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Hedonic property prices and coastal beach width

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Abstract

Previous research suggests that coastal housing values capitalize the quality of nearby beaches but note potential problems related to measurement errors and reverse causation due to beach replenishment. We offer the first hedonic analysis of communities not engaged in beach replenishment, obviating concern over reverse causation. Statistical evidence supports hedonic specifications that account for proximity to the shoreline, though marginal willingness to pay (WTP) varies with the specification. Using an instrumental variables approach, we find significant downward bias in ordinary least squares estimates of marginal WTP derived from the sale of vacant lots compared to two-stage least squares estimates on the same vacant lots. Notably, we do not find evidence of the same downward bias in WTP derived from the sale of existing homes.

KEYWORDS

beach, coastal, erosion, hedonic, housing

JEL CLASSIFICATION

Q51, Q54, Q57

Coastal areas harbor a unique combination of recreation opportunities, aesthetic amenities, ecosystem services, and cultural resources that have historically attracted residential and commercial

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development at much higher rates than noncoastal areas. As a result, many parts of the coast have become densely populated; approximately 40% of the US population lives in a county bordering the ocean, gulf, or great lakes coast, despite the fact that these counties making up only 10% of the US land mass (NOAA, 2016).[1] The unique appeal of coastlines is at least partly related to their dynamic nature. Coastal land forms, large water bodies, and atmospheric conditions interact, giving rise to diverse ecology within a high-energy environment. Nowhere is this more apparent than along the ocean front. Sandy beaches, which make up roughly a third of the world's coastline (Luijendijk et al., 2018), are particularly susceptible to dynamic forces. Although there is substantial spatial heterogeneity, most recent estimates indicate increasing levels of coastal erosion (due to sea-level rise) and that about half of the world's sandy beaches could cease to exist by the end of the century (Vousdoukas et al., 2020). In the United States, approximately 86% of east coast barrier island beaches have experienced chronic erosion during the past century (Zhang et al., 2004), receding at an average of about 1.6 feet per year (Hapke et al., 2010; Morton & Miller, 2005).

In addition to ecological habitat, aesthetic amenities, and support for recreation and tourism, sandy beaches also serve as a natural protective barrier against storm surge. Consequently, mitigating beach erosion is an increasingly important priority for many coastal communities as evidenced by the substantial growth in beach replenishment projects over most of the last 70 years (American Shore and Beach Preservation Association [ASBPA], 2020). Figure 1 shows the volume of sand dredged and mined each year in the United States for purposes of beach replenishment. From 1951 to 2011, the annual volume of sand grew from 7 million cubic yards to over 41 million cubic yards (an average growth rate of 3.4%). The last decade, however, has been characterized by significant declines in overall beach replenishment activity. This is partly

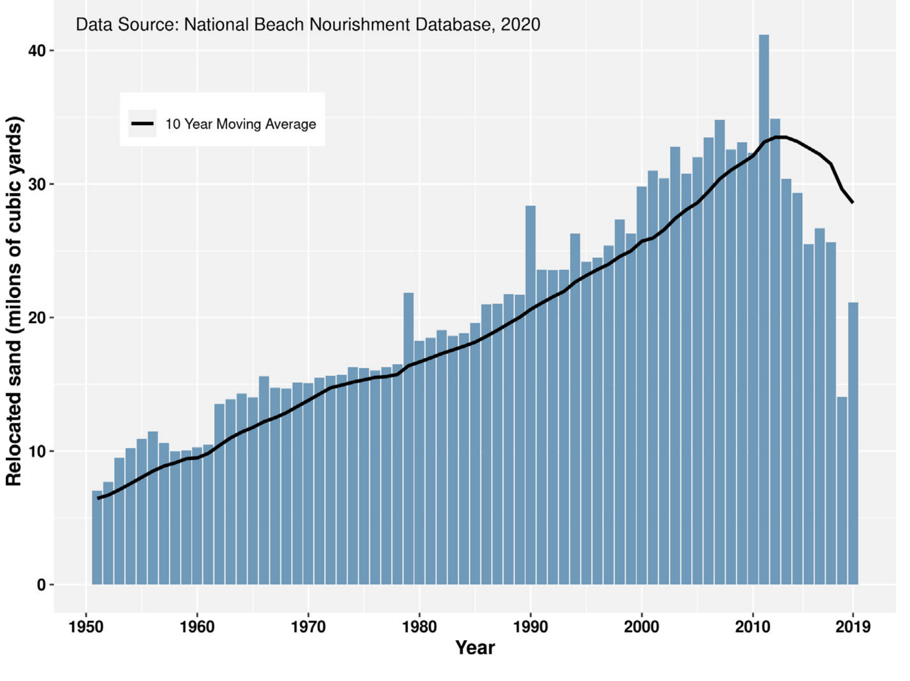

FIGURE 1 Relocated volume of sand for beach nourishment

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driven by increasing scarcity of sand and associated costs of dredging in some locales, but also reflects a shift of the financial burden of beach replenishment from primarily federal to state and local governments (Gopalakrishnan et al., 2018; McNamara et al., 2015).

Although past beach replenishment efforts have been fairly successful in maintaining beach quality, rising sea levels, and escalating management costs have put considerable pressure on the viability of this practice as a sustainable approach to managing shorelines (ASBPA, 2020; Slott et al., 2006). Consequently, accurate estimates of the economic impacts of receding coastlines will be a critical input for future analysis and decisions related to coastal management. Coastal housing markets are of particular interest in this regard, as coastal homes presumably capitalize the amenity value and natural protection that beaches provide. Thus, understanding the effects, coastal beach width has on residential property values is one way to construct estimates of potential lost value from receding coastlines and to assess adaptation measures that can protect coastal resources. In this study, we focus on accurately estimating the magnitude of this effect. More generally, we highlight the usefulness of hedonic models in valuing coastal resources in the context of coastal climate change adaptation and examine some of the empirical challenges that can arise in valuation of actively managed coastal resources. Overall, our results highlight two important aspects empirical researchers should consider in their quest to obtain robust valuation estimates of actively managed coastlines.

First, we highlight the importance of accounting for spatial dimensions of amenity capitalization in coastal housing values. Sandy beaches provide for storm protection and support of recreation and leisure activities. Proximity to the shoreline conveys benefits to beach width, whereas distance from the shoreline implies that storm protection of a particular beach may be less important and recreation opportunities are more diversely reflected in overall beach quality in the area (as opposed to specific point on the nearest beach). Assessing the value of proximal beach width requires accounting for these dimensions of substitution. We contribute to the literature by estimating and comparing a number of functional forms that account for this proximity effect. Generally speaking, we find that hedonic regression models that weigh the implicit value of beach width by the inverse of distance from the shoreline provide the best fit to the housing sales data. Nonetheless, other functional forms may prove useful in other empirical applications, and future research should seek to average or aggregate across suitable specifications when theoretical or empirical guidance is lacking.

