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The Value of Disappearing Beaches: A Hedonic Pricing Model with Endogenous Beach Width

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Working Paper EE 10-04
September 2010

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Abstract

Beach nourishment is used to rebuild eroding beaches with sand dredged from other locations. Previous studies indicate that beach width positively affects coastal property values, but studies ignore the dynamic features of beaches and the feedback that nourishment has on shoreline retreat. We correct for the resulting attenuation and endogeneity bias in a hedonic property value model by instrumenting for beach width using spatially varying coastal geological features. We find that the beach width coefficient is nearly five times larger than the OLS estimate, suggesting that beach width is a much larger portion of property value than previously thought. We use the empirical results to parameterize a dynamic optimization model of beach nourishment decisions and show that the predicted interval between nourishment projects is closer to what we observe in the data when we use the estimate from the instrumental variables model rather than OLS. As coastal communities adapt to climate change, we find that the long-term net value of coastal residential property can fall by as much as 52% when erosion and cost of nourishment sand triple.

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CONTENTS

1. INTRODUCTION

The coastal environment is constantly changing as a result of the interaction between waves, wind, and ocean currents. A gradual landward movement of the shoreline is being observed in many parts of the world and it is estimated that 80% to 90% of the sandy beaches in the United States are receding (Leatherman 1993; Kreisel, Landry, et al. 2005). Simultaneously, there has been an increase in the population density in coastal towns in the United States (Pilkey, Neal, et al. 1998). Recent population reports estimate that coastal counties covering 17% of the land area—excluding Alaska—account for 53% of the U.S. population, and the population in U.S. coastal counties grew by 33 million between 1980 and 2003 (NOAA 2004). These two trends create a natural conflict that has led to active policy intervention to manage coastal erosion in economies that thrive on tourism and depend on the flow of beach amenities.

Beach erosion and the associated benefits from wide beaches have been a concern for coastal managers for decades. However, beach management has received scant attention from resource economists until recently. What is the economic value of increasing the width of a beach in a community? Are the costs of erosion control justified by avoided property losses? Under what conditions can policy interventions to stabilize shorelines be sustained in the long run, especially in the face of rising sea-level and changing storm patterns due to climate change? To what extent are policy interventions aimed at stabilizing shorelines capitalized into property values? Answers to all these questions require reliable estimates of the value of beach width as an essential first step.

Beach nourishment has become a popular beach management option and is used to combat erosion in many parts of the U.S. Atlantic and Pacific coasts. The conventional policy of building hard structures, such as seawalls and jetties, to obstruct the waves and reduce the velocity of ocean currents has fallen out of favor in the recent years, as this approach often exacerbates erosion in neighboring regions (Kraus and Pilkey 1988; Pilkey and Wright 1988). In contrast to building hardened structures, nourishment is the process of artificially rebuilding a beach by periodically replacing an eroding section of the beach with sand dredged from another location (typically off shore or inlets) (Dean 2002). Beach nourishment projects in the United States are primarily federally funded and implemented by the Army Corps of Engineers (ACE) after a benefit-cost analysis. Federal appropriations for nourishment totaled $787 million from 1995 to 2002 (NOAA 2006). The costs associated with implementing a nourishment project include the expected cost of construction, present value of periodic maintenance and any external cost such as the environmental cost associated with a nourishment project. The benefits from beach nourishment, including reduction in storm risks to oceanfront property and recreational benefits from a wider beach, enter the benefit-cost calculations that justify beach nourishment as a policy option.

Empirical studies of coastal communities generally find that wider beaches, lower storm risks, and proximity to the beach are all sources of value. In hedonic models, property values are inversely related to the distance from a beach and positively related to views of the beach (Brown and Pollakowski 1977; Edwards and Gable 1991; Parsons and Wu 1991; Parsons and Powell 2001; Bin, Crawford, et al. 2008). Some studies directly estimate the value of beach width in a hedonic framework and find a positive and significant relationship between beach width and property value (Pompe and Rinehart 1995; Kreisel, Landry, et al. 2005). Others estimate the diminution of property value from erosion risk in a hedonic framework (Kriesel, Alan, et al. 1993; Pompe and

Rinehart 1995; Pompe 2008). For beachfront property, we argue that these are similar exercises in that erosion risk is partly a function of beach width.[1]

Although hedonic models show that there is a positive influence of beach width on the value of coastal property, previous studies have treated beaches as fixed and exogenous characteristics. In reality, beach widths are dynamic; beach widths fluctuate seasonally and can trend upwards (accretion) or downwards (erosion) substantially on a decadal scale, a scale with obvious relevance for a standard 30-year mortgage. Furthermore, when beach stabilization via periodic renourishment is practiced, beach width depends on the timing of the most recent nourishment activity and the length of the nourishment interval, which in turn depends on the erosion rate at the given location. When the width of the beach is measured at any given time, we do not observe where it lies within a nourishment interval. These dynamic features lead to an econometric problem akin to errors-in-variables with an associated attenuation bias.[2] Researchers may measure the beach without error at a point in time, but it is the expected path of beach width over the life of the property that influences the sale price. The hedonic price function more appropriately would associate the value of coastal property with a measure of the average beach width at the location where the property is situated, but this average is unavailable with fine spatial detail.

Beyond attenuation bias, previous work has not considered how policy interventions like nourishment feed back on the rate of shoreline retreat and, in turn, on property values. This feedback suggests endogeneity bias in the hedonic price of beach width. Our paper focuses on this interaction between housing markets and physical coastal processes. If coastal property prices are influenced by beach width and nourishment decisions (which influence the beach width) also depend on benefits from increasing width, then the width of a beach becomes endogenous in the system. Nourishment also leads to a feedback in the coastal system that increases the erosion rate as the beach tends to return to its equilibrium profile (Dean 2002). Ignoring this endogeneity due to the coastal dynamics in the implicit price function will yield biased and inconsistent estimates of the coefficient on beach width (or coefficients on hazard risks that are functions of beach width). Together, attenuation and endogeneity will bias benefit-cost analyses of erosion control strategies, analyses that will grow in importance in the coming decades as communities adapt to climate change.

In contrast to previous hedonic studies of coastal property, in this paper we estimate the implicit price of beach width using instrumental variables. We construct a unique data set that combines real estate data on residential property in 10 coastal North Carolina towns and physical beach quality attributes that we collected. We estimate the value of beach width and instrument for width using variation in the physical coastal system, accounting for spatial heterogeneity with beach-specific fixed effects. We find that accounting for attenuation and endogeneity biases substantially increases the coefficient on beach width compared to the naïve specification in which beach width is exogenous. Our analysis suggests that beach width accounts for a much larger portion of coastal property value when there is severe erosion and shoreline stabilization via beach replenishment is undertaken.

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[1] Economic studies also conduct cost-benefit analyses to evaluate coastal management policy and support the claim that the policy option of beach nourishment is efficient when comparing the value of increased beach width and with the costs of nourishment. Kriesel et al. (2005) explore the feasibility and efficiency of community based policy implementation to manage shoreline erosion in the two barrier islands of Jekyll and Tybee in the Georgia coastline. Though most nourishment projects are currently federally funded, the increasing budgetary and resource constraints make it necessary to explore alternative avenues to fund nourishment projects in the future.

[2] Similar bias could also arise from potential owners having imperfect perceptions about the dynamic path of beach width.

