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Economic Values of Coastal Erosion Management: Joint Estimation of Use and Existence Values with recreation demand and contingent valuation data

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ABSTRACT

Revealed and stated preference survey data from North Carolina households are utilized to estimate structural micro-econometric models of recreation demand and willingness-to-pay (WTP) for coastal erosion management among beach visitors and non-visitors. We test for and reject weak complementarity, implying existence values associated with management of North Carolina's beaches. We find stronger preferences for shoreline retreat (median WTP = $22.20 per household, per year) as a management strategy relative to beach nourishment (WTP = $7.91), and we find substantially weaker preferences for shoreline armoring (WTP = $0.09). Shoreline retreat exhibits much larger estimates of existence values, whereas existence values for shoreline armoring are negative. Our data permit estimates of marginal value of incremental beach width accruing to beach users and non-users (which range from $0.23 and $0.48 per meter).

Economic Values of Coastal Erosion Management: Joint Estimation of Use and Existence Values with Recreation and Contingent Valuation Data.

The coastal zone is a dynamic and recalcitrant ecological system. Management problems stemming from coastal erosion, storms, and sea level rise are exacerbated by development along the coast and, especially, at the water's edge. More than 52% of the U.S. population lives in coastal counties (Joint Ocean Commission, 2012). Focusing on U.S. East Coast, approximately 86% percent of the shoreline has exhibited significant erosion in the past century (Zhang et al., 2004), averaging 1.6 feet of shoreline recession per year (Hapke et al., 2010). A 2000 study by the *Federal Emergency Management Agency* (*FEMA*) and the *Heinz Center* estimates that 25% of homes within 500 feet of the US coastline could be lost by 2060, at a potential cost of $874 million per year (2017 US dollars) (Heinz, 2000).[1] This vulnerability has serious implications for economic welfare of coastal

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[1] Figure converted from year 2000, Q1 to 2017, Q4 using US Housing Price Index for North Carolina.

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households, viability of private and public insurance programs, recreation and tourism along the coast, regional economies adjacent to the coast, and ecological sustainability of coastal systems.

Options for management of shoreline erosion include shoreline hardening (seawalls and other structures designed to protect land and preserve property boundaries), beach replenishment (adding sand to the beach and dune system), and coastal retreat (moving buildings and infrastructure away from eroding shorelines as necessary). The effects of erosion management strategies on the configuration and value of the coastal housing units have been studied by a number of scholars (e.g., Hamilton, 2007; Pompe, 2008; Landry and Hindsley, 2011; Gopalakrishnan et al., 2011; Ranson, 2012; Landry et al., 2019). Management of erosion, however, also has important implications for the local tourism economy, the quality of natural coastal resources, and ecological sustainability over the long term. These aspects of management have received considerably less attention in the economic literature. In the policy world, coastal property owners have been perhaps the most vocal proponents of shoreline hardening and beach replenishment, with other voices and options receiving much less consideration.[2]

This paper employs primary survey data from North Carolina households in order to evaluate the economic welfare effects of beach erosion management alternatives on a more general population. The survey gathers information on use (and, importantly, non-use) of coastal beaches, perceptions of coastal resource quality, knowledge of coastal processes, and stated preference referendum votes for programs to manage coastal erosion. We utilize the existence value definition of Herriges et al. (2004) and build on the microeconomic models of Eom and Larson (2006) and Huang et al., 2016 by linking a count data demand model with a contingent valuation model to develop a joint distribution for the trip count and contingent valuation (CV) binary response variable. In combining revealed preference (RP) recreation demand and stated preference (SP) contingent valuation data, we employ a consistent behavioral model that permits analysis of co-existing use and existence values (Herriges et al., 2004), and we can test how existence values are affected by erosion management strategy, beach width, and negative environmental impacts engendered by management interventions.[3]

Our paper is the first, to our knowledge, to link a count data model to a binary response CV model and to incorporate behavioral data for both users and non-users of the environmental resource under scrutiny. Count data models are appropriate for analysis of recreation demand, as the dependent variable is a non-negative integer. We utilize the Poisson model with a log-normally distributed error term, which accounts for the nature of the dependent variable and allows for unobserved heterogeneity in a flexible yet efficient way (Cameron and Trivedi, 2013). Building on the suggestion of Eom and Larson (2006),[4] our model accounts for users and non-users of North Carolina beach resources. This approach permits a more general test of weak complementary (WC), since we have information from respondents that may view the price of beach recreation as too high, but they may still value existence of beach quality (Huang et al., 2016).

Regression results indicate that demand for beach trips is increasing in income, beach width, beach length, and number of beach access points. Consumer surplus per trip to the NC coast is $200 per household (similar to previous estimates in the literature). We find a statistically significant and positive correlation among trips and WTP for beach erosion management in all models estimated. A likelihood ratio test rejects weak complementary. This implies that the parameter restrictions commonly invoked in analysis of recreation demand do not hold in our dataset; we find evidence of existence values for beach management.

Employing an exponential willingness-to-pay (WTP) function, we reject WC and estimate mean (median) WTP for beach erosion management of $7.91 ($10.70) per household, per year. Willingness-to-pay is considerably smaller (close to $0) for beaches maintained in conjunction with shoreline armoring, but quite a bit larger (around $22 per household, per year) for beaches maintained by shoreline retreat (each relative to beach replenishment). Willingness-to-pay is decreasing in the presence of negative environmental impacts, but this effect does not vary with management approach. Incremental values for beach width from our preferred model indicate mean WTP of $0.24 per meter and median WTP of $0.48 per meter. These results have practical import; values for changing beach conditions that vary with policy approach could be instrumental in analysis of shoreline management and climate adaptation, wherein changes in the built environment, public infrastructure, environmental conditions, human behavior, and policy occur within a tightly coupled human-natural system with considerable spatial and temporal complexity (Slott et al., 2008; Smith et al., 2009; Landry, 2011; McNamara et al., 2011; Lazarus et al., 2011; McNamara and Keeler, 2013; Williams et al., 2013; McNamara et al., 2015; Jin et al., 2015; Gopalakrishnan et al., 2016a, 2016b, 2017; Keeler et al., 2018; Mullin et al., 2018).

Background

Residential and commercial development in the coastal zone facilitates access to and enjoyment of coastal amenities, such as beaches, estuaries, fisheries, and cultural resources. Dynamics of the shore have resulted in various patterns of erosion and

[2] Until recently, North Carolina was one of only two states that prohibited shoreline hardening. In 2012, the NC legislature passed a bill (unsigned and unvetoed by the Govnernor, thus becoming law) that allows terminal groins along inlets, and there are significant pressures to allow other types of shoreline armoring. Similar pressures are growing in other parts of the United States (Gittman, et al. 2015; Dugan et al., 2018) and across the world.

[3] Throughout the manuscript, we follow Herriges et al. (2004) in defining existence values as the difference between total value and recreation value.

[4] Eom and Larson (2006, pg. 514) state “A natural generalization would be to estimate preferences for both users and nonusers”; they recognize that to do this, nonparticipation needs to be accounted for.

accretion, with an overwhelming majority of shorelines along the east coast exhibiting net erosion in recent decades (Zhang et al., 2004; Hapke et al., 2010); the North Carolina coastline, our study site, is no exception (Riggs and Ames, 2003). Driven by wind, waves, storms, and sea level, the erosion of beaches, dunes, bluffs, and estuarine shoreline can threaten the viability of residential and commercial development, as well as public infrastructure. These combined forces can undermine foundations, exposing structures to wave attack, currents, and tidal fluctuations. Waterfront structures face the greatest risk, and owners have strong incentives to install private protective measures or lobby for public projects that protect their property. These erosion management initiatives, however, affect environmental quality and the overall appeal of beaches and estuaries for local users, tourists, and other visitors. Thus, erosion control policies influence environmental quality, sustainability, future adaptation possibilities, and recreation & tourism patterns for the public at large, but policy decisions can be more heavily influenced by coastal residents that face greater personal risk.