Second, we provide insight into hedonic modeling complications on actively managed shorelines. Beach replenishment can create additional challenges for measuring the degree to which housing markets capitalize beach width due to reverse causation in implicit prices (Gopalakrishnan et al., 2011). Our study site obviates this concern via a simplified policy environment in which beaches were not being actively replenished. Thus, we are able to provide estimates of beach width capitalization without having to contend with potential reverse causation. We still employ Instrumental Variables (IV) estimation, however, to address potential errors-in-variables, which can arise due to the fact the current beach width is observed, but the market may capitalize expectations of future beach width (Landry & Hindsley, 2011).

We employ a "post double selection" least aboluste shrinkage and selection operator (LASSO) regression method (Belloni et al., 2014) to choose among a surfeit of IV derived from geophysical seascape measures, finding strong evidence of IV validity, but mixed evidence of errors-in-variables in hedonic regression results. Statistical evidence indicates that IVs based on geophysical properties of the coastline are relevant and valid in predicting beach width. While we find no evidence of errors-in-variables for regressions of housing sales transaction, we do find significant differences in ordinary least squares (OLS) and two-stage least squares (2SLS)

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for sales of vacant lots. We interpret this as potential evidence of market segmentation, where agents involved in the trade of vacant parcels, such as property developers, may be more attentive to coastal risk factors. It is also possible, however, that our hedonic price models of existing homes suffer from mis-specification problems. Thus, we generally put more stock in estimates from vacant lot models, which indicate significant downward bias in standard OLS estimates of the marginal value of beach width accruing to coastal households. Our results highlight the importance of dealing with various sources of endogeneity in analyzing coastal housing markets, but also that those potential sources of estimation bias may not uniformly apply to all types of property market transactions.

The rest of this paper is structured as follows. Section 2 provides an overview of the previous literature concerned with the capitalization of beach width into coastal property values. Section 3 introduces the functional forms we consider for modeling the interaction between beach width and proximity to the shoreline and discusses the use of IV. Section 4 discusses our study setting and the particulars of the data set. Section 5 provides a broad overview of our findings. Section 6 discusses our results, while Section 7 concludes.

CAPITALIZATION OF THE VALUE OF BEACH WIDTH IN COASTAL PROPERTY VALUES

Proximate beaches shield coastal structures from continual waves and currents and episodic storm events, supply space for recreation and leisure activities, and affect the aesthetics of the coastal landscape. While management agencies like the US Army Corps of Engineers (USACE) attempt to value beach width by simulating foregone storm damages attributable to replenishment of beach sand (Landry, 2011), we use property sales values to attempt to establish a relationship between beach width and the preferences of buyers and sellers by assessing property market transactions (Gopalakrishnan et al., 2011; Landry & Hindsley, 2011). A number of studies have been conducted indicating that residential property values capitalize the value of beach width (Catma, 2020; Gopalakrishnan et al., 2011; Hall & Powell, 2001; Landry et al., 2003; Landry & Hindsley, 2011; Pompe & Rinehart, 1995, 1999). These studies typically find that household marginal-willingness-to-pay for increases in beach width is on the order of \$100–\$2000 (1999 USD) per foot, though recent estimates that apply IV find significantly larger values (Gopalakrishnan et al., 2011).

Landry and Hindsley (2011) posit coastal beaches as local public goods that can affect the value of property in close proximity to the shoreline.[2] If the quality of beaches (e.g., size as measured by width, length, or area) varies along the shoreline, the incremental value of beach quality can be capitalized in coastal home and land prices. This capitalized value may reflect erosion and storm protection, as well as potential recreation, leisure, and amenity values. While the quality of local beaches could matter for properties that are in close proximity to the shore, the quality of any particular stretch of beach is likely to become much less important as one locates further from the coastline. Households at significant distances from the shore rely less on local beaches for storm surge and erosion protection and are likely to utilize different parts of the beach for recreation and leisure activities. Beach visitation for these households is likely influenced by transportation infrastructure, access points, and parking facilities.

Early hedonic price studies (Landry et al., 2003; Pompe & Rinehart, 1999) do not address the issue of proximity in their hedonic property price models, including beach width among the regressors but not allowing for the implicit price to vary with distance (other than indirectly

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through average property values at different distances). Nonetheless, these authors find a positive marginal implicit price for beach width. At least two parametric approaches have been utilized to account for the proximity effect of valuation of local beaches. A number of authors have incorporated a distance-beach width interaction term in their hedonic price equations (Catma, 2020; Gopalakrishnan et al., 2011; Pompe & Rinehart, 1995); these authors find a positive value for beach width that declines with distance from the shore. Landry and Hindsley (2011) include proximity dummy variables (ranging from 100 to 600 m distance to the shore) and interact the proximity dummy variables with beach width; this specification restricts the capitalization of beach width values in property sales within the defined proximity band. Their results suggest that the value of beach width is reflected in properties in close proximity to the shore, with the preferred specification associated with 200-m proximity. That is, homes within 200 m capitalize the value of beach width, whereas the prices of home further away are less influenced by width of the nearest beach. Qiu & Gopalakrishnan (2018) use a difference-in-difference approach between nourished and un-nourished communities in Dare County, NC and utilize hurricane Sandy as a natural experiment to analyze how the perceived reduction in risk provided by beach nourishment is capitalized into home values. They find that oceanfront homes capitalize the risk reduction benefits from nourishment much more so than further inland homes.

Abelson and Markandya (1985) were perhaps the first to recognize that implicit values from hedonic price models could be biased if the attribute level of interest changes over time; they focus on the case of perfect information of future attribute levels and examine the effect of omitted variables in econometric analysis. This issue is pertinent for capitalization of beach width, as beach quality is dynamic and evolves over time, complicating interpretation of hedonic price function parameters (Landry et al., 2003; Landry & Hindsley, 2011; Pompe & Rinehart, 1999). Hedonic analysis is complicated by not only the fact that beach width is dynamic, but also because the hedonic equilibrium reflects buyers' and sellers' knowledge of coastal processes and expectations of government intervention (Landry & Hindsley, 2011). Examining the impact of attribute dynamics on bidder behavior in the hedonic price framework, Landry and Hindsley (2011) predict that marginal implicit prices will be upward (downward) biased if buyers expect beaches to erode (accrete) in the future.