A parallel line of research to hedonic models uses dynamic models to study the interactions of complex physical processes and economic decisions made by humans who depend on coastal resources (Yohe, Neumann, et al. 1995; Landry 2007; Smith, McNamara, et al. 2009). When beach erosion is viewed as a dynamic resource problem, the optimal frequency and volume of nourishment depend on the baseline erosion rate, the rate of erosion of a nourished beach, the baseline value of coastal property, the benefits and costs of renourishment, and the rate at which future costs and benefits are discounted (Smith, McNamara, et al. 2009). Our paper begins to bridge the gap between empirically based nonmarket valuation studies of beaches and the conceptual resource economics models of dynamic decisions in the coastal zone. We use the results from the hedonic model to parameterize a dynamic capital-theoretic model of beach nourishment decisions (Smith, McNamara, et al. 2009). We run the model for a range of scenarios with estimates for the value of beach width from our econometric models with exogenous and endogenous width. Our simulation results show that the predicted interval between nourishment projects using the hedonic value with endogenous width is closer to the observed frequency of nourishment in locations in our dataset where there have been more than 10 nourishment projects since 1950. Our results tell a cautionary tale about relying on beach nourishment as a long-run strategy to combat coastal erosion.

The following section describes the econometric model used to estimate the hedonic value of beach width and the instrumenting for beach width. Section 3 describes our dataset, which combines real estate data on coastal North Carolina with data on physical beach attributes that we collected, and the variables we use to instrument for beach width. We then discuss the results of our hedonic analysis. In Section 5 we undertake a series of policy simulations to determine optimal nourishment interval in a representative coastal community using the results from the hedonic analysis to parameterize a dynamic model of optimal beach nourishment. Finally, we conclude with policy implications of this study and directions for future research.

2. HEDONIC PRICING MODEL TO ESTIMATE THE VALUE OF BEACH WIDTH

We use the hedonic pricing model of Rosen (Rosen 1974) to estimate the value of beach width that is capitalized in property values. Price of residential coastal property *i* in location *j* (P_{ij}) is a function of property characteristics (X_{ij}), physical beach quality attributes (Z_{ij}), distance from oceanfront (d_{ij}), width of the beach at the property location (W_{ij}), and the location-specific dummy variables (L_j).

We start with the following model:

$$\ln(P_{ij}) = \alpha X_{ij} + \beta Z_{ij} + \gamma d_{ij} + \omega W_{ij} + \mu L_j + \varepsilon_{ij} \quad (1)$$

where X_{ij} is a vector of structural characteristics of the property *i* in location *j* including built-up area (in 100s of sq. ft.), number of bedrooms, number of bathrooms, dummy variable for multi-storied property (=1 if multi-storied), property type (=1 if condo/0 if Single Family Unit) and age of the property (years). Beach quality attributes (Z_{ij}) include the presence of a vegetated dune and the presence of shells on the beach.

We estimate four hedonic models to recover the value of beach width. First, we estimate the baseline values using Ordinary Least Squares (OLS) for a semi-log and a double-log specification treating beach width as exogenous. We then estimate the models using two-stage least squares (TSLS) with instrumental variables for beach width. We include beach-specific fixed effects (L_{ij}) to account for spatial heterogeneity. In the semi-log model specification, the coefficient on beach width (and other continuous explanatory variables) can be interpreted as the percentage change in the property value resulting from a unit (one foot) increase in the beach width (a unit increase in the continuous attribute). For discrete explanatory variables (dummy variables) the relative change in property value attributed to the presence of the explanatory variable is $e^{\beta} - 1$, where β is the coefficient of the discrete variable (Halvorsen and Palmquist 1980). With a double-log specification, the coefficient on beach width is the percentage change in property value resulting from a 1% increase in the width of the beach, which is the price elasticity of beach width.

We argue that in the presence of beach nourishment as a policy option for beach erosion, beach width at any given time cannot be treated as an exogenous variable. If the value of the property depends on beach width (Edwards and Gable 1991; Kriesel, Alan, et al. 1993; Pompe and Rinehart 1995; Parsons and Powell 2001) and nourishment decisions that determine the width of the beach are also influenced by the benefits from increased beach width that are capitalized in property values (beach amenities or storm protection), then the beach width is endogenous in this system.

Property Value *= f(Beach Width)*

*Beach Width = f[Nourishment Decision(Costs, Benefits (**Property Value**))]*

Therefore, an instrumental variables approach needs to be implemented to recover consistent estimates of the coefficients in the equation. This method has been applied in previous studies to recover endogenous site attributes, such as congestion in recreation choice models (Timmins and Murdock 2007). A valid instrument for beach width is a variable that is correlated with beach width but does not directly influence the property values. Exogenous variation in the morpho-dynamics of the coastal system and physical beach characteristics that are correlated with the width can be used to instrument for the beach width. In this analysis, we use two instruments for beach width.

2.1. Distance to continental shelf

The distance from the shore (high-tide line) to the continental shelf is correlated with the slope of the shoreface profile, which influences the rate of beach erosion and, therefore, the beach width. Larger distance between the high-tide line (where the width is measured) and the continental-shelf line indicates a lower slope of the shoreface profile, which, given a rising sea level, tends to result in more erosion compared to a steeper equilibrium profile (Wolinsky and Murray 2009). In addition, prolonged erosion from gradients in alongshore sediment transport will tend to reduce the shoreface slope, which removes sediment from the upper part of the profile. We use distance from shore to the continental shelf at a depth of 20 m as an instrument for the erosivity of the coastal environment.

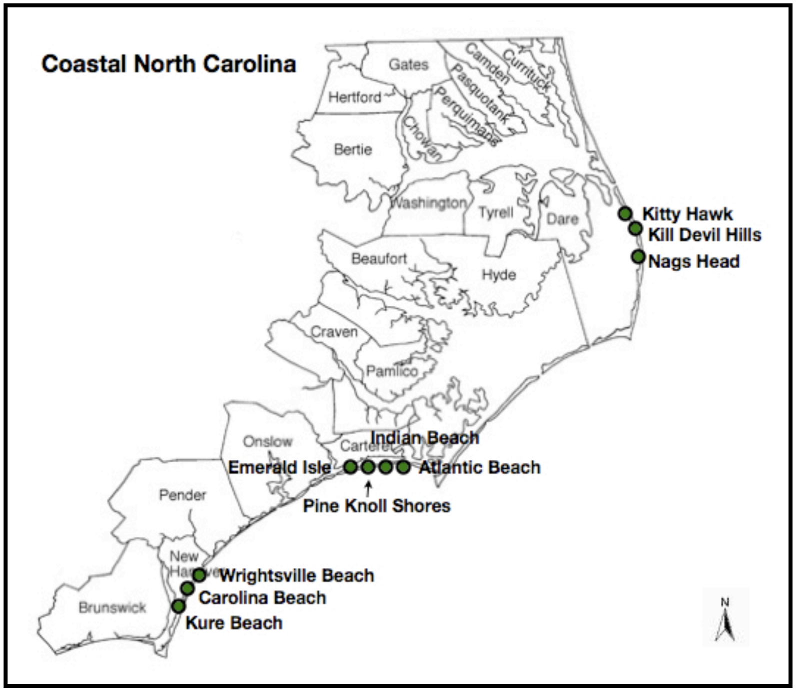
2.2. Beach quality attributes

Physical attributes of the beach, such as the presence of scarps, are also correlated with the width of the beach. A scarp is a steep slope on the erosional face of a dune that is formed by wave action, typically during storm erosion. Beach scarps can be several inches to over six feet high and eventually disappear if the beach remains wide long enough to allow dune regrowth. Scarps are indicative of erosion and increased likeliness of storms in the region (Davis and Fitzgerald 2004). We use the presence of scarps as an instrument for beach width as it is correlated with the width but is not likely to influence the selling price of the coastal property directly.

