0.10)	0.53 (0.09)
Average number of days fished in previous 2 months	4.26 (0.51)	4.26 (0.69)	4.25 (0.70)
Interviewed at a marina (1=yes, 0=no)	0.30 (0.06)	0.29 (0.08)	0.31 (0.08)
Day trip (1=yes, 0=no)	0.41 (0.06)	0.31 (0.05)	0.49 (0.10)
Average angler age on boat (years)	42.79 (1.12)	43.83 (1.73)	41.99 (1.83)
Average wind speed at station nearest the interview site (knots)	4.72 (0.33)	4.73 (0.45)	4.72 (0.38)
Number of observations (boat days)	205	90	115

Standard errors of the population estimates are shown in parentheses.

not appear to differ much between those who purchased fuel and those who did not. Wind speed from the station nearest to the launch site was also added to the data to control for weather conditions that could influence fuel consumption and purchase decisions.

FINAL SPECIFICATIONS AND RESULTS

For the final specification we adopt a semi-log form where the key consumption equation variables (price, income, boat length, duration, and harvest rate) enter linearly.[4] We also include a dummy variable for zones 2 through 8 in the fuel purchase decision equation. These zone dummy variables are omitted from the fuel consumption equation because their parameters (fixed effects) cannot be identified separate from the parameters on the zone-level historic harvest rate and the indicator for the two northernmost zones. This assumes that there are no omitted zone-level factors in the fuel consumption equation.

The estimates of the fuel consumption and purchase decision equation parameters are shown in table 2. The first two columns show the parameter estimates for a "full" specification, which includes all potential variables in both the fuel consumption and the fuel purchase decision equations. The last two columns show the parameter estimates for a "reduced" specification with variables selected based on significance in the "full" MLE results. Each specification was estimated via OLS and MLE. The OLS models estimate equation (9) without the second term using the sub-sample that purchased fuel, whereas the MLE models use the entire sample to estimate the sample likelihood function via maximum likelihood.

An F-test cannot reject ($1.09 \sim F$, df = 4, p-val. = 0.37) the equality of the "full" and "reduced" specifications with the OLS estimator. Similarly, a likelihood ratio test ($4.52 \sim \chi^2$, df = 9, p-val. = 0.87) cannot reject the null hypothesis of equality of fit between the full and reduced MLE models. Both of these results suggest that we can focus on the reduced model in our discussion of the parameter estimates.

In general, the statistically significant OLS and MLE estimates from the reduced model specification (last two columns of table 2) are similar. However, there is evidence that the OLS estimates are biased as anticipated by equation (9), especially for the harvest rate parameter. The estimated variance (σ) and correlation (ρ) parameters are highly significant, suggesting that the MLE estimator is more appropriate than the OLS estimator for the reduced model and this dataset.

Focusing on the MLE estimates in the last column of table 2, all key consumption equation parameters (in the top half of the table), except income and duration, are significant at the 0.10 level. The lack of significance for the coefficient of income suggests that there may be a small, if any, income effect in the demand for boat fuel in this sample of private anglers. However, the parameter on income could also be insignificant due to measurement error associated with the zip code-level proxy used. The significant consumption parameters have the expected signs: fuel consumption decreases with price and for boats launching from zones 1 and 2, but increases with the length of the boat, fishing avidity, and the harvest rate.

Based on the statistically significant MLE parameters in the reduced model of the fuel purchase decision equation (bottom half of the last column in Table 2), the boats on day trips and

4. The double-log specification results are similar. We chose to focus on the semi-log specification because it fit the data slightly better and the welfare calculations are less complicated. Specifically, the double-log model requires a price coefficient that is less than −1, and the CS measures explode as the price coefficient approaches −1.

Table 2. OLS and MLE Estimates for the Fuel Consumption and Purchase Decision Model