Gopalakrishnan et al. (2011) argue that beach width could be endogenous to hedonic price equations due to the role that property values play in benefit–cost analysis (BCA) of beach replenishment operations. The USACE puts great emphasis on housing benefits stemming from beach replenishment, estimating expected storm damages with and without additional sediments in the coastal beach and dune system. The USACE principles and guidelines stipulate the use of housing market values in policy analysis, but in practice housing values are often measured by replacement cost minus depreciation (Yoe, 1993). Depreciated replacement costs can differ markedly from actual market values, so there can be a tenuous role that actual market values play in BCA (Landry & Hindsley, 2011). Nonetheless, for locations with actively managed beaches, there is a potential for reverse causation if property values play an important role in the planning, design, and implementation of beach replenishment projects. Wide beaches may be created in locations where property values are high in order to provide for storm protection, whereas areas with less valuable property may not receive as much sediment, resulting in narrower beaches (Gopalakrishnan et al., 2011).

Importantly, we focus on Dare County, North Carolina property sales in 1997 and 1998. During this period of time, no beach replenishment projects had been previously performed, and there were no formal plans to engage in beach replenishment in the foreseeable future.

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Thus, our analysis is distinct, as it is the only hedonic property analysis of beach width that we are aware of that focuses on a district that is not actively managing its beaches.[3] As such, reverse causation (wider beaches as a result of higher valued coastal property) is not a potential confound in our dataset. We use an array of geophysical measurements as excluded instruments to account for potential endogeneity of beach width (Brutsché et al., 2016; Larson et al., 1999) to assess potential for errors-in-variables related to dynamics of beaches and individual expectations if environmental change (Landry & Hindsley, 2011).

MODEL

Hedonic property price theory is predicated on the simple idea that property values adjust to reflect the value and cost of housing attributes. Rosen (1974) provides a framework for interpreting marginal implicit prices as reflecting homebuyers' marginal value of housing attributes and suppliers' marginal costs of providing attributes. We use the following basic specification for the hedonic price function:

$$ln(\mathbf{P}) = \mathbf{X}\beta + f(q,d) + \mathbf{u}, \tag{1}$$

where $\mathbf{P}$ is $n \times 1$ vector of sales values, $\mathbf{X}$ is a matrix of structural and neighborhood characteristics (including town fixed effects) that influence the natural log of sales price via the coefficient vector β, and $\mathbf{u}$ is $n \times 1$ vector of random error terms.[4] The function $f(q,d)$ specifies the relationship between sales value, beach quality, q, and distance from the shoreline, d.[5] Building on the existing literature, we explore the following functional forms for $f(q,d)$:

$$f(q,d) = \beta_d d + \gamma q, \tag{2a}$$

$$f(q,d) = \beta_d d + \beta_{d,q} d \times q + \gamma q, \tag{2b}$$

$$f(q,d) = \beta_d d + \frac{\gamma q}{d}, \tag{2c}$$

$$f(q,d) = \beta_d d + \gamma d_b \times q. \tag{2d}$$

Specification (2a) posits proximity to the beach and beach width as separable in the hedonic price equation (Landry et al., 2003; Pompe & Rinehart, 1999); this specification implicitly assumes that all properties on the barrier island capitalize beach width and beach proximity as separate covariate effects. Specification (2b) assumes a continuous interaction among beach width and proximity (Gopalakrishnan et al., 2011; Pompe & Rinehart, 1995). Specification (2c) has not appeared previously in the literature, but could offer a parsimonious way to incorporate nonlinearities in the proximity effect by weighting the value of beach width by inverse proximity (obviating the need for an additional parameter as in Equation 2b). The covariate d_b in Equation (2d) is a dummy variable indicating presence in an inclusive ocean proximity band (ranging from 500, 1000, 1500, and 2500 feet from the shore, in 500-feet increments).[6] We consider two primary estimation strategies for Equations (1)–(2d): OLS regression and 2SLS to test for errors-in-variables with regard to beach width (Gopalakrishnan et al., 2011; Landry & Hindsley, 2011).

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We use geophysical shoreline measures as IV to test for errors-in-variables associated with beach width in each of the above specifications. These measures are obtained by employing Geographic Information Systems with bathimetric topographic maps and wave buoy data to measure deep water (≈5 km) wave energy, distance to the "depth of closure," the ratio of significant wave height to breaking wave depth, and distance to the proximal edge of the continental shelf. Wave energy proxies the potential for sediment movement. "Depth of closure" is the offshore water depth at which sand movement into deeper offshore waters ceases; depth-of-closure and the ratio of wave-height-to-breaking-depth are each parameters in equations that describe the depth of the sub-aqueous beach (Larson et al., 1999). Additional candidates for IV include the ratio of outer-to-inner-depths-of-closure and nonlinear transformations that follow geophysical model formulations (Brutsché et al., 2016; Larson et al., 1999).

In total, we have eight possible geophysical instruments, giving us 255 possible unique sets of instruments to consider. Given that the inclusion of irrelevant instruments can bias 2SLS results toward OLS, and including too many instruments can lead to over-fitting the first stage, we consider it prudent to choose a subset of instruments without formal selection criteria. To aid in the instrument selection process we implement the "post double selection" methodology proposed by Belloni et al. (2014), which utilizes a LASSO regression to optimally identify control variables based on their predictive validity over the outcome of interest.[7] Doing so allows us to optimally instrument for beach width by using the fewest possible instruments necessary to generate the requisite exogenous variation in beach width. Consequently using this method minimizes the chances of over-fitting the first stage regression while ensuring relevance of included instruments.

DATA

We obtained parcel sales data from the county tax assessor website. The data comprise residential property sales in Dare County, North Carolina for the years 1997 and 1998. Figure 2 shows the coastal townships along Dare County's Outer Banks, with Duck at the far north and Hatteras to the south. We drop the lowest 5% of the price distribution to remove potential transactions that are not "arms-length"; this includes housing sales less than \$42,500 and vacant lot sales less than \$17,200. The final data set includes 1986 observations and is comprised of both parcels with pre-existing or new homes (67%) and vacant lots (33%). Descriptive statistics are presented in Table 1.

The average selling price for homes (vacant lots) is \$140,427 (\$78,109) in constant 1999 dollars. Homes sold during this time tend to have larger plots than vacant lots (1 acre compared to 0.39 acres), and existing home sales exhibit a greater proportion of beach frontage (18% compared to 12%). Other water frontage (sound or canal) accounted for around 2%–4% of home and vacant lot sales. The majority of the sales occur in the Northern Outer Banks, within the communities of Nags Head, Kill Devil Hills, and Kitty Hawk (see Figure 2). For existing homes (vacant lots) the average distance from the beach was around 2000 feet (1840 feet), with a minimum of 111 (239) and a maximum of 9963 feet (9806 feet). For housing sales (vacant lots), the median distance is 1847 feet (1489 feet), and the 25th percentile is 829 feet (700 feet). The skew toward the oceanfront reflects the relative density of development and the fact that the width of Dare County barrier islands varies along the shore.

The average home in the data set is about 16 years old with three bedrooms and two bathrooms. Around 3% are new home sales, and 15% are multi-unit dwellings (i.e., condominiums).