3. DATA

We use a unique dataset that combines real estate data on residential property in 10 coastal towns in North Carolina with data on physical beach quality attributes that we collected. The data covers ten beaches in three counties along the coast of North Carolina, including Nags Head, Kill Devil Hills, and Kitty Hawk in Dare County (Outer Banks); Atlantic beach, Emerald Isle, Indian Beach and Pine Knoll Shores in Carteret county; and Carolina Beach, Kure Beach, and Wrightsville Beach in New Hanover County. The towns in our data are located in three of the most populated regions (NCOSBM 2008) and represent locations situated on different parts of the cuspate-cape features of the North Carolina coast. The evolution of the beach at each location will be influenced to a different degree by the waves that reach the shoreline and transport sediment (e.g., Emerald Isle, Pine Knoll Shores, Indian Beach, and Atlantic Beach are typically *shadowed* from storm waves that commonly approach from the Northeast)(Slott, Murray, et al. 2006). They span tourist destinations far from the mainland (the northern Outer Banks in Dare County), tourist destinations close to the mainland (Bogue Banks in Carteret County), and beaches near the densely populated Wilmington area (New Hanover County). The counties included in our sample are among the 10 counties that generate the highest tourism-related revenue in the state (TEIM 2005) and the ports in New Hanover and Carteret County contribute up to 30 million dollars in state and local tax revenue (EDF 2007). The three locations also belong to the same recreation/rental market as vacationers consider locations in the Outer Banks, Carteret County, and New Hanover County when deciding where to go on a vacation. Recreational demand studies that have used stated preference methods to estimate the value of beaches and recreational site choice studies in North Carolina include beaches located in these three regions (Bin, Landry, et al. 2005; Hindsley, Landry, et al. 2007; Whitehead, Dumas, et al. 2008). Our data covers regions in the Outer Banks that have never undertaken beach nourishment (Dare County) and regions, such as Wrightsville Beach, that have been periodically undertaking beach nourishment for over 50 years. Figure 1 shows a map of the areas covered in the study.

Figure 1. Study region.



We collected sales records for residential properties, which include single-family property (SFP) and condominiums, for the 10 coastal towns in North Carolina. These records were acquired from the public records at County Tax Assessor's Office and supplemented with records purchased from First American Real Estate Solutions. The data include property characteristics such as the number of bedrooms, bathrooms, built-up area (in sq. ft.), year the property was built, sale date, and sale price for all transactions that occurred between January 1, 2004, and December 31, 2007. In the analysis, we use the most recent transaction. We also include only properties that are located within 500 m of the ocean. We use Google Earth to identify properties within this spatial domain. We geocode the data and measure the distance to beach (meters) using the Euclidean distance tool in Google Earth. We assigned a value of 10 m for oceanfront properties. Table 1 contains the summary statistics of the variables used in the analysis.

Table 1. Description of variables and summary statistics.

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
Sale Price (in 1000s $)	**1555**	682.53	671.61	50	8000
Age of Property	**1555**	24.82	15.96	1	86
Built-up area	**1444**	1758.78	1049.72	253	6734
Number of Bedrooms	**1555**	3.37	1.72	1	10
Number of Bathrooms	**1555**	2.73	1.56	1	10
Multi-Storied (=1 if #Stories > 1)	**1555**	0.47	0.50	0	1
Distance from Ocean (m)	**1555**	120.92	109.50	10	482
Property Type (=1 if Condo)	**1555**	0.40	0.49	0	1
Beach Width (ft.)	**1555**	95.28	25.75	13.12	213.2
Shells	**1555**	0.12	0.29	0	1
Dunes	**1555**	0.57	0.45	0	1
Atlantic Beach	**1555**	0.18	0.38	0	1
Carolina Beach	**1555**	0.15	0.36	0	1
Emerald Isle	**1555**	0.22	0.41	0	1
Indian Beach/Pine Knoll Shores	**1555**	0.11	0.31	0	1
Kill Devil Hills	**1555**	0.03	0.18	0	1
Kitty Hawk	**1555**	0.03	0.17	0	1
Kure Beach	**1555**	0.09	0.29	0	1
Nags Head	**1555**	0.09	0.29	0	1
Wrightsville Beach	**1555**	0.10	0.31	0	1
Scarps	**1555**	0.26	0.41	0	1
Distance to Continental Shelf (km)	**1555**	14.75	4.80	3.20	24.18

We collected data on beach attributes at cross-street transects that were approximately 400 m apart and aligned with the public access points on the beach. Beach width was measured via GPS[3] from the high-tide line to the dune line. The horizontal error reported by the GPS unit ranged between 13 ft. and 18 ft. when measuring the beach from the point of the high-tide line to the base of the dune line. The wetted high-tide line was identified visually based on the presence of wrack and wetted sand and knowledge of the current phase of the tidal cycle. Tape measurements were also taken at randomly selected points to cross-check GPS measurement error. The range of beach width varied from 13 ft. to 213 ft. Beach width for each individual property was interpolated using a distance-weighted average of the two closest measurement points.

We noted the presence of qualitative beach attributes, such as the presence of shells, vegetated dunes, protective structures, sandbags placed to protect the property, and the presence of a pier, at each transect where beach width was measured. All these attributes were recorded as dummy variables that take a value 1 if present at a location and 0 otherwise. Qualitative beach attributes were interpolated for all the properties in the dataset by a distance weighted average of the two nearest measurement points.

For the first instrument for beach width, the distance to the continental-shelf line from the point of the high-tide line at which beach width is measured, we identified the continental shelf at 20 m depth using bathymetry data (U.S. Coastal Relief Model Grids) that is available from the NOAA National Geophysical Data Center (Divins 2009). The distance to the 20-meter bathymetry line is measured in meters from the high-tide line at each transect where the beach width is measured. We measured the distance to continental shelf using the GIS Spatial Analyst tool to measure the Euclidean distance from point to line. We then interpolated the distance to continental shelf for the entire data using distance weighted average of the two nearest measures.

For the second instrument for beach width (the presence of scarps), at each transect where the width was measured, we recorded the presence of scarps as a binary variable (0 or 1) along with other beach quality attributes and similarly interpolated the values for the entire data.

4. RESULTS AND DISCUSSION

4.1. Econometric results

The results from the four hedonic models are presented in Table 2. The dependent variable in all four models is the natural log of the sale price. In Model (1) we use a semi-log specification where the explanatory variables are not transformed. The coefficients on most of the property characteristics have the expected sign. The built-up living area and number of bedrooms have positive coefficients that are significant at the 1% level. The coefficient on age of the property is negative but is not statistically significant. The coefficient on Condo is negative and significant at the 1% level, indicating that the value of condominiums is less than that of single-family residential properties. The coefficient of the dummy variable indicating if the property is multi-storied is negative, which seems counterintuitive on the surface. However, this finding could reflect the fact that many multi-storied oceanfront buildings are in fact duplexes, making them more similar to condominiums.[4] The coefficient on the interaction of distance to ocean and beach width is negative

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[3] Garmin GPSMAP 76S using the "3-D GPS" mode.