One objective of this paper is an analysis of public support and willingness to pay for coastal erosion control in order to fill a gap in the existing literature. While much has been learned about coastal residents' value of beach quality through analysis of property value data (e.g., Pompe, 2008; Landry and Hindsley, 2011; Gopalakrishnan et al., 2011; Ranson, 2012; Landry et al., 2019), comparatively little is known about general public support and economic value for erosion management policies and how such policies may affect use and non-use values. Coastal erosion can result in diminished beach and dune quality, and management of erosion can create situations where the beach is transformed into a construction zone or is littered with debris and dilapidated buildings at certain points in time. Policies to manage erosion can include beach replenishment, shoreline armoring, or coastal retreat, each of which may garner different levels of support among the general public and may impact choice, experience, and value of recreational users.

Beach replenishment involves periodically replacing eroded beach and dune sand; while this can improve beach width and dune height (thus augmenting beach habitat), it may have negative impacts on other beach quality measures (texture, color, etc.) and can induce negative environmental impacts at the sand mining or placement sites. Shoreline armoring can provide protection to coastal development and affect the distribution of sand, but often has negative environmental and aesthetic impacts (including destruction of habitat, disruption of sand sharing across parts of the beach, and loss of beach width in some areas). Along sandy beaches, replenishment is usually conducted in conjunction with armoring in order to ameliorate some of these negative effects.

In contrast to *active* management of beach resources, coastal retreat is a *passive* management approach that entails moving structures and infrastructure to adapt to an evolving coastline; while this approach attempts to allow a natural barrier island system to persist, it can restrict access by limiting the extent and quality of residential and commercial development and public infrastructure that supports beach recreation and leisure activities. The process of retreat can be unsightly, as buildings and infrastructure are moved or demolished. Moreover, since it involves removal of structures and loss of land, shoreline retreat permits natural forces to impinge upon public and private property and raises legal issues related to public trust, eminent domain, and compensation.

Each of these policies induces an array of benefits and costs that may have diverse impacts on concerned parties. The interests of coastal private property owners are perhaps more obvious than the preferences and concerns of recreational users and non-users. Since erosion control projects typically entail use of public funds and can have significant impact on the quality of natural resources (beaches, water quality, ecological habitat, etc.), the overall support for different approaches to coastal erosion management, their potential impact on recreation values, and the benefits and costs engendered by the approaches need more thorough evaluation. In addition to our methodological contributions, we provide an assessment of economic benefits and costs of coastal erosion management policies to provide for a better understanding of tradeoffs that relate to the impact of erosion control on the recreation and tourism sectors and a more generalized segment of the population of North Carolina.

Literature

Early reviews of economic values related to beach resources and management of coastal erosion include Freeman (1995) and Bin et al. (2005). We thus focus primarily on the literature since. Of particular note is the introduction of dynamic optimization models designed to identify optimal rotation times for beach replenishment – identifying efficient sand quantities and scheduling of sediment restoration activities (Landry, 2008, 2011; Smith et al., 2009), exploration of spatial externalities among communities engaging in beach replenishment (Slott et al., 2008; McNamara et al., 2011; Lazarus et al., 2011; Williams et al., 2013; Gopalakrishnan et al., 2016a, 2016b, 2017), and political economy models of coastal development, risk mitigation, and abandonment (McNamara and Keeler, 2013; Mullin et al., 2018). A recent paper by McNamara et al. (2015) examines the effects of stochastic coastal storms, replenishment costs, erosion rates, and federal replenishment subsidies on optimal beach rotation and the resulting property values.

In addition to information on geomorphology and atmospheric conditions, dynamic optimization models require inputs on the economic value of beach sediments and the economic costs of management (e.g. manipulating the sediment budget to augment beach width and dune mass). The hedonic property price valuation method has been used to estimate marginal willingness to pay for increments in beach width (Landry et al., 2003; Pompe, 2008; Landry and Hindsley, 2011; Gopalakrishnan et al., 2011; Landry et al., 2019). Empirical estimates suggest that homeowners are willing to pay $22 to $1400 for an additional foot of beach width, though some estimates are as high as $8000 for beachfront homes.

Recreation demand models have been used to analyze preferences for beach trips and the influence of trip attributes on economic value. These measures can also play a prominent role in shoreline management and optimization models. Empirical papers include repeated nested logit models of whether and where to go to the beach in San Diego (Lew and Larson, 2008), nested discrete choice models of recreation participation, activity, and site for California beaches (Pendleton et al., 2012), and single-site demand models that combine revealed and stated trip demand for North Carolina beaches (Whitehead et al., 2008, 2010) and Delaware beaches (Parsons et al., 2013).

Pendleton et al. (2012) find that the value of beach width varies systematically by activity, with sand-based activities exhibiting the largest value relative to water-based or pavement-based activities. Increasing beach width enhances economic value, but only up to moderate width levels. They estimate consumer surplus ranges between $13 and $74 per trip, and aggregate welfare measures for increasing beach width in the Los Angeles area by 50% are over $3 million per year. Whitehead et al. (2008) estimate consumer surplus of around $90 per trip for North Carolina beaches, which increases by $25 with improvements in beach access and $7 with wider beaches. Parsons et al. (2013) estimate the value of Delaware beach visits at $81/trip for those that stay overnight and $33/trip for single-day trips; welfare losses from narrowing of the beach width by one-quarter its current width are about $5 per day, and doubling the current beach width increases economic value by about $3 per day.

An important component of beach management is the potential for external costs imposed upon the surrounding environment (Speybroek et al., 2006). These have received little attention in the literature, with a notable exception being the study of Huang et al. (2007), which examines economic costs of wildlife impacts associated with beach replenishment; residents of New Hampshire and Maine are willing to pay on the order of $4 to $6 per household to prevent these impacts.[5] Likewise, there has been little research on households' WTP or support for the different ways that coastal erosion can be managed – shoreline armoring, beach replenishment, and shoreline retreat. These distinct approaches can be viewed as a subset of adaptive measures that can be employed to manage sea-level rise – each invoking unique profiles of costs and benefits over time, accruing to different classes of property owners, public resources, beach visitors, and concerned non-users.

Our analysis provides information on household preferences for the different approaches to managing coastal erosion, while incorporating potential changes in the environment. We explore the influence of variability in beach width, environmental impacts, and individual characteristics (e.g., environmental attitudes, political ideology, education, income, etc.) on WTP for beach replenishment, shoreline armoring, and coastal retreat for beach users and non-users. Employing a utility-theoretic valuation framework, we use revealed preference demand data and stated preference contingent valuation data to estimate total value of coastal erosion management in North Carolina, while testing for the presence of existence value.

Data

Our data focus on visitation to and management of the North Carolina's ocean beaches. Shoreline armoring has been proscribed in the state since the 1980s, though some oceanfront properties facing high erosion risk use large sandbags to protect their homes. The North Carolina legislature, however, recently approved the use of terminal groins,[6] and some suspect that they may permit more hardening of the shoreline in the near future. Beach replenishment is conducted along many parts of the North Carolina coast; some projects are part of ongoing federal operations that were approved decades ago (e.g. Wrightsville Beach), and others are funded locally (e.g. Carteret County). Like most parts of the U.S. coast, shoreline retreat is typically only employed as a measure of last resort, but there are parts of the North Carolina shore that have had to embrace retreat (e.g. South Nags Head).