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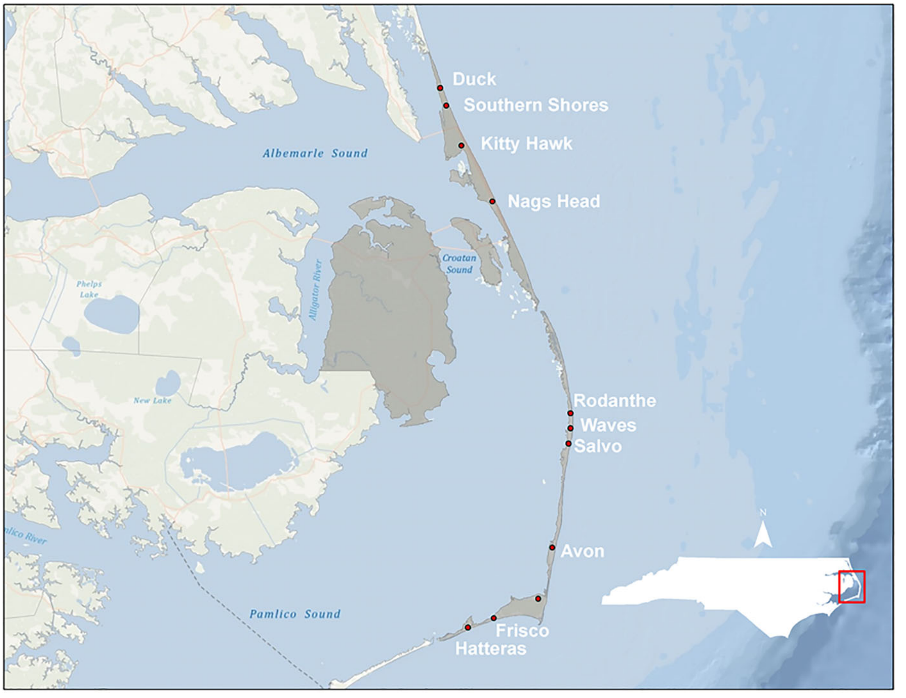

FIGURE 2 Dare County and the outer banks of North Carolina

Most homes have central heating and air conditioning. Slightly less than half have multiple stories. Very few homes have brick or stone finishes or hardwood flooring. Forty-five percent of observed sales occurred in 1997[8] compared to the remaining 55% in 1998.

Accurate information on current beach width at the time of sale is important for understanding and analyzing the relationship between housing values and beach quality (Gopalakrishnan et al., 2011; Landry et al., 2003; Landry & Hindsley, 2011; Pompe & Rinehart, 1999). High-tide beach width is measured by digitizing rectified aerial photographs taken in spring of 1997 and 1998; the existence of two sequential years of high-quality aerial imagery influenced our decision to focus on homes sales in 1997 and 1998. While a single annual snapshot of beach conditions is certainly not ideal, it represents the best available information and is an improvement over previous analyses that have inferred beach width in previous or intervening years (e.g., Landry & Hindsley, 2011). Average high-tide beach width is around 160 feet, with a minimum of 53 feet and a maximum of 444 feet.

Panel C of Table 1 presents descriptive statistics for geophysical IV. Geophysical instruments include distance to "depth of closure" (which provide a measure of the sub-aqueous beach profile), distance to the edge of the continental shelf (the sub-aqueous edge of the continental plate), wave energy, and wave height (Brutsché et al., 2016; Larson et al., 1999). Each of these measures should correlate with beach width because bathymetry, sediment, and waves create beaches. Distance to the "depth of closure" (the 18-foot isobath) is measured using bathymetric maps overlaid on dry-land topo-maps with digitized beaches. The average distance ("Dist. to DOC") is around 15,454 feet (min = 9717 feet; max = 32,701 feet). The average property is located 21,892 feet from the edge of the continental shelf ("Dist. to Cont. Shelf") with a

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TABLE 1 Descriptive statistics

	Housing				Vacant lots			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Panel A: Property characteristics								
Sale price ($1000)	140.43	104.00	42.92	1379.44	78.11	77.86	17.36	556.88
Beach width (ft.)	160.76	50.17	52.95	444.16	161.27	45.47	64.94	370.64
Distance to beach (100 ft)	19.94	17.23	1.11	99.63	22.77	18.39	2.39	98.06
Acre	1.00	2.89	0.08	16.41	0.39	0.62	0.07	14.29
Ocean front	0.18	0.38	0.00	1.00	0.12	0.33	0.00	1.00
Sound front	0.02	0.15	0.00	1.00	0.03	0.18	0.00	1.00
Canal front	0.04	0.20	0.00	1.00	0.03	0.17	0.00	1.00
Condo	0.15	0.36	0.00	1.00				
Home age (<1 year)	0.03	0.16	0.00	1.00				
Home age (2–10 years)	0.33	0.47	0.00	1.00				
Home age (11–20 years)	0.15	0.36	0.00	1.00				
Home age (21–30 years)	0.08	0.27	0.00	1.00				
Brick–Stone	0.06	0.24	0.00	1.00				
Hardwood	0.04	0.19	0.00	1.00				
Central air	0.94	0.23	0.00	1.00				
Bathrooms	2.24	0.85	1.00	7.50				
Bedrooms	3.21	1.01	0.00	8.00				
Multi-story	0.41	0.49	0.00	1.00				
1997	0.45	0.50	0.00	1.00	0.43	0.50	0.00	1.00
Panel B: Town fixed effects								
Frisco	0.04	0.19	0.00	1.00	0.05	0.23	0.00	1.00
Buxton	0.01	0.11	0.00	1.00	0.02	0.15	0.00	1.00
Avon	0.07	0.26	0.00	1.00	0.07	0.25	0.00	1.00
Nagshead	0.28	0.45	0.00	1.00	0.27	0.44	0.00	1.00
Southern Shores	0.01	0.11	0.00	1.00	0.03	0.16	0.00	1.00
Rodanthe	0.02	0.14	0.00	1.00	0.02	0.13	0.00	1.00
Waves	0.01	0.10	0.00	1.00	0.02	0.14	0.00	1.00
Hatteras	0.04	0.19	0.00	1.00	0.06	0.24	0.00	1.00
Kitty Hawk	0.12	0.33	0.00	1.00	0.14	0.35	0.00	1.00
Salvo	0.01	0.12	0.00	1.00	0.04	0.19	0.00	1.00
Panel C: Geophysical instruments								
Dist. to D.o.C	154.54	56.27	97.17	327.01	166.00	62.52	97.35	334.85
Dist. to cont. shelf	218.92	45.38	105.43	272.07	211.85	50.56	105.69	272.72
Wave energy	5.05	0.78	4.46	6.93	5.18	0.83	4.46	6.93
Wave height/breaking depth	0.12	0.03	0.08	0.15	0.11	0.03	0.08	0.15
Z ratio	3.02	0.58	2.12	3.84	2.98	0.59	2.12	3.84