[4] This conjecture reflects our personal impressions formed while collecting the physical beach attribute data and from examining data from websites for North Carolina beach vacation rentals. The data set does not allow us to test this conjecture.

(−0.00002) and statistically significant at the 1% level. The coefficient on beach width in this model is 0.002, which implies that beach width has a positive influence on property value but the value of beach width decreases as the distance to the ocean increases. For oceanfront property (with distance to ocean 10 m) we can interpret this result as 0.18% increase in the value resulting from one foot increase in the beach width. This estimate is of comparable magnitude to an estimate (0.0017) found in the literature from a study with the same model specification for another location (Landry, Keeler, et al. 2003). If beach width is an exogenous, fixed attribute, an additional foot of beach width is likely to increase the value of an average oceanfront property in North Carolina (valued at $800,000, which is the mean value of oceanfront property in our data and with a distance of 10 m) by $1,440. Further, we find the marginal value of additional beach width reduces for properties that are located further away from the beach and is close to zero for those that are located over 100 m away from the beach. We also include two physical beach quality attributes—the presence of vegetated dunes and the presence of shells—as explanatory variables. We find that both have a positive influence on property value but the effect of dunes is not statistically significant. We included monthly dummies for time of sale and beach-specific location dummies to account for spatial heterogeneity. We find that relative to Kitty Hawk, the northernmost beach in our study, all other towns have higher property values. The value of coastal properties is highest in Wrightsville beach (which has been nourished most frequently) and properties in towns in the Outer Banks (that have never undertaken beach nourishment) are valued lower.

In Model (2) we use a double log specification where all the continuous explanatory variables are also transformed by taking their natural logs. As in Model (1) we find that most coefficients on the property characteristics have the expected signs and are significant at the 1% level. The coefficient on beach width is 0.15. This estimate is comparable to the estimates in the literature (Pompe and Rinehart 1995), where the same specification is used and the coefficient beach width was reported as 0.25. As in model (1), the coefficient on the interaction between width and distance is negative (−0.04) indicating that the value of additional beach width decreases as the distance from the ocean increases. The coefficients on width and the interaction between width and distance suggest that, if beach width is exogenous, a 1% increase in beach width results in 0.08% increase in the value of oceanfront property, for which the distance to ocean is 10 m. We include monthly dummies to control for time of sale and include location dummies.

Models (3) and (4) are estimated using two-stage least squares (TSLS) instrumenting for endogenous beach width using geomorphological variables—distance to continental-shelf line and the presence of scarps. If the width is endogenous, the interaction between width and distance to ocean will also be an endogenous variable. We construct instruments for the interaction term by multiplying the predicted value of beach width from the first-stage regression with the distance variable (Wooldridge 2002). Model (3) is estimated using a semi-log specification and the results can be compared to the naïve estimates in Model (1). We find that the coefficient on beach width in this model is 0.011, which is more than five times larger than the coefficient in Model (1). The coefficient on the interaction of distance to ocean and the width is negative (−0.00002) and statistically significant at the 1% level. We find that the coefficients on all other explanatory variables do not change significantly compared to the OLS estimates. Our results indicate that the value of an average oceanfront property (valued at $800,000, which is the mean value of oceanfront property in our data and with a distance of 10 m) will increase by $8,800 with an additional foot of beach width, which is over five times larger than the effect when beach width is exogenous.

In Model (4), a double-log specification is used and the results are compared to the naïve estimates in Model (2). The coefficient on beach width is 0.603, which is four times as large as the estimated coefficient in Model (2). When we account for the endogeneity of width, the coefficients on width and the interaction between width and distance indicate that a 1% increase in beach width results in 0.5% increase in the value of oceanfront property.[5] We find that incorporating the endogeneity of beach width and correcting for the inconsistency of the OLS estimates significantly increases the value of the beach in both model specifications. Moreover, the width coefficient in the TSLS model is substantially larger than previous studies have found. Therefore, beach width accounts for a much larger portion of coastal property value when we incorporate the feedbacks between beach dynamics and coastal property value.

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5. We calculate the price elasticity of beach width for oceanfront properties (for which the distance is 10m) as follows:

$$\frac{dP}{dW}\cdot\frac{W}{P} = \beta_W + \beta_{WxD}\ln(D) = 0.603 - 0.049\ln(10) = 0.49$$

We use this elasticity (0.5) in all the simulations.

Table 2. Hedonic pricing model results.

Variables	OLS (Semi-log)	OLS (Double-log)	TSLS (Semi-log)	TSLS (Double-log)
Built-up Area (100s sq ft)	0.056***	0.570***	0.042***	0.534***
	(0.0086)	(0.0526)	(0.0088)	(0.0483)
Number of Bedrooms	0.205***	0.211***	0.207***	0.232***
	(0.0492)	(0.0551)	(0.0374)	(0.0473)
Rooms^2	−0.016***		−0.014***	
	(0.0051)		(0.0035)	
Number of Bathrooms	0.045	0.161**	0.101**	0.153***
	(0.0503)	(0.0680)	(0.0476)	(0.0491)
Baths^2	0.003		−0.006	
	(0.0052)		(0.0052)	
Multi-Storied	−0.114***	−0.101***	−0.130***	−0.111***
	(0.0319)	(0.0309)	(0.0340)	(0.0306)
Property Type (=1 if Condo)	−0.163***	−0.175***	−0.212***	−0.197***
	(0.0429)	(0.0380)	(0.0432)	(0.0376)
Age	−0.005	−0.010	−0.008***	−0.034
	(0.0034)	(0.0247)	(0.0031)	(0.0214)
Age^2	0.00008*		0.0001**	
	(0.00005)		(0.00004)	
Beach Width (Feet)	0.002***	0.150***	0.011***	0.603***
	(0.0006)	(0.0406)	(0.0026)	(0.2043)
Distance x Width (Feet)	−0.00002***	−0.043***	−0.00003***	−0.049***
	(0.0000)	(0.0031)	(0.0000)	(0.0037)
Dunes	0.051	0.088***	0.156***	0.164***
	(0.0317)	(0.0299)	(0.0427)	(0.0441)
Shells	0.106***	0.091**	0.120***	0.082**
	(0.0378)	(0.0364)	(0.0402)	(0.0371)
Atlantic Beach	0.104	0.110*	0.012	0.057
	(0.0700)	(0.0646)	(0.0884)	(0.0816)
Carolina Beach	0.111	0.044	−0.128	−0.110
	(0.0775)	(0.0689)	(0.1140)	(0.1109)
Emerald Isle	0.292***	0.249***	0.200**	0.197**
	(0.0596)	(0.0543)	(0.0835)	(0.0777)
Indian Beach / Pine Knoll Shores	0.198***	0.059	−0.031	−0.070

Variables	OLS (Semi-log)	OLS (Double-log)	TSLS (Semi-log)	TSLS (Double-log)
	(0.0721)	(0.0660)	(0.1098)	(0.1005)
Kill Devil Hills	0.140**	0.128**	0.075	0.109
	(0.0706)	(0.0648)	(0.0987)	(0.0892)
Kure Beach	0.255***	0.240***	−0.021	0.061
	(0.0811)	(0.0747)	(0.1254)	(0.1219)
Nags Head	0.116*	0.129**	0.133	0.171**
	(0.0674)	(0.0558)	(0.0858)	(0.0784)
Wrightsville Beach	0.647***	0.684***	0.352***	0.521***
	(0.0904)	(0.0835)	(0.1317)	(0.1184)
Constant	11.714***	8.631***	11.056***	7.491***
	(0.1597)	(0.3526)	(0.2511)	(0.6364)
Monthly Time Dummies	**Included**	**Included**	**Included**	**Included**
Observations	1444	1444	1444	1444
R-squared	0.6658	0.6830	0.5972	0.6565

At first glance, the results from the TSLS models seem counterintuitive. We might expect that correcting for the endogeneity of beach width will decrease the coefficient on width if property values have a positive influence on the nourishment decision and, therefore, on width. There are two reasons for the negative bias in the OLS coefficients. First, nourishment influences beach width dynamically through the effect on the erosivity of the coastal environment. While nourishment increases the beach width (a positive effect), it also makes the beach erode faster (a negative effect). A higher coefficient on beach width indicates that property values are more sensitive to changes in beach width when the erosion rate is high (leading to more frequent nourishment). Second, the negative bias in the OLS coefficient is due to measurement error, as we observe width only at a given point in time and the hedonic model estimates the flow of benefits from maintaining an average beach width.