The data were collected through contract with *Online Sampling Solutions, Inc.* In late fall of 2013. The data provider gave us access to their *Research Now* panel,[7] which is designed for research purposes, actively managed, and recruited using standard marketing research techniques. These sorts of large Internet panels garner participation from households by providing financial incentives from a rotating sample of respondents. They usually provide for much better response rates than mail or phone surveys and have known characteristics (e.g. income, education level) that allow for analysis of sample response bias. We received a 61% response rate, and our data compare favorably to the population based on observables collected via U.S. Census (more on this below). We note, however, that since we are partially focusing on recreation demand, we over-sample beach users in our sampling design. We, thus, cannot claim that our sample is representative of the general population of North Carolina, but it does include information from households that visit the beach and those that do not.

The survey questionnaire included a short pre-amble to describe the resource problem under study:

This survey is about North Carolina beaches.

[5] On the other hand, Shivlani et al. (2003) find that willingness to pay for additional beach width that provides additional habitat to sea turtle in Florida increases willingness to pay by about 25% - from $2.22 v. $2.78 per household, per visit.

[6] Groins are shore-perpendicular structures designed to protect downdrift land and/or trap sand. Terminal groins are found at the end of the beach, often adjacent to waterways.

[7] Research Now has since merged with Survey Sampling International to form Dynata, www.dynata.com.

Table 1
Details of beach erosion management alternatives.

Beach Erosion Management Scenarios	Description of Policy
Beach Replenishment	Public funding for replenishment of North Carolina beaches. This policy will improve beach width, providing for improved recreation, storm protection, and ecological habitat.
Shoreline Armoring (with replenishment)	Public funding for shoreline armoring in conjunction with replenishment of North Carolina beaches. This policy will protect oceanfront development and improve beach width, providing for improved recreation, storm protection, and ecological habitat.
Coastal Retreat	Public funding for coastal retreat along North Carolina beaches. This policy will provide funds for relocating building and infrastructure, which will improve beach width, providing for improved recreation, storm protection and ecological habitat.
Status Quo	No state program - coastal communities would pursue limited beach nourishment and continued erosion. Overall coastal beach width would continue to decline, leading to loss of beach area for recreation and tourism and loss of natural beach habitat.

Beaches provide for storm protection and coastal recreation. Wind, waves, currents, storms, and changing sea levels have contributed to the erosion of coastal beaches. About 75% of North Carolina beaches have eroded an average of 2.7 feet per year in the past 20 years. Between 1% and 2% of the North Carolina coastline has no dry sand at high tide.

The instrument collects information on subjects' knowledge of coastal processes (trends in sea level and damage due to coastal storms); beliefs about coastal erosion; and attitudes toward federal, state, and local governments' management of erosion. All respondents are asked to describe their level of concern (using Likert scales) over beach width, protection of coastal properties, and the use of public money for erosion management.

We collect information on past and planned future recreation trips to the North Carolina coast. The contingent valuation part of the survey is designed to assess a cooperative state program that would pursue a concerted strategy to manage erosion on all North Carolina beaches. The proffered strategies are beach replenishment, shoreline armoring in conjunction with beach replenishment, and shoreline retreat, each relative to a status quo of no state erosion control program. For each possible strategy, a brief description of the approach was provided, as well as potential negative environmental impacts. Table 1 provides brief summaries. (See the Appendix for additional details.) Each respondent was asked to describe their level of support for each of the coastal management strategies and the status quo (ranging from strongly oppose to strongly support).

As we are interested in both use and non-use (existence) values, we make a distinction between those respondents that visit beaches and those that do not. We classify respondents as beach users if they reported at least one trip to East Coast beaches in the previous 24 months. While the distinction is somewhat arbitrary, this screening question permits us to identify households that have recently used East Coast beaches and to gather detailed trip information only from those households. For these subjects, we collect information on trips to North Carolina Beaches and to other East Coast beaches in previous 12 months. While 12-month recall is demanding of subjects, we provide a detailed map of the North Carolina coast to help jog memories and our data collection period (late fall) was chosen to help respondents book-end the peak summer season when most trips are taken.[8]

In addition, we include a series of contingent valuation (CV) questions to assess WTP for beach erosion management. In assessing each specific erosion management strategy, we utilized a 'between' research design, wherein approximately one-third of the sample was allocated to 'nourish', 'armor', or 'retreat'. Each respondent is asked a polychotomous choice question (Yes/No/Undecided) regarding their willingness to vote in support of their assigned erosion management plan at a randomly assigned price. Also varying 'between' are beach width and environmental effects related to erosion management. Each respondent is systematically assigned to one of the cases I—IV in Table 2 for elicitation of their initial CV response.[9] Each beach width is depicted with color photos that include a single-person for scale. (See the Appendix.)

The payment vehicle was described as an increase in beach property taxes (2 cents per $100 value) accompanied by an increase in overall state income tax. The inclusion of property taxes was incorporated to account for perceived inequity that was revealed during pre-testing. The randomly assigned bid levels were developed based on a range of realistic coastal erosion management cost estimates and pre-tests: $4, $28, $49, $81, and $114 per household, per year. The survey included the following text to enhance incentive compatibility (Landry and List, 2007):

Imagine that you have the opportunity to vote on the proposed coastal erosion management plan, __________. If more than 50% of North Carolina households vote for the plan then it would be put into practice.

Sometimes when people are asked to evaluate a proposed policy like this one, it is easy for them to say they support a policy either because they are not being asked to pay at the same time, or they don't think they will have to pay based on their response.

8 In addition to revealed preference trips, we inquire about stated preferences. Each respondent is asked to state their expected future trips to North Carolina and other East Coast beaches over next 12 months under current conditions (average NC beach width of about 100 feet), and expected trips under a scenario in which North Carolina beaches are heavily eroded to an average width of 30 feet. These data are not analyzed in the current paper.

9 Follow-up CV evaluations and SP trip information are also collected moving horizontally or vertically in Table 2 (thus adding a 'within' dimension to the trip data). These data are not utilized in the current paper.

Table 2
Experimental design for contingent valuation study.

		Environmental Impacts	
		Minimal	Negative
Beach Width	*Wide*	I. Wide beaches (e.g., 50-foot increase); minimal environmental impacts associated with management strategy	II. Wide beaches (e.g., 50-foot increase); negative environmental impacts associated with management strategy
	Wider	III. Wider beaches (e.g., 150-foot increase); minimal environmental impacts associated with management strategy	IV. Wider beaches (e.g., 150-foot increase); negative environmental impacts associated with management strategy

We want you to only respond with what you actually think you would do given the beach impacts and the estimated cost to your household.

Also consider your personal income and current payment obligations. If you vote for the policy then you would have ________ less to spend on other things each year. If you pay property taxes on a beach house you would have even less to spend on other things each year.

There is no right or wrong answer but results from this study will be shared with North Carolina coastal policy makers.

The first blank was filled with their assigned policy scenario ('nourish', 'armor', or 'retreat'), and the second blank was filled with their randomly assigned bid. Immediately following their polychotomous choice, they were asked to state their level of certainty in their response.

Lastly, respondents were asked to indicate their level of agreement with statements regarding the suitability of voting referenda to influence coastal erosion policy, the likelihood that results of the survey would be shared with North Carolina policy makers, and the likelihood that the results of the survey would influence policy makers. We also measured the self-assessed understanding of the information contained in the survey and respondents' confidence in the ability of North Carolina State Government to implement the proffered beach erosion policy.