(Continues)

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TABLE 1 (Continued)

	Housing				Vacant lots			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Wave α	2.94	0.30	2.71	3.64	2.99	0.31	2.71	3.64
Wave energy × wave height	0.08	0.01	0.06	0.10	0.08	0.01	0.06	0.10
Z ratio × DOC	0.01	0.00	0.00	0.02	0.01	0.00	0.00	0.02
Observations	1321				665			

minimum of 10,543 feet and max of 27,207 feet. Average annualized deep water wave energy ("Wave Energy") is over 5 kW/m, with a minimum of 4.46 and a maximum of almost 7. The average of breaking wave height to depth ("Wave Height/Breaking Depth") is 0.12 (min = 0.08; max = 0.15). In addition to these raw geophysical measures, we have additional IV that are nonlinear transformations of the above raw measures that are derived from the beach engineering literature: Z-ratio, wave-alpha, and wave energy × wave height (e.g., Brutsché et al., 2016; Larson et al., 1999).[9]

RESULTS

In total, the various combinations of property type, choice of estimator, and functional form for the proximity-width relationship yield 32 regressions that are estimated to obtain our complete set of results. For purposes of brevity, we provide a very general overview of the results here with limited detail on individual regressions and instead focus on our estimates of marginal willingness to pay. Standard diagnostic tests indicate 2SLS estimation is preferable over OLS estimation for models based on vacant lot sales while diagnostics do not suggest 2SLS estimation to be necessary for models based on existing home sales.[10] Thus OLS and 2SLS, for models based on existing homes and vacant lots, respectively, are our preferred specifications moving forward. We return to the differences in 2SLS and OLS estimation and offer advice for practitioners in the discussion section.

Overall, our preferred estimators indicate general evidence of capitalization, suggesting that property buyers do consider beach width, either for its protection or amenity value, when consider a home or vacant lot purchase. However, we do observe some variation in statistical significance depending on how the relationship between property values, beach width, and distance to the shore is specified. Further discussion on differences across model specifications and full reporting of all regression coefficients is available in Appendix A.

Marginal willingness to pay estimates for beach width derived from the preferred specification for homes sales (OLS) and vacant lots (2SLS) are depicted in Figure 3.[11] For specifications (2a–2d), we calculate marginal willingness to pay (WTP) for oceanfront property and the band of properties ranging from 500 to 2500 feet from the shoreline (in inclusive 500-foot increments).[12] Focusing on marginal WTP derived from sales of existing homes, specifications (2a) and (2b) are statistically insignificant. For the inverse-distance specification (2c), marginal WTP exceeds $1000 per foot for ocean front homes and homes within 500 feet of the shoreline (specifically, $2374 and $1025 per foot of beach width, respectively), but falls monotonically as the distance increases (as specified by the functional form). The smallest marginal WTP estimate is

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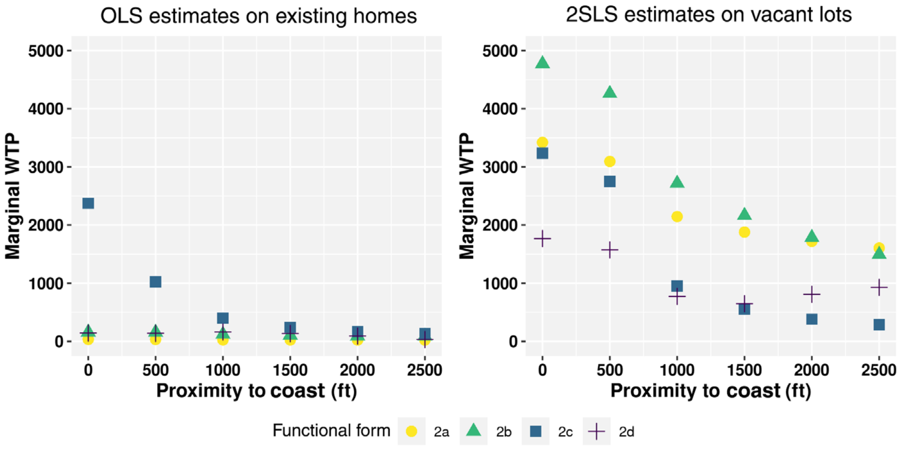

FIGURE 3 WTP for additional feet of beach width

$132 per foot (for homes within 2500 feet). The final specification (2d) finds relatively low marginal WTP for beach width, ranging from $32 to $160 per foot (all estimates in 1999 US dollars).

Turning to welfare estimates derived from sales of vacant lots, we find much more consistency across specifications (2a) to (2d). Marginal WTP at the oceanfront exceeds $1000 per foot (ranging from $4773 for specification (2b) to $1769 for specification (2d)). Specifications (2a–2c) find decreasing marginal WTP as distance increases, while results for (2d) are not monotonic nor statistically significant. Notably, WTP estimates from vacant lot sales exceed estimates from sales of existing homes for every specification/distance combination.

DISCUSSION

Focusing on a shoreline that is not actively managing beaches through replenishment, we explore capitalization of beach quality in hedonic price specifications that differently account for proximity to the shoreline, and we assess the potential for errors-in-variables stemming from the dynamic nature of beach quality. By examining a coastal housing market that does not actively engage in beach replenishment, we obviate concerns over reverse causation related to property values playing a role in beach width (via benefit–cost analyses procedures and guidelines that define standard project assessment protocol attributable to the USACE; Landry, 2011; Gopalakrishnan et al., 2011). We consider this a primary contribution since all previous hedonic price analyses have utilized data from communities that are actively employing beach replenishment as a coastal management strategy. Gopalakrishnan et al. (2011) show that this may lead to reverse causation in hedonic property price analysis; our data cannot exhibit this potential confound. In addition, we model transactions for existing homes separately from sales of vacant lots. We find striking empirical differences across these two market segments.

For the sale of existing homes, we consistently find no evidence of errors-in-variables. While IV related to offshore bathymetry and wave climate are relevant in explaining variation in beach width and (arguably) redundant in hedonic price models, two-stage least squares estimates exhibit no appreciable difference in parameter estimates relative to OLS. This result suggests, at first blush that standard hedonic price analysis of beach width can be conducted

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without concern for errors-in-variables, as long as the community is not engaging in beach replenishment. The analyst just needs to have sufficient data on property and environmental characteristics and, realizing the testing for capitalization is a joint hypothesis of effect and functional form, explore various relationships for proximity to the shoreline (e.g., Equations 2a–2d).