	Full		Reduced	
	OLS	MLE	OLS	MLE
	Fuel Consumption			
Intercept	3.34***	2.70	3.46***	3.70***
	(1.23)	(2.55)	(1.01)	(1.03)
Fuel price	−0.62**	−1.12	−0.66**	−0.76***
	(0.31)	(0.71)	(0.29)	(0.21)
Income	−0.00	−0.00	−0.00	−0.01
	(0.00)	(0.01)	(0.01)	(0.01)
Boat length	0.06***	0.06	0.06***	0.07***
	(0.02)	(0.05)	(0.02)	(0.01)
Duration	0.01	−0.01	0.01	−0.04
	(0.04)	(0.08)	(0.04)	(0.05)
Historic harvest rate	1.55	8.76***	1.88	2.86*
	(1.14)	(1.40)	(1.26)	(1.65)
Launched from zones 1 or 2	−0.61***	0.08	−0.54***	−0.42***
	(0.15)	(0.30)	(0.13)	(0.16)
Days fished in previous 2 mo.	0.02**	0.01	0.02*	0.03***
	(0.01)	(0.01)	(0.01)	(0.01)
Launched from marina	0.04	0.41**		
	(0.12)	(0.18)		
Day trip	−0.12	0.37		
	(0.13)	(0.26)		
Age	0.01	0.00		
	(0.01)	(0.01)		
Wind speed	−0.02	0.01		
	(0.02)	(0.03)		
	Fuel Purchase Decision			
Intercept		2.65		0.03
		(3.19)		(0.42)
Launched from zone 2		0.16		0.50
		(0.24)		(0.32)
Launched from zone 3		−1.15***		−0.98**
		(0.38)		(0.42)
Launched from zone 4		−0.66		−0.32
		(0.41)		(0.45)
Launched from zone 5		−1.72***		−1.25*
		(0.46)		(0.69)
Launched from zone 6		5.54*		5.08***
		(3.04)		(1.85)
Launched from zone 7		−0.69		−0.70
		(0.47)		(0.54)
Launched from zone 8		0.55		0.30
		(0.59)		(0.65)
Fuel price		−0.87		
		(0.91)		
Income		−0.00		
		(0.01)		
Boat length		0.01		
		(0.04)		
Duration		−0.04		
		(0.08)		
Days fished in previous 2 mo.		−0.02		
		(0.01)		

Table 2 (*Continued*)

	Full		Reduced	
	OLS	MLE	OLS	MLE
	Fuel Purchase Decision			
Launched from marina		0.47**		0.04
		(0.22)		(0.19)
Day trip		0.83***		0.79***
		(0.26)		(0.28)
Age		−0.01		−0.01
		(0.01)		(0.01)
Wind speed		0.05		0.08
		(0.05)		(0.06)
σ		0.43***		0.61***
		(0.06)		(0.11)
ρ		0.48**		−0.96***
		(0.24)		(0.07)
Adj. R^2 or Log-lik.	0.28	−556.88	0.28	−559.14
Num. obs.	115	205	115	205

*** p < 0.01, ** p < 0.05, * p < 0.1. Robust standard errors are shown in parentheses.

those launching from zone 6 are more likely to purchase fuel. Boats launching from zones 3, 4, and 5 are less likely to purchase fuel.

The marginal effects of the variables in the consumption equation are complicated functions of the parameters and the distribution because the expectation of conditonal purchases and unconditional consumption and purchases are given by:

$$E(x'|x'>0)=\exp\left\{g\beta+\frac{\sigma^2}{2}\right\}\frac{\Phi(z\theta+\sigma\rho)}{\Phi(z\theta)^2}, \tag{11}$$

$$E(x)=E(x')=E(x'|x'>0)\Phi(z\theta)=\exp\left\{g\beta+\frac{\sigma^2}{2}\right\}\frac{\Phi(z\theta+\sigma\rho)}{\Phi(z\theta)}. \tag{12}$$

However, if a variable does not appear in the fuel purchase decision equation, then the mean elasticity with respect to fuel consumption reduces to the standard formula for the semi-log specification; i.e., the parameter times the mean of the related variable.

The demand for boat fuel consumed per day is price elastic. In fact, the estimated MLE reduced model boat fuel price elasticity of −1.90 (−0.76*2.50) is considerably greater than the range of short-run price elasticity estimates of −0.20 to −0.30 for the household demand for automobile fuel (Basso and Tae Hoon 2007). This result may be attributed to the discretionary nature of recreational fishing.

The harvest rate elasticity in the reduced MLE model is positive, 0.34 (2.86*0.12), suggesting that the substitution effect outweighs the productivity effect on fuel demand for a change in the harvest rate. In this case, the fuel demand curve shifts out with an increase in the harvest rate, as depicted in figure 1. The estimated harvest rate elasticities suggests that fuel usage increases by around one third of one percent for every one percent increase in the historic average number of fish caught and kept per angler, per hour fished.