Our sample is refined to include only households that took less than 31 trips during the previous 12 months, and we drop households that own a beach house on the NC coast. Descriptive statistics are presented in Table 3. Eighty-two percent of our respondents met our classification as a beach user (having visited an East Coast beach within the previous 24 months), and the average number of trips to NC beaches over the previous 12 months was 2.13. (This includes both single-day and overnight trips.) Beach site characteristics were measured using aerial photography and include average beach width, beach length, parking area (m^2/km), number of official access points per kilometer, and a dummy variable indicating ferry-access only. For those respondents visiting a single beach, characteristics of that beach are utilized in the demand equation. For those visiting numerous beaches, we employ a weighted average of characteristics (with weights given by the relative proportion of trips to a given site). For non-visitors, characteristics at the nearest beach were utilized.[10] Average beach width (length) was 49.7 m (22,385 m), with a minimum of 18.3 (6350) and a maximum of 95 (88,700). The policy scenario included increasing beach width an average of 22.5 m.[11] The average parking area was 1227 square-meters per kilometer, and the average site had 2.7 beach access points per kilometer. Just over 5 percent of the visited beaches were ferry-access only.

When queried about the support for the various beach erosion management strategies, similar proportions (around 46%) supported or strongly supported the three options identified — beach replenishment, shoreline armoring, and shoreline retreat - while only 16% supported the status quo (limited beach replenishment and continued erosion). The average annual tax increase associated with the erosion control policy was $56, and just over 26% of the sample responded affirmatively to the CV question. Seventy-two percent of respondents support the idea of a referendum for assessing coastal erosion policy, and over two-thirds believe the results generated by our survey will be shared with NC policymakers. Almost 80% claim to have understood all information presented in the survey. Over half of respondents perceive that survey results could have consequences regarding policy adoption, and the same proportion have confidence that policymakers can effectively implement the management strategy.

Table 3 also includes information on household characteristics. Forty-three percent of respondents were male, with a household size of 2.3 persons. U.S. Census 2010 indicates 49% males and average household size of 2.5 persons for North Carolina. Whereas 67% of our sample has a bachelor's degree or greater educational attainment, the NC average is 26.5% (U.S. Census 2010). Median income for our sample is $62,500 (mean = $90,332), while the NC median is $46,291 (U.S. Census 2010). Eighty-seven percent of our sample reported being white (NC average is 72%). Over 7% of respondents indicated membership in an environmental organization. Nineteen percent self-identified the political view as liberal, while 39% (34%) reported moderate (conservative) political views; the remaining 8% indicated 'none of the above' for political view. Eight-six percent of respondents voted in the 2012 Presidential Election. We again note that our sample is not necessarily representative of North

[10] Our approach to measuring site characteristics is in the spirit of Haener et al. (2004); their paper suggests that if households are making choices at a finer scale it is better to aggregate to the level of analysis. The weighted average approach is used with 24% of the data for which household make trips to more than one beach, while the nearest beach assumption is used for 35% of the data, associated with zero trips to the North Carolina coast.

[11] The survey presented beach width changes in feet; we converted to meters and adjusted downward by 25% to account for beach shape returning to equilibrium profile after replenishment (Smith et al., 2009)

Table 3
Descriptive statistics.

Variable	Mean	Std. Dev	Min	Max	
Beach visitor (=1)	0.822	–	0	1	
Beach trips	2.130	3.769	0	30	
Travel cost	270.706	131.797	3.281	728.647	
Beach Characteristics					
Beachwidth (m)	49.711	16.947	18.29	95	
Beachlength (m)	22,385	10,015.4	6350	88,700	
Parking_area (m^2/km)	1227.35	401.271	0	2033.78	
Access_km (points/km)	2.897	1.196	0.011	5.811	
Ferry_only	0.054	–	0	1	
Management/CV Factors					
Favor_nourishment (=1)	0.466	–	0	1	
Favor armor (=1)	0.462	–	0	1	
Favor retreat (=1)	0.447	–	0	1	
Favor Status quo (=1)	0.163	–	0	1	
tax	56.17	39.16	4	114	
Vote (=1 for "Yes")	0.264	–	0	1	
Support referendum (=1)	0.716	–	0	1	
Share policymakers (=1)	0.692	–	0	1	
Survey consequences (=1)	0.555	–	0	1	
Understand (=1)	0.796	–	0	1	
Confidence (=1)	0.542	–	0	1	
Respondent Characteristics					
Male (=1)	0.436	–	0	1	
Household size	2.334	1.097	1	10	
Children (=1)	0.3625	0.834	0	8	
White	(=1)	0.875	–	0	1
College degree (=1)	0.361	–	0	1	
Graduate degree (=1)	0.320	–	0	1	
Environmental (=1)	0.079	–	0	1	
Income ($1,000s	90.403	54.197	0	312.392	
Liberal (=1)	0.190	–	0	1	
Moderate (=1)	0.394	–	0	1	
Conservative (=1)	0.336	–	0	1	
Voted in 2012 (=1)	0.857	–	0	1	

N = 803 observations.

Carolina households, but does provide information from a more general population of users and non-users than would be found in a typical hedonic property model or recreation demand of beach visitors.

Methods

We build on the concepts of use and existence value developed by Hanemann (1988) and refined by Herriges et al. (2004). Importantly, Herriges, Kling, and Phaneuf point out that revealed preference data alone cannot be used to assess existence values or test the assumption of weak complementarity. Following their framework, we define the consumer's expenditure function:

$$E(p, Q, \tilde{U}) = \min_{y}\{p'y | T[u(y, Q), Q] \geq \tilde{U}\} = e(p, Q, \theta(\tilde{U}, Q)) \quad (1)$$

where $T[u(y,Q),Q]$ is the direct utility function (increasing in $u(\bullet)$ and Q, and $u(y, Q)$ is increasing and quasi-concave). The final expression in equation (1) indicates that part of the necessary expenditures to attain a given level of utility depend upon consumption of private market goods, but part can depend upon non-market public good provision $[\theta(\tilde{U},Q)]$. The latter factor is independent of choices that depend upon prices (p) and thus can represent existence value, but to assess this part of preferences we require stated preference data.[12]

Econometrically, we build on the models of Ebert (1998), Eom and Larson (2006), and Huang et al., 2016 to jointly estimate parameters of recreation demand and existence values. Ebert (1998) shows how the incomplete demand system framework can be used with information on WTP for a public good to recover the underlying preference ordering. If the Slutsky substitution matrix associated with the incomplete demand system and WTP function is symmetric and negative semi-definite,

[12] Herriges et al. (2004) also explore decomposition of revealed preference use values into direct and indirect use, with the latter corresponding to values that remain when a household faces the choke price for recreation. Since our primary focus is on the semi-log demand form (equation (2)), choke price is infinite. Thus, we are unable to assess the possibility of indirect use values.

then conditions hold for weak integrability that will guarantee the existence of a pseudo-indirect utility function, which permits evaluation of exact welfare measures for goods within the incomplete system (Proposition 2' (Ebert, 1998, pg. 250)).

Eom and Larson (2006) apply this method using a semi-log specification for recreation demand, which is integrated to recover a quasi-expenditure function, $e\ [p,\ Q,\ \theta(\tilde{U},Q)]$, that depends upon travel cost, p, environmental quality, Q, and a constant-of-integration, θ. The constant term can be thought of as an index of utility, and to incorporate potential existence value, it can be specified to depend upon Q. With appropriate data, the quasi-expenditure function can be used to assess welfare of changes related to p or Q and can test for weak complementarity (which entails no existence value). When existence value is present, the closed-form expression for welfare estimation permits a separation of use and existence values. Employing recreation demand and contingent valuation data, Egan (2011) applies the Eom and Larson model to Iowa lakes data, finding support for weak complementarity (rejecting existence value).