The analysis of vacant lot sales, however, does not support this conclusion. We find statistical support for the IV approach in analyzing vacant lot sales, and we find significant differences among OLS and 2SLS estimates for these transactions. We construe this as evidence of errors-in-variables for sales of vacant lots in Dare County, NC. Since reverse causation due to beach replenishment cannot be the mechanism, we interpret this finding as evidence of measurement error in assessing beach width (Landry & Hindsley, 2011). Recognizing that certain characteristics of a capital asset may evolve over time, one can assess how current pricing may respond to anticipated changes (Abelson & Markandya, 1985). Previous research has examined the effects of open space preservation, in particular, the countervailing impacts related to amenity provision and land supply restrictions (Balsdon, 2012; Riddel, 2001) and how amenities and land supply impacts simultaneously affect land and labor markets (Albouy, 2016; Roback, 1982). Beach width does not exhibit such countervailing effects, and, due to the remote nature of many beach communities, the large proportion of retiree residents, and the significance of second home ownership, labor markets are likely to play a much less significant role in capitalization of coastal amenities. As such, we argue that the nonmarket value of beach width is likely to be reflected primarily in real estate transactions.

We consider it somewhat surprising that we find such divergent results across hedonic models for sales of existing homes and vacant lots on a coastline that does not engage in beach replenishment. Since the coastal housing market we are analyzing is fairly small, we confront limited sample sizes, and we cannot control for neighborhood effects that are often otherwise proxied for with census-level variables. This presents a dilemma for interpreting the differential effects across hedonic price regression models. We explore two interpretations of results: the first presumes that our models are properly specified to identify capitalization and valuation of beach quality effects in both markets segments; the second recognizes that we are apt to fall prey to model mis-specification and seeks to interpret the divergent results in the light of potential differential effects across market segments.

Assuming both models are correctly specified, sales of existing homes and vacant lots present very different effects regarding capitalization of beach width (and perhaps other elements of environmental quality). Existing analyses of willingness-to-pay for beach quality through hedonic analysis have focused primarily on sales of existing homes (Catma, 2020; Dundas, 2017; Gopalakrishnan et al., 2011; Hall & Powell, 2001; Landry & Hindsley, 2011), the exceptions being (Pompe & Rinehart, 1995, 1999). Taking the divergent results at face value, we infer that buyers and sellers of vacant lots may have better information about coastal dynamics or exhibit greater concern for the protective and recreational qualities of beach sediments. Given experience and expertise, developers and builders may be more savvy in their assessment of vacant lots relative to transactions for existing homes that include less experienced agents.[13] Under this interpretation, willingness-to-pay estimates from the sale of vacant lots could provide better benefit estimates, since they may reflect superior information and risk assessment abilities.

On the other hand, the divergence of results could be related to model mis-specification problems. Contemporary guidance on valid inference in recovering willingness-to-pay from property values indicates that spatial fixed effects, quasi-experimental identification, and

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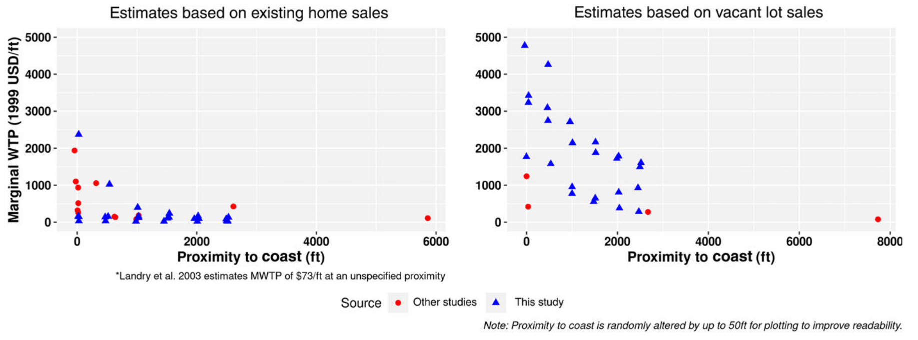

FIGURE 4 Comparison of WTP estimates to the existing literature

controls for housing market dynamics are most effective at producing robust estimates of WTP (Kuminoff et al., 2010). While we focus on a small-time horizon (2 years of sales) and employ town fixed effects, we are not able to utilize other innovations in identification. As such, we believe our housing sales model is relatively more likely to suffer from omitted variable bias. Since housing units are significantly more heterogeneous than plots of land in the same county, we suspect the difference in estimates across models could reflect some aspect of omitted housing quality. On a related note, although lots tend to be more homogeneous than existing homes, it is possible that there are fundamental differences in quality between lots with existing homes and vacant lots that are driving the differences in WTP. For example, in our own sample, transacted vacant parcels tend to be less likely to be oceanfront property and are smaller on average. Although we control for these differences, it is possible that there is some unobservable measure of quality that characterizes lots with existing homes that are not applicable to vacant parcels (i.e. if high-quality lots were the first to be converted to existing homes leaving only low-quality lots in the vacant parcels market).

Figure 4 summarizes the relationship between our own WTP estimates (across all specifications) with estimates from the existing literature.[14] Our estimates of WTP based on existing home sales are not obviously incompatible with the existing literature. Most existing estimates in the literature are based on ocean front homes. Our own estimates based on ocean front homes either underestimate (specifications 2a, 2b, and 2d) or overestimate (specification 2c) compared to past estimates; although, again, most of the existing literature does not address potential sources of endogneity. Our estimates of WTP based on vacant lot sales are generally much higher than the existing literature. However, the existing estimates in the literature come from only two papers with relatively small sample sizes and do not control for endogeneity—something that our standard instrumental variable diagnostics suggest is necessary to avoid biased estimates.

Although we have discussed at length the statistical significance of our WTP estimates, we have not touched on the economic significance, which in practice is dependent on local erosion rates and the potential efficacy of beach nourishment projects. Fitting a linear model to long-term rates of shoreline change for all of Dare County (using data on shoreline location from 1849 to 1997) suggests an average long-term erosion rate of −2.27 ft/year[15] (Miller et al., 2005). Our WTP estimates suggest that owners of existing ocean front homes would be willing to pay between \$80 and \$5390[16] per year to counteract 2.27 feet of beach erosion. Estimates based on sales of vacant lots suggest that owners of oceanfront vacant lots are willing to pay between \$4015 and \$10,834 per year to mitigate this same rate of erosion.[17]

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To put the potential cost of actually mitigating beach erosion into perspective, consider Dare County's most recently planned proposal for nourishing the beaches in Avon, NC. The project, planned for 2022, will nourish 2.5 miles of beach (covering the majority of the Avon coastline) at an estimated inflation-adjusted cost of $8.17 million (1999 USD) and will add approximately 100 feet of beach width to the existing beaches (County of Dare, 2020). This works out to approximately $81,650 (1999 USD) per foot of additional beach width. Distributed among Avon's approximately 2000 households suggests the project will cost about $41 (1999 USD) per household for each foot of beach width added.[18] Notably, all but one specification (2a for existing home sales) indicated marginal WTP above $41 per foot suggesting that eliciting financial support from residents for what would otherwise be unfunded beach nourishment projects (in the form of local taxes) may be viewed favorably by the public. Although there is likely to be substantial heterogeneity in the cost of future beach nourish projects, our results suggest that in some cases beach nourishment could remain an economically viable way to fortify existing coastlines (though this will depend upon how costs evolve with sea level rise and dwindling sand reserves).