We include monthly dummies to control for time of sale and location specific fixed effects. As in the OLS models, the coefficient on Wrightsville Beach, which has undertaken 23 nourishment projects since 1939, is the largest indicating that the average baseline value of coastal property in Wrightsville beach is 50% higher than at Kitty Hawk. The geographical coverage of each beach is small and the location fixed effects absorb factors that lead to variation in property values at the zip code level. We do not include other common neighborhood characteristics, such as school district, because there is no variation within each beach town.

4.2. Tests for endogeneity of beach width

We conduct two model specification tests to test for the endogeneity of beach width. For both specifications of the model, semi-log and double-log, the Wu-Hausman and the Durbin-Wu-Hausman tests reject the null hypothesis that beach width is an exogenous variable, justifying the need for using instrumental variables estimation in this model (Baum 2003). These results are presented in Table 3.

Table 3. Tests for endogeneity of beach width and instrument validity.

	(1)	(2)	(3)	(4)
	OLS (Semi-log)	**OLS (Double-log)**	**TSLS (Semi-log)**	**TSLS (Double-log)**
Tests for endogeneity of width				
Wu-Hausman F-Test Statistic			17.69***	4.52**
Durbin-Wu-Hausman Chi^2-Test			36.32***	9.43***
First-Stage Regression Summary				
Shea Partial R^2 (Width)			0.06	0.05
Shea Partial R^2 (Width x Distance)			0.71	0.66
Angrist-Pischke F Statistic (Width) (Weak Instruments Test)			33.20***	29.46***
Over-identification Test				
Sargan Test Statistic (Over-identification)			0.018	0.14
Sargan Test P-value			(0.9)	(0.71)
*** p<0.01, ** p<0.05, * p<0.1 Robust standard errors in parentheses				

4.3. Instrument validity

The validity of the instruments used for the endogenous variables can be tested using the first-stage regression. To recover consistent estimates of the coefficients in the equation, the instrumental variables need to satisfy three conditions: (1) relevance (the instruments must be correlated with the endogenous variable), (2) exogeneity (instruments must not be correlated with the error terms) and (3) excludability (instruments do not impact property values conditional on beach width and other regressors). The partial R^2 statistic in the first-stage regression is the squared partial correlation between the excluded instruments (distance to shelf line, presence of scarps) and the endogenous regressor (beach width) and is a measure of instrument relevance (Shea 1997; Hahn and Hausman 2002; Baum 2003). The strength of instruments can also be expressed by the F-test for joint significance of all instruments in the first-stage regression (Baum 2003). We use the Shea Partial R^2 statistic to test for instrument relevance with multiple endogenous variables as the beach width and the interaction between width and distance to ocean are endogenous in this model (Shea 1997). We also use the Angrist-Pischke multivariate F-test, which tests whether one endogenous variable is weakly identified in the presence of multiple endogenous variables (Angrist and Pischke 2009). The weak instrument test is conditional on the other endogenous variables passing the weak instruments test. When there is only one endogenous this is the same as the Cragg-Donald F-statistic (Stock and Yogo 2002; Stock, Yogo, et al. 2003) to test for weak instruments. The results, presented in Table 3, indicate that the instruments are valid.

Finally, we conduct the Sargan Test for over identification of the instruments. To be valid instruments we need the instruments to not be correlated with the error term in the system. When there are two instruments, the null hypothesis in the Sargan test is that, conditional on at least one instrument being exogenous, all the instruments are exogenous and influence the dependent variable (sale price) only through the endogenous variable (beach width). A rejection of the null hypothesis indicates that a subset of the instruments is endogenous but the endogeneity of individual instruments is untestable (Wooldridge 2002; Cameron and Trivedi 2006). We find that the instruments pass the over-identification test under both semi-log and double-log specifications because we fail to reject the null hypothesis that the instruments are exogenous in both models. These results are also presented in Table 3.

5. DYNAMIC POLICY SIMULATIONS

We use the results from the hedonic model to run a series of dynamic simulations to assess the importance of accurately measuring the value of beach width and to explore the long-run implications of beach management strategies. We base the simulations on a capital-theoretic model developed by Smith et al. (Smith, McNamara, et al. 2009). When the beach is viewed as a natural resource, the problem faced by the coastal manager is to choose an optimal beach renourishment strategy to manage a representative beach community, trading off costs of nourishment with benefits of shoreline protection and coastal amenities. This problem is different from the conventional resource economics problem because the economic value of the resource (benefits to society) is derived from maintaining the resource base or preventing the beach from eroding rather than from extracting or harvesting the resource. Smith et al. (Smith, McNamara, et al. 2009) develop a positive model of a sandy beach facing erosion as a renewable resource that is periodically renourished to return to an initial width. Following the Hartman model for forest resource management, nourishment is viewed as an optimal rotation problem, where a nourished beach is like a capital investment that provides benefits in the form of amenity flows and storm protection over a certain time period (Hartman 1976). The dynamic nourishment problem is to choose the optimal time interval between repeated renourishment projects. The problem is analogous to the Faustmann rotation model in the forestry literature applied in reverse (Faustmann 1849). In the forestry model, we have a standing forest that has a growth function and high fixed cost of harvesting. The optimal harvest rotation is chosen by maximizing the present value of the stream of discounted net benefits from harvested time over an infinite horizon. The same method is applied in reverse to the beach management problem where there is an eroding beach, rather than a growing forest, that provides amenity flow value. The coastal manager chooses an optimal time interval between nourishment projects that have high fixed costs and variable costs depending on the volume of nourishment.