Huang et al. (2016) expand the empirical framework for joint estimation, considering an array of functional froms for recreation demand and WTP. They focus primary attention on a semi-log demand specification, but their Appendix includes detailed derivations with five other common demand functional forms. Following Huang et al. (2016), we employ the following demand specification for recreation trips, Y:

$$\mathrm{E}(Y) = \exp(\beta p + \gamma \ln(m) + \delta \ln(Q) + \alpha'(Z)), \tag{2}$$

Where p is the travel cost (including monetary operating costs derived from AAA and opportunity costs of time assuming 1/3 implicit wage rate)[13]; m represents household income; Q is an environmental quality indicator, and Z includes other covariates.[14] Following LaFrance (1990) and von Haefen and Roger (2002), we model the individual demand equation as an incomplete demand system for $k+1$ beach destinations, treating the other k sites as unobserved. We normalize all prices and income by a numeriare good (county-level housing price index) to impose homogeneity, and restrict substitute site cross-price coefficients to be zero in order to impose symmetry of the Slutsky substitution matrix (LaFrance, 1990; von Haefen and Roger, 2002).[15] Among items in the Z matrix, we include a constant term and site characteristics: ln (beach length), access point/km, parking spaces/km, and ferry-only access (proportion or dummy variable).

Because 35% of households report no beach trips for the North Carolina coast, a continuous model of trip demand is not applicable. The trip data are over-dispersed given that the mean number of trips observed is 2.14, and the variance of trips is 3.77. Thus, both a negative binomial model and a Poisson log-normal model were fit to the trip demand data. The Poisson log-normal model produced a larger log-likelihood than the negative binomial specification. Although estimation is more computationally demanding for the Poisson log-normal count data demand model, we now show how it can be jointly estimated with the probit CV model to incorporate stated preference responses that would alter quality levels of the recreation site(s).

As defined by Aitchison and Ho, 1989 the univariate Poisson-log normal probability mass function is obtained from a Poisson probability mass function in which the location parameter λ is assumed to follow a log-normal distribution. That is $\ln(\lambda) \sim N(\mu, \sigma^2)$, and the resulting distribution has the form:

$$\theta(\tilde{U},Q)P(Y=y) = \int_{R_+} \frac{e^{-\lambda}\lambda^y}{\lambda y!} \frac{e^{-.5(\ln(\lambda)-\mu)^2/\sigma^2}}{\sigma\sqrt{2\pi}} d\lambda \quad y = 0,\ 1,\ 2, \tag{3}$$

Evaluation of this integral is made difficult due to the requirement that $\lambda > 0$. Introducing the change of variable $\ln(\lambda) = \mu + \sigma\varepsilon$, where $\varepsilon \sim N(0,1)$ with the corresponding Jacobian of transformation, $\lambda\sigma$, then yields the probability mass function:

[13] Fezzi et al. (2014) and Wolff (2014) estimate that the opportunity cost of travel time is 3/4 and 1/2 of the wage rate instead of 1/3. If that is the case with our sample then the use of 1/3 wage will downwardly bias the consumer surplus estimates. Unfortunately, we are not able to test the models of Fezzi et al. (2014) and Wolff (2014) with our data. Therefore, we do not deviate from the standard measurement of the opportunity cost of travel time in this study.

[14] In addition to the semi-log form in (2), we also estimated a semi-log model that is linear in Q [$\mathrm{E}(Y) = \exp(\beta p + \gamma ln(m) + \delta(Q) + \alpha'(Z))$] and a log-linear model [$\mathrm{E}(Y) = \exp(\beta \ln p + \gamma \ln(m) + \delta \ln(Q) + \alpha'(Z))$] (both from Huang et al. (2016)). For the semi-log model with linear Q term, the full RP-SP specification converged to a log likelihood value of −1703.23 which is slightly smaller than the −1702.85 found for our original model. Thus, there is no compelling reason to adopt this version of the semi-log specification. For the log-linear model, the full RP-SP specification converged to a log likelihood value of −1670. 25, suggesting a better fit than equation (2). The estimate of β was −0.7088 (se = 0.0375) and the estimate of δ was −0.0141 (se = 0.0135). Huang et al. (2016) require that $\beta < -1$ in their Appendix Table A, which is partly why we did not further consider this model initially. This restriction is necessary for the existence of WC and presumes that Q is an environmental amenity such that $\delta > 0$. We posit that Q can be considered an environmental amenity if $0 > \beta > -1$ and $\delta < 0$, though this form may explicitly violate WC. We have calculated the full sample welfare measures for the log-linear model and find that the results are very similar to those from the specification of recreation demand in equation (2) (e.g. 3% difference in median WTP, but larger difference in mean). Given the log-linear model's rather unconventional estimation results, we focus on the results from equation (2). The results from the log-linear model, however, are presented in Appendix Table A1.

[15] An alternative is to specify incomplete demand system for one destination and treat other sites as outside of the demand system.

$$P(Y=y)=\int_{-\infty}^{\infty}\frac{e^{-\lambda}\lambda^{y}}{y!}\frac{e^{-.5\varepsilon^{2}}}{\sqrt{2\pi}}d\varepsilon \quad where\ \lambda\ =\ e^{\mu+\sigma\in} \tag{4}$$

Now consider a latent variable model for WTP for beach erosion control program: WTP* = Xω + ν where ν is normally distributed with mean zero and variance σ_{ν}^2. Under the contingent valuation scenario, the respondent will vote yes when WTP*>tax which generates the probit probability: Prob (yes) = $\Phi((X\omega - tax)/\sigma_{\nu})$. Here Φ(.) represents the standard normal cumulative distribution function. Next suppose that there is a normally distributed random variable w such that w ~ N (μ_w, σ_w^2). Then it is well known that:

$$\text{Prob}\left(\text{yes}\middle|\text{w}\right)\ =\ \varphi\left([(X\omega-\text{tax})/\sigma_{\nu}+\ \rho(\text{w}-\mu_{\text{w}})\ /\ \sigma_{\text{w}}]\ \Big/\ \sqrt{1-\rho^{2}}\right. \tag{5}$$

Because this conditional probability is based on Gaussian distribution theory, in general it cannot be employed with a count data variable. One exception is when w represents log λ in the Poisson-log normal distribution. The conditional probability becomes:

$$P(\text{yes}|\ln(\lambda))=\Phi\left([(\omega'X-\text{tax})\ /\ \ \sigma_{\nu}+\rho(\ln(\lambda)-\mu)\ /\ \sigma]\ \Big/\ \sqrt{1-\rho^{2}}\right). \tag{6}$$

The joint distribution of the count and the binary response variable is given by multiplying the marginal and the conditional distributions to yield:

$$P(Y=y,\ WTP^{*}>tax)=\int_{-\infty}^{\infty}\Phi\left(\frac{(\omega'X-tax)/\sigma_{\nu}+\rho\varepsilon}{\sqrt{1-\rho^{2}}}\right)\frac{e^{-\lambda}\lambda^{y}}{y!}\frac{e^{-.5\varepsilon^{2}}}{\sqrt{2\pi}}d\varepsilon \tag{7}$$

where, again, $\lambda = e^{\mu+\sigma\varepsilon}$. Equation (7) represents likelihood contributions given by those respondents that answer affirmatively to the CV scenario. Likelihood of “No” responses is given by:

$$p(Y=y,\ WTP^{*}\le tax)=\int_{-\infty}^{\infty}\Phi\left(\frac{\frac{tax-\omega'X}{\sigma_{\nu}}-\rho\varepsilon}{\sqrt{1-\rho^{2}}}\right)\frac{e^{-\lambda}\lambda^{y}}{y!}\frac{e^{-.5\varepsilon^{2}}}{\sqrt{2\pi}}d\varepsilon \tag{8}$$