More generally, the results presented here highlight some of the empirical challenges associated with using hedonic models to value dynamic coastal resources. Notably, we find that marginal WTP estimates for additional beach width can vary drastically based on whether endogeneity is considered and how the interaction between substitute protection measures is modeled. Figure 3 presents a visualization of WTP estimates, separated out by property type and functional form. Differences in marginal WTP vary substantially based on property type (which also includes differences in estimator).

Similarly, despite all functional forms for the interaction between coastal proximity and beach width having comparably similar F-Statistics and R-squared values, the chosen functional form can significantly alter the final WTP estimates. More important than any specific trends in our WTP estimates is the issue that two researchers whom both make econometrically sound modeling decisions, but focus on a single model, could infer very different welfare implications. Given that hedonic models may be used to guide future coastal natural resource management decisions, it is important to ensure that the implied valuation estimates are robust.

Machine learning, a field that has been relatively slow to be adopted by applied economists, may offer some potential solutions to the empirical challenges we have highlighted. In particular, we see two machine learning concepts that could be valuable here. The first is the use of symbolic regression to help guide the choice of function form for modeling the interaction between coastal resources. The second is the concept of ensembling to aggregate multiple estimates.

Symbolic regression, much like standard supervised machine learning models, takes a set of input variables (or "features" in the parlance of machine learning practitioners) and attempts to find a way to predict the output variable. Most commonly used forms of supervised machine learning do this using a set of weights (ex: neural networks) or a series of decision trees (ex: XGboost, random forest), which are notoriously difficult to interpret and are not particularly suitable for casual inference (Ribeiro et al., 2016). Symbolic regressions, on the other hand, use the input variables to predict the output variable by generating a closed-form expression that maps the input variables to the output variable (Schmidt & Lipson, 2009).[19] This means the researcher is left with an equation than represents the proposed relationship between the input variables and output of interest. Thus, the properties of the generated expression can easily be examined to learn something about the nature of the relationship between the input variables and the output variable. Turning to our own analysis, use of symbolic regression could

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potentially be employed to automatically generate a handful of candidate functional forms that could plausibly represent an array of hedonic relationships (which typically have no direct basis in theory), including the relationship between a home proximity to the shore line and beach width. A plethora of functional forms, however, does not provide a panacea for obtaining robust WTP estimates given that multiple functional forms can have similar model fit, but significantly different implied WTP estimates (as is seen in some of our results).

The concept of ensemble learning offers a framework for approaching the latter problem. The idea behind ensemble learning is that any one model is naive to some degree, but the aggregation of multiple naive models produces estimates or predictions that are better than each of the constituent models by themselves (Opitz & Maclin, 1999; Polikar, 2006). This concept is both intuitive and common in human decision-making (i.e. most individuals obtain multiple opinions from different doctors before undergoing a major surgery). Popular ensembling algorithms include random forest and XGboost, which both use a series of very simple decision trees to make predictions, where most individual trees have rather poor predictive validity, but when aggregated tend to perform quite well. Another form of ensembling is Bayesian model averaging (Hoeting et al., 1999), which averages coefficient estimates over a set of candidate models that contain different sets of covariates. In practice, however, any set of specifications or models could be aggregated to form an ensemble. In our own case, our entire set of WTP estimates could conceivably be aggregated by averaging to obtain a single WTP estimate. More advanced aggregation techniques, however, may offer better results. For example, each individual estimate could be weighted based on the model fit that generated the estimate, thus better fitting models more heavily influence the final aggregated WTP estimate. Stacking, a practice in which the output of one model becomes the input of another model, could also yield better results (Todorovski & Džeroski, 2003).

Overall, we believe that embracing the use of more automated empirical techniques in situations where traditional econometric practices failing to deliver guidance could be a way to obtain more robust valuation estimates. For example, a savvy programmer could set up a symbolic regression to generate multiple candidate functional forms that could explain the relationship between beach width and proximity to the coast, include each functional form in a linear regression, then aggregate each derived WTP estimate into an ensembled estimate using some type of weighting scheme. Future research, in the form of simulation studies applied to common valuation scenarios, could be particularly helpful in providing guidance on exactly how to implement these potential solutions to obtain more accurate welfare measures.

These potential improvements in empirical methodology, however, are untested and may be out of reach for some policy analysis practitioners. On a more pragmatic level, our results suggest that 2SLS results can vary substantially from OLS results for some property types. In light of this, we find it prudent to always estimate 2SLS models (in additions to OLS estimation) for analysis of beach width capitalization if appropriate instruments are available. In addition, given that we find small differences in model specification can lead to quite different WTP estimates, we believe it would be unwise to place too much faith in any single estimate, particularly in large stakes policy decisions. Instead, we believe it is prudent to consider multiple WTP estimates across varying model specifications when informing policy decisions.

CONCLUSIONS

Coastal beaches are local public goods, providing erosion, storm surge, and flood protection to coastal housing, and—like local parks—offering recreation and leisure potential for those that live in close proximity. Beaches and dunes also may supply scenic and aesthetic amenities. As a hazard mitigant, property sales in areas with good beach quality may command a premium over areas with poor beach quality. As a recreational amenity, beaches provide space for outdoor activities that are enjoyed by residents and tourists. Thus, we hypothesize that hedonic property price analysis with functional forms that take account of shoreline proximity can be used to test for capitalization of beach quality (e.g., width) in coastal housing prices. Generally, our results vary with functional form for beach width capitalization. Some forms do not appear to fit our data, whereas others do. Since hedonic functional forms are not know a priori, we recommend future researchers test a full array of specifications for beach width capitalization.

Our analysis is the first to our knowledge to apply hedonic price regression to coastal housing prices in a jurisdiction that has not employed beach replenishment to manipulate beach width. As such, our policy environment is simplified, and we harbor no concern over reverse causation due to the potential use of property values in analysis and justification of beach replenishment (Gopalakrishnan et al., 2011; Landry & Hindsley, 2011). We find no evidence of errors-in-variables for hedonic price regressions of sales of existing homes, but we do find evidence of errors-in-variables for vacant lot sales. We interpret this difference as potentially stemming from market segmentation, in which transactions for existing homes appear to capitalize current measures of beach width, but transactions for vacant lots exhibit bias in capitalization of beach width. Nonetheless, instrument diagnostics suggest that we are able to adequately account for this bias (when present) using geophysical instruments related to beach shape and wave climate. For vacant lot sales models, the marginal implicit prices from the preferred 2SLS estimates indicate large downward bias in OLS estimates.