We briefly summarize the analytical details of the dynamic beach nourishment model here and refer readers to Smith et al. (Smith, McNamara, et al. 2009) for further details. The value of a property is the discounted sum of the infinite stream of net benefits. Beach width (W) changes dynamically as a function of background erosion (γ) and exponential decay from nourishment projects (θ). Each time a community nourishes, it resets the beach at W_0 such that the beach width at time *t* is:

$$W(t) = (1-\mu)W_0 + \mu e^{-\theta t} W_0 - \gamma t. \tag{2}$$

The total benefits for an interval *T* between two nourishment projects are:

$$B(T) = \int_0^T e^{-\delta t} \delta \alpha [W(t)^\beta]dt, \tag{3}$$

where α is the baseline property value, β is the hedonic coefficient on beach width, and δ is the discount rate (also assumed to be the same as capitalization rate here). The costs of nourishment are the sum of fixed costs (c) and variable costs (ϕ times the amount of beach width added):

(4) $$C(T) = c + \phi(W_0 - W(T)).$$

Substituting (2) into (4) and simplifying, costs are

(5) $$C(T) = c + \phi(\mu W_0(1 - e^{-\theta T}) + \gamma T)$$

Assuming time autonomous erosion dynamics, the beach nourishment decision can be written as a Faustmann-like rotation. T^* maximizes the present value of an infinite rotation and the equilibrium property value is then:

(6) $$v(T^*) = (B(T^*) - C(T^*))/(1 - e^{-\delta T^*}).$$

5.1. *Simulation results*

The value of beach width enters the benefit function as an exponential function. The hedonic values of beach width estimated using OLS and TSLS with the double-log specification (Model (2) and Model (4)) are used to run a series of simulations that predict an optimal time interval between nourishment projects for a representative beach community. All the simulations use an initial beach width of 100 ft, which reflects the average beach width in our dataset. The discount factor is 0.06. Baseline erosion rate is assumed to be 2ft per year. It is assumed that 35% of the beach retreats exponentially for the nourished portion of the beach to return to the equilibrium profile. The exponential decay rate is 10% per year. The nourishment costs include two components. Fixed costs are associated with capital equipment needed for dredging sand and the costs of planning the project. Variable costs are a function of the amount of nourishment sand required. This amount, in turn, is proportional to the width of beach build-out. The model assumes a fixed cost of $2,000 and a variable cost of $300 per cross-shore foot of beach build-out[6] (costs normalized to an individual property with average alongshore width). Parameter values used in the simulations are presented in Table 4 (See (Smith, McNamara, et al. 2009) and (Slott, Smith, et al. 2008) for a more detailed discussion of the parameters).

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[6] We follow Slott et al. (2008) to calculate the cost of nourishment sand needed to build out the beach by w_n ft using

$=$

L is the alongshore length of the beach (10km) and D is the limiting depth (10m) to which the cross-shore profile extends. Beach fill to extend the width of the beach will have to cover the depth D. The volume of sand needed to increase the width of the beach by one meter is approximately 100,000 cubic meters of sand $[1m \times 10000m \times 10m]$. Cost of nourishment sand is $5 per cubic meter. Assuming that there are 50 properties (oceanfront) along one km length of the beach and converting measurement to feet we get the normalized cost of nourishment sand per cubic feet of cross-shore build out to be approximately $310

$$\left[\frac{(33000 \times 33 \times 1) \times (5/35.31)}{500}\right]$$

Total fixed cost of a nourishment event is assumed $1,000,000 normalized over individual 500 properties, amounting to a fixed cost of $2,000 per property.

Table 4. Parameter values used in simulations.

Parameter	Value	Description
δ	0.06	Discount factor
γ	2	Baseline Erosion (Feet/year)
θ	0.10	Exponential Erosion Rate
μ	0.35	Portion of the beach that is nourished
x_0	100	Initial Width (Feet)
c	2	Fixed Cost (Scale: 1000$)
ϕ	0.3	Variable Cost per foot of cross-shore build out (Scale: 1000s $)
α		Baseline Property Values (Scale: 1000s $)

To conduct simulations, we partition property value into baseline value and a value for beach width. The baseline value collapses all housing attributes and their associated hedonic prices into one number with the exception of beach width. We calculate the optimal nourishment interval for a range of values for the baseline property value and the hedonic coefficient of the value of beach width (Table 5).

Table 5. Optimal nourishment interval (in years) for different baseline property values and hedonic values of beach width.

		Baseline Property Values (in 1000s $)										
		20	30	40	50	100	120	140	160	180	200	250
Hedonic Beach Values (β)	0.05	12.09	11.85	11.62	11.40	10.40	10.05	9.72	9.42	9.13	8.87	8.27
	0.15	10.56	9.76	9.08	8.49	6.53	6.02	5.61	5.27	4.97	4.72	4.23
	0.25	8.42	7.27	6.44	5.82	4.14	3.77	3.49	3.25	3.06	2.90	2.58
	0.35	6.21	5.12	4.43	3.96	2.76	2.51	2.32	2.16	2.04	1.93	1.72
	0.45	4.43	3.59	3.09	2.75	1.92	1.74	1.61	1.50	1.41	1.34	1.19
	0.55	3.16	2.55	2.20	1.96	1.37	1.24	1.15	1.07	1.01	0.96	0.85
	0.65	2.28	1.85	1.59	1.42	0.99	0.90	0.83	0.78	0.73	0.70	0.62

The baseline property values range from $30,000 to $250,000 and the hedonic beach values range from 0.05 to 0.65. As we would expect, communities undertake beach replenishment more frequently as the hedonic value of beach width increases and with higher baseline property values. This suggests that, if the nourishment decisions are capitalized into housing property values we will observe more frequent nourishment in places that have higher property values. The capitalized value of beach nourishment, reflected in the long-run discounted net benefits, increases significantly as the beach value coefficient increases (Table 6).

Table 6. Present value of long-run net benefits for predicted nourishment intervals (in 1000s $).

		Baseline Property Values (in 1000s $)									
		30	40	50	100	120	140	160	180	200	250
Hedonic Beach Values (β)	0.05	2.2	14.6	27.0	89.1	114.0	138.9	163.8	188.7	213.6	275.8
	0.15	22.5	41.8	61.1	158.1	197.1	236.1	275.2	314.3	353.5	451.5
	0.25	54.5	84.8	115.3	268.5	330.2	391.9	453.8	515.7	577.7	733.0
	0.35	105.8	153.8	202.1	445.3	543.1	641.1	739.3	837.6	935.9	1182.3
	0.45	187.9	264.3	341.1	727.6	883.0	1038.7	1194.6	1350.7	1507.0	1898.1
	0.55	319.6	441.3	563.4	1178.1	1425.1	1672.4	1920.1	2168.0	2416.1	3037.2
	0.65	530.4	724.1	918.5	1895.9	2288.4	2681.4	3074.8	3468.6	3862.6	4848.7

We run the model for six baseline property values that are representative of locations in our dataset where nourishments have occurred using the OLS and the TSLS estimates of the hedonic value of beach width for oceanfront properties (Refer to footnote 5). Nourishment data are from the online Beach Nourishment Database maintained by the Program for the Study of Developed Shorelines, Western Carolina University (PSDS). Table 7 presents a comparison of the predicted nourishment intervals (calculated with the TSLS estimate and the OLS estimate of beach value) with the observed nourishment frequency. We find that the predicted optimal duration between nourishments using TSLS estimate is closer to the observed data in five of the six locations in our data. For Wrightsville beach, where shoreline stabilization measures have been undertaken since 1939, the model predicts a nourishment interval of 2.00 years with the TSLS estimate of the hedonic value of beach width and the average time period between nourishments observed in the data is 2.22 years. Though we have few observations of nourishment frequency in our data, the results of the analysis suggest that the nourishment decisions are capitalized into property values and the beach width contributes to a greater portion of the property value than previously believed. Incorporating the endogeneity of beach width in estimating the hedonic pricing model gives us more accurate measures of the value of beach width. The numerical simulations are indicative of the broad implications of combining the empirical nonmarket valuation results with a dynamic model of nourishment decisions. We do not expect the results to precisely predict the real world conditions because of the lack of adequate data on the frequency of nourishment projects in multiple locations. Further, we only have data on when nourishment was undertaken on a particular beach. While this may not necessarily imply that repeated nourishment was done in the same portion of the beach in each location, our model assumes that every nourishment project in each location covers the same region. Lack of spatially refined data on nourishment is a limitation of our model.