To complete the joint distributions in (7) and (8), we require a form for WTP, which depends on the specification of existence value. Duality permits us to recover the expenditure function in equation (1) from the revealed preference trip demand in equation (2). Existence value is accounted for in the constant of integration $\theta(\tilde{U},Q)$. We consider two specifications:

1] No existence value [constant of integration is independent of Q: $\theta = \tilde{U}$];
2] An exponential form [$\theta = \tilde{U}e^{-W\theta\phi}$]

Using the expenditure function specification in equation (1) and the results of Huang et al. (2016), WTP for coastal erosion management programs are, respectively:

$$WTP\ =\ m-\left[m^{1-\gamma}+(1-\gamma)e^{Z\alpha+\beta p+\frac{\sigma_{\varepsilon}^{2}}{2}}\left(Q_{1}^{\delta}-Q_{0}^{\delta}\right)\Big/\beta\right]^{1/(1-\gamma)} \tag{9}$$

$$WTP\ =\ m-\left[e^{-\varphi dQ}m^{1-\gamma}+(1-\gamma)e^{Z\alpha+\beta p+\frac{\sigma_{\varepsilon}^{2}}{2}}\left(Q_{1}^{\delta}-e^{-\varphi dQ}Q_{0}^{\delta}\right)\Big/\beta\right]^{1/(1-\gamma)} \tag{10}$$

where $dQ = Q_1 - Q_0$ and $\phi = W\theta_{\phi}$.[16] Equation (9) does not allow for existence value related to the public good (Q), since Q does not appear in the constant of integration (the part of utility that doesn’t depend upon recreation trips), whereas equation (10) does. In our application, we specify the W vector to depend upon an array of environmental characteristics — erosion control

[16] Huang et al. (2016) provide details on a wide array of specifications for demand and WTP. We attempted to estimate a quadratic WTP function, but (similar to Huang et al. (2016)), we did not get convergence.

Table 4
Joint estimation of trip demands and WTP.

Variable	Specification 1 (No EXV)		Specification 2 (Exponential EXV)	
	Parameter Estimate	Std. Error	Parameter Estimate	Std. Error
Constant	−15.104***	1.153	−15.042***	1.148
Price	−0.005***	0.000	−0.005***	0.000
Ln (Income)	0.289***	0.070	0.285***	0.070
Ln (BeachWidth)	0.053***	0.020	0.047*	0.024
Ln (BeachLength)	1.264***	0.084	1.265***	0.084
ParkArea	−0.018	0.016	−0.018	0.016
Access Points	0.410***	0.065	0.410***	0.065
Ferry	0.781***	0.264	0.788***	0.264
σ(ε)	0.708***	0.038	0.708***	0.038
σ(ν)	133.024***	14.579	124.117***	14.764
P	0.171**	0.073	0.184**	0.075
Constant			−0.106***[a]	0.047
Armor			−0.101*[a]	0.057
Retreat			0.096**[a]	0.047
Impact			0.145***[a]	0.051
Armor*Impact			0.079[a]	0.071
Retreat*Impact			−0.054[a]	0.062
Children			0.029*[a]	0.016
Male			0.035[a]	0.027
Log Likelihood	−1732.3		−1702.85	

Statistically significant at 1% chance of Type I error; 5%; 10%.
N = 803 observations.
[a] Multiply coefficients and their corresponding standard errors by 10^{-4}.

policy, beach width, and absence of negative environmental impacts — introduced in the experimental design of the CV survey. These expressions for WTP are substituted in place of $\omega'X$ in equations (7) and (8), forming the basis for the log-likelihood function. This microeconomic specification permits tests of weak complementarity, a separation of use and existence value, and testing of covariate effects on use and existence values. WTP for a change in Q has a closed form solution, and with sufficient variation in the data we can compute incremental WTP for Q (beach width). The parameters are estimated using higher-order rectangular integration of the likelihood function in MATLAB.

Results

Parameter estimates for the joint distribution of trip demand and WTP are presented in Table 4. Column one displays results for the model with no existence value (1] $\theta = \tilde{U}$), and column two displays results for the exponential ($\theta = \tilde{U}e^{-W\theta\phi}$) specification of existence value. For the trip demand equation, we find fairly consistent results for both specifications, with a price elasticity of −1.33 and income elasticities of 0.289 and 0.285. Recreation demand is increasing in beach width (elasticities of 0.053 and 0.047), beach length (elasticities of about 1.26), access points per kilometer (elasticities of 1.19), and ferry-only access (elasticities around 0.04). Parking area is not statistically significant in either specification. The variance of the ln-location parameter ($\sigma(\varepsilon)$) is around 0.7 and statistically significant in both models; this supports the Poisson-log normal model over the nested Poisson specification. Each model suggests a per-trip surplus estimate of $200 per household.

Turning to parameters for the distribution of WTP, we estimate statistically significant variance ($\sigma(\nu)$ ranging from $124 to $133) for WTP for the coastal erosion management plan. Note, there is some payoff to using the system estimator for recreation demand and WTP (in terms of efficiency), since in both specifications the estimate of ρ is statistically significant and positive (0.171 and 0.184). The marginal effects are non-linear expressions derived from WTP expressions in (9) and (10), but the parameter signs indicate the direction of influence. From exponential existence value (EXV) we find WTP for beach erosion control is decreasing in armoring, increasing in shoreline retreat (each relative to beach replenishment), increasing in absence of negative environmental impacts, and increasing in the number of children in the household. Comparing models (9) and (10), the weak complementary hypothesis can be soundly rejected ($\chi^2_{LRT} = 58.9$, p-value < 0.000001).

Welfare measures for coastal erosion management depend on the specification chosen as shown in Table 5. Models (9) and (10) find positive and statistically significant mean WTP of $10.03 and $7.91 per household, per year for coastal erosion management, respectively; corresponding median WTP values are $5.64 and $10.70 per household, per year.[17] Given the variation in initial (via RP data) and subsequent (via SP data) beach width, WTP can be expressed in incremental units. Mean

[17] Note, the mean and median WTP measures differ in relative magnitude across the two model specifications. We infer this as indicative of irregularity in the distributions of WTP.

Table 5
WTP for coastal erosion management.

	Specification 1 (No EXV)	Specification 2 (Exponential EXV)
Mean WTP	\$10.03	\$7.914
	(3.880)	(1.869)
Mean WTP per Meter	\$0.3506	\$0.2459
	(0.135)	(0.057)
Median WTP	\$5.643	\$10.70
	(2.229)	(2.645)
Median WTP per Meter	\$0.2327	\$0.4773
	(0.0939)	(0.1104)

Standard errors appear in parentheses and are obtained using asymptotic approximations.

WTP for beach width is between \$0.25 and \$0.35 per meter, and median WTP for beach width ranges between \$0.24 and \$0.48 per meter.

Table 6 presents WTP estimates for sub-samples defined by the assigned beach erosion policy treatment: beach replenishment, shoreline armoring, or shoreline retreat. Standard errors are generated via jack-knife procedure. We find significantly greater mean and median WTP for shoreline retreat: \$34.35 and \$22.20 (per household, per year), respectively; relative to beach replenishment: \$9.24 and \$7.45, respectively; and shoreline armoring: -\$19.37 and \$0.09, respectively. Table 7 presents existence value (EXV); for example, existence value for model (10) can be defined as E [Y] converges to zero, as:

$$EXV = m - \left[e^{-\varphi dQ} m^{1-\gamma}\right]^{1/(1-\gamma)} = m - e^{-\varphi dQ} m = m\left(1 - e^{-\varphi dQ}\right) \tag{11}$$

with the remaining WTP being attributable to use value:

$$\text{UV} = \text{WTP} - \text{EXV} \tag{12}$$

Considering the median welfare measures, we derive the following breakdowns in UV and EV: Full Sample: UV = \$5.49; EXV = \$5.21; Retreat Scenario: UV = \$7.56; EXV = \$14.64; Armor Scenario: UV = \$9.31; EXV = \$-9.21; Nourish Scenario: UV = \$4.72; EXV = \$2.73 (Table 7—all values per household, per year).