The estimated fuel demand (consumption) equation can be used to calculate welfare effects of a change in the harvest rate, q. The essential input assumption is mathematically equivalent to the WC assumption (Bockstael and McConnell 2007), and von Haefen (2007) derives the WC-consistent expenditure functions corresponding to our semi-log uncompensated demand specification. This expenditure function could be used to calculate the compensating variation welfare measure defined in expression (2) and figure 1. However, the income parameter is small and not statistically different than zero in our estimated fuel demand equation, suggesting a minimal income effect (assuming no measurement error). In this case, we could assume that the compensated and uncompensated demands are close and that the measure in (2) can be approximated as changes in consumer surplus (CS) based on shifts in the estimated uncompensated demand equation. However, von Haefen (2007) also shows the semi-log demand function is consistent with the Willig condition and, therefore, the CS measure is bounded by CV and equivalent variation (Bockstael and McConnell 1993). The expression for the change in CS per fishing day (i.e., user day) for a change in the harvest rate using the semi-log form in (5) is:

$$\Delta CS = -\frac{1}{\beta_p}(\hat{x}^1 - \hat{x}^0), \beta_p \neq 0, \tag{13}$$

where β_p is the price parameter, $\hat{x}^0$ and $\hat{x}^1$ are the predicted average fuel consumption per fishing day evaluated at q^0 and q^1, respectively, with all other variables, including price, held constant. Equation (10) is used to predict the average fuel consumption levels, $\hat{x}^0$ and $\hat{x}^1$, per fishing day at different levels of q. Note that the reciprocal of the price parameter gives the CS per gallon.

We use the full sample averages (column "All" in table 1) and the MLE parameters for the reduced model (last column in table 2) to evaluate equation (13) for a one unit increase in the average number of fish harvested *per angler per day*. This is not the same as a one unit change in the harvest rate variable because the harvest rate variable is measured as the average number of fish kept *per angler per hour per day*. In this case a one unit change per angler is given by one divided by the average hours fishing. The average hours fished per day in our sample is 5.19 hours (not reported in table 1), so a one unit change in the harvest rate per angler is $1/5.19 = 0.19$. Given the small average harvest rate reported for the full sample (0.12) in Table 1, this change is relatively large (>150%). However, we report this measure for comparison with estimates in the literature.

The uncertainty of the CS estimate can be examined using a parametric bootstrap procedure that randomly draws parameters from a distribution based on the estimated coefficients and covariance matrix from the reduced MLE model (Creel and Loomis 1991). We draw 10,000 vectors from the multivariate normal distribution that is truncated such that the price parameter is less than zero and the harvest parameter is greater than or equal to zero. There is a 0.96 joint probability that these parameter restrictions hold based on the estimates from the MLE model. Each parameter vector draw is used to evaluate the CS expression in equation (13) and its components; i.e., the CS per gallon and the quantity consumed before and after the change in harvest rate. We then take the 2.5% and 97.5% quantiles to get a ~95% confidence interval on the CS estimate and its components.

The results of the bootstrap analysis are shown in table 3, where the first two rows show the statistics for the two restricted parameters. Despite the upper truncation at −1, the median

Table 3. Results of the Parametric Bootstrap

	Quantile		
Estimate	2.5%	50%	97.5%
Price coefficient	−1.16	−0.76	−0.35
Harvest rate coefficient	0.37	2.96	6.17
Base fuel consumption (gallons)	13.27	16.68	21.30
Fuel consumption with 1 fish increase per angler per day (gallons)	18.41	30.30	54.91
Consumer surplus per gallon	$0.86	$1.32	$2.86
Change in consumer surplus with 1 fish increase per angler per day	$1.57	$18.00	$73.50

Based on 10,000 draws from a multivariate normal distribution of the coefficients from the MLE estimation of the reduced form model. The distribution is truncated such that the price coefficient is less than zero and the harvest rate coefficient is greater than or equal to zero.

price coefficient from the bootstrap is the same as the original MLE estimate. The median harvest rate coefficient from the bootstrap is slightly higher than the original MLE estimate (2.86) due to the lower truncation at zero. Median fuel consumption is expected to increase almost 14 gallons with a one-fish increase in harvest per angler. This change is multiplied by the expected median CS change per gallon of $1.32 to get the median change in CS of $18 expected with a one-fish increase in harvest per angler. Comparable CS per-fish estimates (in 2009 dollars) for dolphinfish ($4.41 to $13.82) and king mackerel ($28.96 to $90.98) in the Southeast US are reported in Carter and Liese (2012).[5] Our estimate of WTP per fish is within the range, but less than the mean ($28.76) of the estimates reported in the meta-analysis by Johnston et al. (2006) based on 391 estimates from 48 different studies of US recreational fisheries. Note, however, that the confidence interval on our CS per fish estimate is quite wide ranging, from around $1.50 to over $70.