Table 7. Comparison of predicted optimal nourishment interval and observed nourishment frequency.

Description	Atlantic Beach	Carolina Beach	Emerald Isle	Indian Beach /Pine Knoll Shores	Kure Beach	Wrightsville Beach	Outer Banks
Observations	271	180	313	158	122	90	189
Mean Property Value (1000s $)	322.72	367.17	572.14	442.37	544.12	676.48	695.82
Mean Predicted Value (TSLS)	330.78	392.91	609.70	446.88	549.54	768.14	731.45
Baseline Values 1 (w/o beach value) OLS Estimate	256.61	290.53	456.00	350.93	429.29	530.77	558.07
Baseline Values 2 (w/o beach value) TSLS Estimate	35.99	38.75	64.91	48.62	55.84	65.89	86.44
Mean Width	90.7	99.9	88.8	100.1	107.1	120.1	80.4
Year of First Nourishment	1973	1955	1984	2001	1997	1939	
Most Recent Nourishment	2005	2004	2005	2004	2004	2006	
Observed Number of Nourishments	6	28	14	2	3	23	0
Observed Rotation Length	5.33	1.75	1.50	1.50	2.33	2.22	
Optimal Rotation w/OLS ($\beta = 0.1$)	5.66	5.34	4.28	4.88	4.42	3.97	
Optimal Rotation w/TSLS ($\beta = 0.5$)	2.75	2.64	2.02	2.35	2.18	2.00	

The simulations discussed above assume that there are no constraints on the availability of nourishment sand and that the cost of sand and rate of erosion remain unchanged. As climate change induces sea-level rise and increased storminess (Komar and Allen 2007) the demand for erosion control will grow. The future availability of appropriate sand for beach nourishment is a serious concern for coastal managers. In Table 8 we present the percentage decrease in the cumulative value function, which is the implied value of the property from capitalizing the evolution of the beach width and the nourishment decision for a representative community, resulting from increased baseline erosion and higher variable costs of nourishment sand due to scarcity. These simulations use baseline property values for beaches in our dataset that have been renourished more than 10 times since 1950: Carolina Beach, Emerald Isle and Wrightsville Beach. Baseline erosion rates (γ) range from 2 ft/year to 6 ft/year and the variable costs (ϕ) of nourishment sand range from $300 to $1,200 per cross-shore foot of beach build-out. As above, we use the elasticity of beach width of 0.5 for oceanfront properties. (Refer to Footnote 5).

Table 8A shows the results for a community with a baseline property value (α) of $39,000 (not including the value of beach width and based on mean values from the hedonic model). We find that nourishment interval decreases with higher rates of erosion and with higher variable costs. The value function declines dramatically as erosion and sand costs increase. For baseline property value $39,000 (representative of Carolina Beach) we find that, compared to the baseline scenario, the cumulative value at the optimal rotation decreases by 52% when the erosion rates triple (from 2ft/year to 6ft/year) and the cost of nourishment quadruple (from $300 to $1,200 per cross-shore ft of beach build-out).

Table 8. Decrease (%) in discounted net value with increased erosion rate and variable costs of nourishment sand.

Baseline Scenario:
Erosion rate (γ) = 2ft/year
Variable costs (ϕ) = $300 per ft of cross-shore build out

Table 8A. Baseline property value = 39,000 (Carolina Beach).

		Baseline Erosion Rate (γ) due to Sea-Level Rise								
		2	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
Variable Cost of Nourishment Sand (ϕ)	0.30	0.00	1.18	2.34	3.48	4.61	5.72	6.81	7.89	8.97
	0.45	4.09	5.67	7.23	8.77	10.28	11.79	13.27	14.74	16.21
	0.60	8.18	10.16	12.12	14.05	15.96	17.85	19.73	21.59	23.44
	0.75	12.27	14.65	17.01	19.33	21.64	23.92	26.19	28.45	30.67
	0.90	16.36	19.14	21.89	24.61	27.31	29.98	32.64	35.28	37.90
	1.05	20.45	23.63	26.78	29.89	32.98	36.05	39.09	42.12	45.13
	1.20	24.54	28.12	31.67	35.18	38.66	42.11	45.54	48.96	52.36

Table 8B presents similar results for communities with baseline property values of $65,000 (value of beach width not included). We find that the discounted value of cumulative net benefits can decrease by as much as 30% in a community with mean property value $65,000 (representative of Wrightsville Beach and Emerald Isle) if the costs of nourishment sand increase by a factor of four and the baseline erosion triples.

Table 8B. Baseline property value = 65,000 (Emerald Isle, Wrightsville Beach).

		Baseline Erosion Rate (γ) due to Sea Level Rise								
		2	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
Variable Cost of Nourishment Sand (ϕ)	**0.30**	0.00	0.73	1.44	2.14	2.83	3.51	4.18	4.84	5.49
	0.45	2.33	3.29	4.22	5.14	6.06	6.96	7.85	8.73	9.60
	0.60	4.67	5.85	7.01	8.15	9.28	10.41	11.52	12.62	13.71
	0.75	7.00	8.41	9.79	11.16	12.51	13.85	15.19	16.51	17.82
	0.90	9.34	10.97	12.57	14.16	15.74	17.30	18.86	20.40	21.93
	1.05	11.67	13.53	15.36	17.17	18.97	20.75	22.53	24.29	26.04
	1.20	14.01	16.09	18.14	20.18	22.20	24.20	26.20	28.18	30.15

The hedonic model estimates the value of coastal property ideally as a function of the average width at which the beach is maintained. In the empirical model, we measure the beach width at various locations but we do not observe where the width lies along the nourishment interval. This leads to an econometric bias that is similar to attenuation bias due to measurement error of the regressor (width). To understand the underlying physical-economic dynamics, we conduct a Monte Carlo simulation experiment (Appendix A) to examine the attenuation bias due to the choice of nourishment intervals. Our simulation results support the empirical results indicating that the value of beach width is underestimated when the model is estimated using OLS.

6. CONCLUSION

Beach erosion is a serious concern for coastal economies that depend heavily on revenue from tourism. While it has been a focal issue for coastal planners for many years, the economic implications of changing shoreline positions have received attention from resource economists only recently. Wide beaches provide benefits to coastal communities through storm protection and recreational amenity flow, but the magnitude of these benefits is yet to be fully understood. The value of beach width is reflected in the housing market, which is directly influenced by the dynamic physical processes that govern the coastal system.

This paper is the first to incorporate the endogenous interaction between coastal real estate prices and the width of the beach in isolating the value of beach width. Accounting for the attenuation due to dynamics and endogeneity of beach width, which can be altered through policy intervention via beach nourishment, we estimate a hedonic pricing model using instrumental variables and find that the coefficient on width is nearly five times as large as the OLS estimate. We conclude that beach width contributes to the value of coastal property to a greater extent than previously believed. The hedonic analysis recovers consistent estimates of the marginal value of beach width, which is a necessary first step for an accurate benefit-cost analysis of beach nourishment as a policy option. Our results also suggest that the value of policy interventions via beach nourishment is capitalized into the housing market. While our results may not change the outcome of a static evaluation of coastal policy options, it could have a significant impact on the long-run policy decisions.