Lastly, we explored potential differences in WTP for users and non-users by including a dummy variable for beach non-users in $\phi = W\theta_{\phi}$ in equation (10). Adding a non-user dummy variable produces a parameter estimate of −0.0352 (with a standard error of 0.0323) and reduces the log-likelihood by 3.85. An alternative specification that dropped all covariates in ϕ except the beach non-user dummy variable produced a similar parameter estimate and much lower log-likelihood (−28.45). Thus, our data suggest no differences in existence value among users and non-users.

Discussion

Following Ebert (1998), Eom and Larson (2006), and Huang et al. (2016), we estimate models of beach recreation demand and total WTP for beach erosion control policies that effect beach width and coastal environmental quality. We utilize internet survey data with a response rate of 61%; our sample, however, exhibits greater levels of income and education than the general population of North Carolina. Otherwise, it appears to be fairly representative. Results of our structural econometric model indicate that households value beach trips at around \$200 (or around \$417 per household annually) and are WTP for coastal erosion management, with WTP being greater for shoreline retreat, followed by nourishment, with shoreline armoring coming in a very distant third. Almost three-fourths of our sample believe a state referendum is a good way to decide on erosion policy; over two-thirds believing results will be shared with policy makers, and more than half thinking it may have policy consequences. We have yet to explore the implications of these dimensions of the sample on economic value; this remains an important area of future research.

We expect that beach erosion management can affect existence values for some portion of stakeholders, and our sampling protocol captures information from users and non-users of North Carolina beaches. As such, we adopt a research design that can account for use and existence values. Our formulation permits correlation among recreation demand and WTP and allows for testing of weak complementarity (which implies zero existence value and is often assumed in analysis of recreation demand). Economic benefits of a state-level erosion management program are estimated as mean WTP of \$7.91 per household, per year (median WTP of \$10.70). Given the current (revealed preference) and simulated (stated preference) variation in beach width (permitting identification of the δ parameter in recreation demand model [equation (2)] and WTP models (9) and (10)), we are able to estimate incremental WTP per meter of beach width, which ranges from \$0.24 to \$0.48 per meter, per household, per year. Estimates of marginal values of beach width have been derived from hedonic property models (Pompe, 2008; Landry and Hindsley, 2011; Gopalakrishnan et al., 2011; Ranson, 2012; Landry and Liu, 2011), but are otherwise rare in the literature. Such estimates are instrumental in application of optimal control models to coastal management (Slott et al., 2008; Smith et al., 2009; Landry, 2011; McNamara et al., 2011; Lazarus et al., 2011; McNamara and Keeler,

Table 6
WTP for coastal erosion management.

	WTP Full Sample	Retreat Scenario	Armor Scenario	Nourish Scenario
Mean WTP	$7.914	$34.45	-$19.37	$9.241
	(1.869)	(2.45)	(3.53)	(2.61)
Mean WTP/Meter	$0.2459	$1.152	-$0.659	$0.2621
	(0.057)	(0.062)	(0.115)	(0.076)
Median WTP	$10.70	$22.20	$0.0998	$7.449
	(2.645)	(3.07)	(4.42)	(3.270)
Median WTP/Meter	$0.4773	$0.9495	$0.0065	$0.3106
	(0.1104)	(0.077)	(0.144)	(0.095)

Sample Composition: 33.7% Retreat, 34.4% Armor, 31.9% Nourish.

2013; Williams et al., 2013; McNamara et al., 2015; Jin et al., 2015; Gopalakrishnan et al., 2016a, 2016b, 2017; Keeler et al., 2018; Mullin et al., 2018).

Microeconomic theory can be used to define use and existence values stemming from a change in natural resources (Ebert, 1998; Herriges et al., 2004), and through combination of appropriate revealed and stated preference data, econometric results can provide evidence on existence values (Eom and Larson, 2006; Huang et al. 2016). In the context of revealed preference analysis of recreation demand, analysts often assume weak complementarity between demand for recreation trips and the quality of the recreation site. This entails an untestable assumption about preferences that permits recovery of welfare estimates, but imposes zero existence value (Herriges et al., 2004). By combining revealed preferences with stated preference data, likelihood ratio tests provide evidence for rejection of the assumption of weak complementarity between beach quality and beach visitation at a high level of confidence (p-value less than 0.000001). We first consider total WTP for coastal erosion management programs in North Carolina, then the breakdown of total WTP into use and existence value.

Examining WTP estimates by policy approach (which are assigned to subjects via *between* experimental design), we find median WTP estimates of $22.20 per household, per year (hh/year) for shoreline retreat, $0.10/hh/year for shoreline armoring, and $7.45/hh/year for beach nourishment.[18] The U.S. Census estimates 3,815,392 households in North Carolina in 2015. Scaling our median WTP values produces aggregate economic welfare estimates of $84.7 million per year for shoreline retreat, approximately $381,000 per year for shoreline armoring, and $28.4 million per year for beach replenishment. Given our primary focus on beach visitors and the potential for over-representation of higher income households and those with greater educational attainment, these estimates may be considered upper bounds on population estimations. Nonetheless, as the status quo management approach, beach replenishment appears to have substantial support among NC households, with significant aggregate willingness to pay, while shoreline armoring appears to have a very low level or support. Somewhat surprisingly, our sample of NC households exhibits a much higher level of support and WTP for shoreline retreat. This warrants additional research into administrative, logistical, and legal aspects of adapting to coastal erosion through moving of buildings and infrastructure.

Breaking down median WTP into use and existence value components via equations (11) and (12), we find existence values for the full sample that are similar in magnitude to use values: UV = $5.49; EXV = $5.21 (all values in hh/year terms), but these aggregate values mask considerable heterogeneity by policy approach. For shoreline retreat, we find existence values that exceed use value by a factor of almost two: UV = $7.56; EXV = $14.64. Whereas for beach nourishment, use values exceed existence values: UV = $4.72; EXV = $2.73. The shoreline armoring scenario produces negative estimates of existence value (EXV = $-9.21) which are similar in absolute value to use value estimates (UV = $9.31), rendering median total WTP for shoreline armoring close to zero.

We estimate positive economic values associated with avoidance of negative environmental impacts of beach erosion management. In our survey, these are described as follows: <u>Beach Nourishment</u>: disruption of ocean-bottom habitats, increased cloudiness in coastal waters; burial of beach organisms and alteration of sand texture on the beach (mostly short term, but can be more long-term with poor project management); <u>Shoreline Armoring</u>: disruption of continuous beach and loss of beach habitat; <u>Shoreline Retreat</u>: temporary disruption of continuous beach; temporary loss of beach habitat; temporary presence of debris on some parts of the beach (see Appendix for more details). Using a between experimental design, some subjects receive scenarios that include these negative environmental impacts, whereas others receive scenarios without negative environmental impacts. Results indicate greater WTP when these environmental impacts are absent, but the parametric estimates do not differ by erosion management strategy.

[18] Corresponding Mean WTP estimates are $34.45/hh/year for shoreline retreat, -$19.37/hh/year for shoreline armoring, and $9.24/hh/year for beach nourishment, indicating a positive skew in WTP for shoreline retreat and beach nourishment, but a negative skew for shoreline armoring.