Aside from BCA of coastal protection projects, empirical estimates of the value of beaches can play a role in decisions on how to adapt to sea-level rise (Gopalakrishnan et al., 2016, 2018; McNamara & Keeler, 2013; Qiu & Gopalakrishnan, 2018). Evidence of errors-in-variables for a subset of transactions and the magnitude of downward bias we find suggest that some existing empirical estimates on hedonic values of beach width may be inadequate for benefit–cost or adaptation analysis.

Future research on coastal hedonic property markets may focus on locations or time periods in which beach replenishment was not a confounding factor. Such locations are currently becoming less common, however, as many communities rush to respond to environmental change along the coast. If researchers choose to examine historical sales data, as we have, and they plan to focus exclusively on sales of existing homes, IV approaches may not be necessary. Since this cannot be ascertained a priori, however, they should still seek out IV to test the validity of their estimates. If differences are found across market segments (however construed), one could explore the influence of market participants (whether homebuilder/commercial, locals or residents with experience in coastal housing markets, etc.) on endogeneity, capitalization, and marginal implicit prices within the context of hedonic sorting models (Bayer & Timmins, 2007; Klaiber & Phaneuf, 2010; Klaiber & Smith, 2011).

Beaches are naturally complex topological features, with variability in color and texture of sand, slope, width, presence of vegetation, and presence and size of dunes, among other features. Beach width is a primary determinant of space for recreation and leisure activities, as well as storm and erosion protection, and can be manipulated by placement of sand, making it a natural candidate for analysis. Nonetheless, buyers' and sellers' assessment of coastal sediment quality could be more complex and nuanced than presumed by standard hedonic price analysis of natural features. Perhaps more important, coastal dynamics render beaches and surrounding environments evolving landscapes. As capital assets, coastal housing entitles buyers access to

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this evolving landscape, and perceptions of future environmental conditions could play an important role in value formation, bidding behavior, and evolving coastal housing market dynamics. As such, additional data on housing market participants' knowledge of coastal dynamics, perceptions of environmental change, and expectations of management interventions would be very informative in model formulation and interpretation. This remains an important area for future research.

ENDNOTES

[1] Excluding Alaska.

[2] Note, we will use proximity to beach and proximity to shoreline interchangeably, but in application, we use Euclidean distance to the landward edge of the beach as our measure of proximity.

[3] All of the previous hedonic literature, Pompe and Rinehart (1995, 1999); Hall and Powell (2001); Landry and Hindsley (2011); Gopalakrishnan et al. (2011); Dundas (2017); Qiu & Gopalakrishnan (2018); Catma (2020), is focused on locations that include communities actively engaging in beach replenishment.

[4] Box-Cox transformations of the dependent variable support the use of the natural log transformation.

[5] In our application, we measure beach quality as the width of the nearest sandy beach (not including dunes) at high-tide; Euclidean distance from the shoreline (nearest landward edge of the beach) is utilized as a measure of proximity.

[6] An alternative specification might utilize a series of dummy variables for different distance ranges (e.g., 1–200 feet, 201–400 feet, etc.). Due to lack of data, this specification did not work with our models, but could be explored in future work

[7] Specifically, in the case of an endogenous regressor, the procedure amounts to replacing the OLS estimator in each stage of 2SLS with a LASSO estimator. A LASSO regression is used in the first stage to select the instruments that best predict the endogenous variable, followed by a LASSO regression in the second stage to limit control variables to those that best predict the outcome of interest. Finally, a 2SLS estimator can be constructed using the selected variables. Given that there is a strong theoretical basis for including our selected property characteristics in a hedonic regression, we limit the LASSO penalization to only apply to the candidate IV.

[8] The "1997" variable serves to capture unobservable characteristics that differ between 1997 and 1998. Notably, Hurricane Fran hit the Outer Banks in September of 1996 meaning home buyers in 1997 may have been particularly attuned to the protection value of wider beaches compared to later buyers.

[9] *Z*-ratio is the depth of closure divided by the breaking wave depth (Larson et al., 1999), and wave-alpha is derived from an integral equation of the equilibrium beach profile shape, in which wave height is raised to the power $-2/3$ (which is an empirically calibrated constant; Dean, 1991).

[10] Further details on diagnostic tests for choosing between 2SLS and OLS estimation are available in Appendix A.

[11] Both OLS and 2SLS derived WTP estimates for each property type along with confidence intervals for each estimate can be found in the Appendix (tables C1 and C2).

[12] For oceanfront homes, we assess marginal WTP at the closest distance to the beach that a home (vacant lot) is observed in our data (111 feet for existing homes, 238 feet for vacant lots). For nonoceanfront homes, WTP is evaluated at the midpoint of the interval (e.g., 500 feet for the 1000 foot bin).

[13] In utilizing a difference-in-difference model to assess the effects of sea-level-rise risk information on home values, Filippova et al. (2020) make a similar conclusion for coastal homes sales in New Zealand.

[14] Besides our own study, Figure 4 synthesizes the information from Pompe and Rinehart (1995, 1999); Landry et al. (2003); Landry and Hindsley (2011); Gopalakrishnan et al. (2011), and Catma (2020). Pompe and Rinehart (1999) do not estimate WTP within discrete proximity bands and do not provide a maximum summary stat for their sample's distance to the coast. Thus, we set proximity to the mean of the sample, which is provided.

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[15] Erosion rates are subject to nontrivial amounts of heterogeneity with some areas of the outer-banks experiencing much greater erosion rates, while other areas experience beach accretion. Figure D1 in Appendix D displays the distribution of long-term erosion rates for 8849 distinct GIS points along the Outer Banks Coast.

[16] If specification (2c) is ignored (which is an outlier compared to the other specification), this range falls between $80 and $358.

[17] Although the estimated WTP to counteract the average erosion rate is much larger for vacant lot sales, the estimates are perhaps reasonable if purchasers of vacant lots are primarily interested in developing them into short-term rentals. (Landry, 2012) uses data on short-term rentals from 1979 to 1997 in both Dare County, NC and Brunswick County, GA and finds that the average annual rental income for such properties is $28,430 (in 1997 USD). Thus, annual payments of $4015–$10,834 to maintain beach width and increase the operable lifespan of a short-term rental could be reasonable if annual rents collected are several multiples above annual erosion mitigation costs.

[18] This is an upper bound on the average cost per property, as the 2000 households do not include any existing vacant lots in Avon.

[19] For example, Schmidt and Lipson (2009) demonstrate the abilities of symbolic regression by feeding raw data from physical systems into a symbolic regression and show that the algorithm is able to recover equations representing some of the fundamental laws of physics without any prior information, or "knowledge" of physics.

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