CONCLUSIONS

A number of methods have been developed to estimate the economic value of environmental quality. Bockstael and McConnell (1983) suggested a way that the household production framework could be used to derive estimates when an essential input can be identified, but the application of this approach has been limited, especially using an essential input traded in a market. We report on the first application of this strategy that uses an estimate of the continuous demand for a market-based essential input to measure the value of changes in environmental quality. Specifically, we estimate the value of changes in the quality of sportfishing harvest through changes in angler demand for boat fuel. The focus here is on the production of fishing quality. This strategy differs from the typical use of the household production framework to motivate the travel cost method where the focus is on the production of user days. Fishing days are not explicitly traded in markets so “prices” must be approximated in the travel cost method.

5. Carter and Liese (2012) also summarize (their Table 7) the economic value estimates for changes in the king mackerel harvest rate that appear in the literature. The estimates range from −$41.04 to $39.33 (in 2009 dollars) per fish. All estimates are converted to 2009 dollars using the USA Consumer Price Index series CUSR0000SA0 for December of the study year and December 2009.

Our estimate of angler demand for boat fuel is also a first. We provide a novel application of the IPM to address the storability of boat fuel across days of offshore fishing departing from North Carolina. The results suggest that the short-run demand for boat fuel is price elastic. In fact, boat fuel price elasticity estimate is more than six times larger than typical estimates for the household demand for automobile fuel. This is consistent with the definition of boating and fishing as recreational activities within the discretionary portion of the household budget.

The difference in the area under the estimated boat fuel demand curve with two distinct harvest rates is used to estimate angler WTP per fish. Our estimates are similar to other estimates in the literature based on the travel cost method and stated preference techniques. However, our valuation method has the advantage of using market data, which may be less costly to collect than stated preferences and easier to verify than information on travel distance and the opportunity cost of time. For example, we can speculate how at least some of the recreational salmon harvest value estimates from two recent studies in the Northwestern US might have also been obtained using our proposed approach.

Anderson and Lee (2013) used a choice experiment study to estimate the economic value of salmon on private and charter boat trips in the Pacific Northwest. Larson and Lew (2013) conducted a travel cost study to estimate the value of salmon on single-day private boat fishing trips in Southeast Alaska. Both studies involved mail surveys that took at least two years to develop, test, and administer. The data was used to generate estimates of the economic value for various types and sizes of salmon catch and release. Our essential input approach could be used to generate similar kinds of value estimates with information on spatially explicit historic catch rates for the types and sizes of salmon and trip-level data on at least one year of fuel consumption for private boat fishing days. The catch rate data for both studies is available (as documented in the papers), so the main data collection required to implement the essential input approach would be to obtain information about boat fuel consumption, fuel price, boat length, duration, and income for a sample of private boat anglers. This information could be obtained from a relatively short mail survey or a few add-on questions to existing creel surveys. It is important to note, however, that the thorough studies by Anderson and Lee and Larson and Lew allow for the examination of changes in economic value over more margins (e.g., changes in fishing days) than the simple version of the essential input approach developed in this article.

This study should be regarded as a first look at boat fuel demand for sportfishing and the proposed alternative approach to estimating the value of a recreationally harvested fish. Our models and estimation methods were based on limited data. As a result, our model of angler behaviour focused only on the changes in fuel used during a fishing day after the decisions regarding whether to fish, where to launch, and how long to fish were made. Collection of richer data that allows for a more inclusive behavioural model, incorporating other relevant decisions, would be an important avenue for future research. Also, the available data here has restricted the definition of fishing quality used in this study. While average harvest rates remain a popular measure of fishing quality, contemporary travel cost models explicitly model the harvest production process (McConnell, Strand, and Blake-Hedges 1995; and Larson and Lew 2013).

The estimate of fuel demand and related welfare measures could be improved with better data on fuel consumption and prices. At a minimum, anglers should be queried about fuel *usage* on each fishing day rather than *purchases*. We only had information on fuel purchases and used statistical assumptions (i.e., the IPM) to identify consumption. Sampling should be done at the boat level to obtain information about the fuel usage. Our survey asked each angler how much they paid and then we had to aggregate to get usage at the boat level. This can introduce measurement error and is an inefficient way to collect boat-level data. It is difficult to collect information on the price of fuel for every day spent fishing because anglers don't purchase fuel every time they go fishing. Therefore, we do not necessarily know the relevant price for the fuel consumption decisions each fishing day as is common with infrequently purchased products. It might be possible to use existing sources for fuel prices, such as the weekly retail prices available from the U.S. Energy Information Administration to proxy the opportunity cost of fuel on each day. In this case, the model could be expanded to consider fuel consumption and harvest rates over time. Finally, our dataset was relatively small and the resulting welfare measures relatively imprecise. Further testing of the proposed valuation method with larger datasets in other settings is warranted.

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