Table 7
Existence values (EXV) for coastal erosion management.

	Full Sample	Retreat Scenario	Armor Scenario	Nourish Scenario
Mean EXV	$-0.915	$25.21	$-27.54	$0.134
	(1.805)	(2.20)	(3.56)	(2.49)
Mean EXV/Meter	-$0.063	$0.8319	-$0.9594	$0.044
	(0.056)	(0.057)	(0.113)	(0.073)
Median EXV	$5.21	$14.64	-$9.21	$2.733
	(2.26)	(2.75)	(4.46)	(3.13)
Median EXV/Meter	$0.2032	$0.6509	-$0.3584	$0.1138
	(0.070)	(0.071)	(0.141)	(0.091)

Conclusions

As a major front in the evolution of climatic change, the coastal zone exhibits significant management problems related to coastal erosion, storms, sea level rise, and—in many areas—burgeoning coastal development and increasing populations. Coastal vulnerability entails serious implications for economic welfare, human livelihoods, and environmental sustainability. Using survey data from a sample of North Carolina households, we assess economic values stemming from coastal erosion management strategies and changes in beach width. Our combined RP-SP approach builds on existing research (Herriges et al., 2004; Eom and Larson, 2006; Huang et al. 2016) by extending the model framework to utilize a count data regression model and our dataset is the first, to our knowledge, to include preference information from both users and non-users. We estimate structural micro-econometric models of beach recreation demand and total WTP for beach erosion control policies that effect beach width and coastal environmental quality. Our formulation permits correlation among recreation demand and WTP and tests of weak complementarity (which implies zero existence value and is often assumed in analysis of recreation demand).

While our sample is not necessarily representative of the NC population, we find evidence of significant welfare gains stemming from shoreline retreat (with a large component for existence value), modest support for beach nourishment (with significantly lower existence values), and null values associated with shoreline armoring (consisting of negative existence values that are of similar magnitude to use values). The results suggest that organized adaptation to shoreline change has considerable support amongst some NC households and deserves more study; a large part of public support appears to be driven by existence values that surround passive adaptation to shoreline change (e.g. identifying areas of greatest vulnerability and relocating public infrastructure and private buildings). On the other hand, hardening of the shoreline with seawalls, rock piles, and revetments to protect property and infrastructure has a low level of support among households in our dataset, primarily driven by negative existence values. There is significant evidence of negative externalities imposed by shoreline armoring (prohibiting natural movement of sediments and reflecting wave energy that leads to a scouring and removal of beach sand); these deleterious environmental effects appear to be driving negative existence values for shoreline armoring.

Existing variation in beach width embedded within the RP data combined with contingent, scenario-defined changes in beach width within the SP data permit identification of the value of changes in beach width, which enables a per-unit value for non-marginal beach width changes. Our estimates range from $0.24 to $0.48 per meter, per household, per year ($2012 US). These types of estimates, which vary with erosion control policy, are informative for policy analysis and are instrumental in application of optimal control models to coastal management and coastal adaptation to sea level rise (Landry 2008, 2011; Smith et al., 2009). Incorporating economic values related to property values, recreation, and existence of coastal habitats will provide for more sound assessment of coastal protection and adaptation decisions.

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Appendix

Table A1
Log-Linear Model Estimates

(Exponential EXV)	Parameter Estimate	Standard Error
Constant	−11.1660	1.0983
Ln (Price)	−0.7088	0.0375
Ln (Income)	0.2149	0.0646
Ln (BeachWidth)	−0.0141	0.0135
Ln (BeachLength)	1.2239	0.0816
ParkArea	−0.0164	0.0153
Access Points	0.4284	0.0615
Ferry	0.7452	0.2476
σ(ε)	0.6328	0.0369
σ(ν)	124.4130	14.7944
rho	0.2197	0.0792
Constant	−0.1161	0.0520
Armor	−0.1147	0.0640
Retreat	0.1046	0.0521
Impact	0.1616	0.0558
Armor*Impact	0.0879	0.0791
Retreat*Impact	−0.0555	0.0689
Children	0.0304	0.0182
Male	0.0390	0.0298
Log Likelihood	−1670.25	
Full Sample Measures	WTP	EXV
Mean	$6.90	-$0.87
Median	$10.36	$5.31

A. Descriptions of Management Scenarios

1. **Beach nourishment** involves adding sand to the beach to increase beach width and build dunes. The beach will still erode over time so sand must be added about every 3−5 years to maintain width. Beach nourishment would be paid for by a public program that provides funds to periodically place sand on North Carolina beaches.

Beaches that have been nourished provide for greater storm protection for coastal communities and provide for recreational and leisure benefits for all visitors.

Potential negative environmental impacts from beach nourishment include:

- disruption of ocean-bottom habitats, which can affect turtles, fish communities, and small creatures like clams and crabs
- increased cloudiness and alterations to sediment movement in coastal waters
- burial of beach organisms and alteration of sand texture on the beach, which can affect plants, turtle nesting, shorebird habitat, and small creatures like clams and crabs

Most of these effects are short term, but can present *longer term problems if incompatible sand is mined from the wrong areas offshore*.

Once complete *beach nourishment can provide additional beach habitat for coastal animals and plants*, such as sea turtles, shorebirds, dune mice, dune plants, and small creatures like clams and crabs.

2. **Shoreline armoring** uses concrete and rocks to protect coastal buildings, roads, and utilities. This process often erodes the beach and can increase erosion at other nearby beaches. **Beach nourishment** can be used to maintain beaches where this erosion occurs. Shoreline armoring and beach nourishment would be paid for by a public program that provides funds to construct and maintain shoreline armor and periodically place sand on North Carolina beaches.

Potential negative environmental impacts from shoreline armoring and beach nourishment include:

- disruption of ocean-bottom habitats, which can effect turtles, fish communities, and small creatures like clams and crabs
- increased cloudiness and alterations to sediment movement in coastal waters
- burial of beach organisms and alteration of sand texture on the beach, which can affect plants, turtle nesting, shorebird habitat, and small creatures like clams and crabs
Most of these effects are short term, but can present *longer term problems if incompatible sand is mined from the wrong areas offshore.*

The negative impacts of shoreline armoring are more permanent and include:

- disruption of continuous beach
- loss of beach habitat.

Beaches would be wide, but could be interrupted by seawalls, rocks, and concrete. These negative impacts can be minimized through beach nourishment and careful project management.

3. **Retreat and adaptation** involves moving vulnerable buildings, roads and utilities out of harm's way to adapt to the changing shoreline. This approach allows the beach to evolve naturally. Some debris can be temporarily left on the beach during the retreat. Parts of the beach may be inaccessible at times as buildings and infrastructure are moved. Shoreline retreat and adaptation would be paid for by a public program that provides funds to move buildings, roads, and infrastructure out of harm's way and to offer partial compensation to those that lose their land. Retreat would only be implemented when shoreline erosion gets severe enough to require adaptation.

Potential negative environmental impacts of **shoreline retreat and adaptation:**

- temporary disruption of continuous beach
- temporary loss of beach habitat
- temporary presence of debris on some parts of the beach.

Most of these effects appear to be short term. There are no negative impacts after the debris is removed. Negative environmental impacts can be minimized through careful project management.

B. Visual Aids

Description of Baseline.

Along the North Carolina coastline, the average beach width is around 100 feet. The pictures below indicate what the current beach width looks like:

Erosion scenario (SP1): If nothing is done to combat beach erosion, beaches along the North Carolina coast could face significant erosion that could reduce beach width to 30 feet. The pictures below indicates an average beach width of 30 feet.

The picture below indicates the increase in beach width to 150 feet.

The picture below indicates the increase in beach width to 250 feet.

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