From a resource economics perspective, a beach is a dynamic natural resource that generates value through storm protection and recreational flow. Nonmarket valuation techniques have been applied to estimate the value of beach width using models that assume equilibrium market conditions. However, in order to capture the complexity and dynamic interlinkages between the economic and coastal systems, we need an integrated model. In this paper we take a first step towards bridging the gap between static, empirical nonmarket valuation studies and dynamic resource models of beach nourishment decisions. Using the results from the hedonic analysis we parameterize a dynamic capital-theorectic model of optimal beach nourishment decision. We find that the nourishment intervals predicted using estimates of the value of beach width accounting for the dynamic beach and endogeneity are generally closer to the observed nourishment frequency in the locations where shoreline stabilization measures have been undertaken. Our simulation results indicate that the value of coastal residential property can fall by as much as 52% in places like Carolina Beach when the baseline erosion triples and variable costs of sand quadruple. Though seemingly counterintuitive, we find that increase in variable costs leads to more frequent nourishment for our model parameters (suggested as theoretically possible in (Smith, McNamara, et al. 2009). The simulation results thus highlight the importance of sand availability in maintaining coastal property values over time. Our empirical results coupled with numerical simulations also tell a cautionary tale about potential errors-in-variables problems in other hedonic settings. Environmental attributes in hedonic models such as air quality are likely to be dynamic, whether they vary seasonally, trend in a particular direction, or both. Measuring these attributes precisely at a point in time could generate attenuation bias as if they were measured with error.

Our results raise important concerns about the sustainability of beach nourishment as a long-run policy option to manage eroding beaches; communities are likely to face increasing budget and resource constraints as sea-level rise and increased storminess due to climate change increase the demand for erosion control. The increase in demand and competition among coastal communities for the high quality sand resource could potentially lead to a race to dredge. Nourishment quality sand is largely a common-pool resource, and individual communities may accelerate their extraction of economically recoverable sand before other communities have a chance to access it. Since use of this resource is largely unregulated, one can imagine a tragedy of the sand commons unfolding over the coming decades. Our analysis motivates further research in this area to better understand the dynamics of beach erosion and the use of sand as a resource in managing shorelines.

APPENDIX

MONTE CARLO SIMULATION TO UNDERSTAND TO PHYSICAL-ECONOMIC DYNAMICS OF THE COASTAL SYSTEM AND THE HOUSING MARKET

The hedonic model estimates the value of coastal property ideally as a function of the average width at which the beach is maintained. In the empirical model, we measure the beach width at various locations but we do not observe where the width lies along the nourishment interval. This leads to an econometric bias that is similar to attenuation bias due to measurement error of the regressor (width). The hedonic price function is the discounted value of the stream of benefits from beach attributes: $\ln(V_{ij}) = \alpha_{ij} + \beta \ln(w_{ij}) + \varepsilon_{ij}$ where α is the baseline property value (captures all attributes other than width) and w_{ij} is the width of the beach. The observed beach width can be represented as $w_{ij} = w_j^{*} + v_{ij}(t)$ where w_j^{*} is the average width at which the beach is maintained in location j and $v_{ij}(t)$ are deviations from the average width. $v_{ij}(t)$ has mean $E[v(t)] = 0$ and variance σ_v. This is similar to the classic errors-in-variables model. To understand the underlying physical-economic dynamics, we conduct a Monte Carlo simulation experiment. Based on the optimal nourishment model described in equations (2) through (6) in Section 5, we simulate the beach width and the capitalized value of amenity flow for a range of erosion rates and estimate the coefficients [δ, 1, β] of the hedonic price function given by $V = e^{-\delta t}\alpha[w(t)]^{\beta}$.

Beach width $w(t)$ follows the state equation (2). And the beach return to initial width w_0 every T* years (Optimal nourishment interval). Parameter values are summarized in Table 3. Baseline property values are collapsed into a single parameter. For each simulation run, we draw a baseline property value $\alpha \sim$ U(20, 100). We draw 50 observations of erosion rates (ft/ year) $\gamma_j \sim U(1,10); j \in [1,50]$. The optimal nourishment interval T_j^{*} is calculated for each (A, γ_j) by solving the model described in Section 5. We then, draw a random sample of 100 time points (t_i) within each interval T_j^{*} and calculate beach width w_{ij} at each t_{ij}.

Benefits from a single nourishment interval calculated at t_{ij} are:

$$(7)\quad B(t_{ij}) = \int_{t_{ij}}^{T_j^{*}} e^{-\delta t_{ij}} \delta\alpha[w_j(s)]^{\beta}\, ds + e^{-\delta T_j^{*}} \int_{0}^{t_{ij}} e^{-\delta t_{ij}} \delta\alpha[w_j(s)]^{\beta}\, ds,$$

recognizing that a draw from the interior of a nourishment interval will produce the end of one interval and the beginning of the next. The cumulative value from an infinite stream of benefits is

$$V_{ij} = \frac{B(t_{ij})}{1 - e^{-\delta T_j^{*}}}$$

The constructed data set is then used to estimate the hedonic price function:

$$(8)\qquad \ln(V_{ij}) = -\delta t_{ij} + a\ln(\alpha) + \beta\ln(w_{ij}) + \varepsilon_{ij},$$

where $\varepsilon_{ij} \sim N(0,0.1)$. For the TSLS estimation we use γ_j, the erosion rate at location *j,* as an instrument for x_{ij} and we recover estimates of the parameters [δ^0, a^0, β^0]. We run the model

10,000 times and in each run we draw a sample of 100 time points within each nourishment interval at which the beach width and the value are calculated for each erosion rate. We then estimate the hedonic value of width using OLS and IV (instrumenting for width using the erosion rate). We also estimate the hedonic value of width using OLS and IV with the average beach width at each location (for each erosion rate and baseline property value) as the regressor without measurement error.

The Monte Carlo simulation results indicate that the value of beach width is underestimated when the model is estimated using OLS. Table 8 presents the mean, standard deviation and median of the estimated parameters of the hedonic model for 10000 Monte Carlo iterations. Recall that measurement error in this context means using a point measurement of beach width when it is the dynamic path of the beach (effectively the average width) that contributes to value. We find that the Monte Carlo experiment recovers the true value using IV and that the magnitude of the OLS estimate of the coefficient on beach width is smaller than the TSLS estimate, which is similar to our results in the empirical model. Further, when we remove variation within each location (each specific erosion rate) and use the average width as the explanatory variable, we find that the difference between OLS estimates and the IV estimates is smaller and both models recover estimates closer to the true parameter value. Therefore, it appears that the IV approach corrects for both sources of inconsistency under rotational nourishment.

Table 9A. Monte Carlo simulation of hedonic model when the average maintained width of the beach is unknown.

		(1)			(2)		
Estimated	**True Value**	**OLS**			**TSLS**		
		Mean	**Std. Dev**	**Median**	**Mean**	**Std. Dev**	**Median**
$\delta 0$	**-0.06**	-0.039	0.003	-0.039	-0.059	0.0005	-0.059
$\alpha 0$	**1.00**	1.411	0.026	1.411	0.996	0.185	1.035
$\beta 0$	**0.60**	0.183	0.026	0.183	0.604	0.186	0.565

Table 9B. Monte Carlo Simulation of the hedonic model when the average maintained width of the beach is known.

		(3)			(4)		
Estimated	**True Value**	**OLS**			**TSLS**		
		Mean	**Std. Dev**	**Median**	**Mean**	**Std. Dev**	**Median**
$\delta 0$	**-0.06**	-0.059	0.0004	-0.059	-0.06	0.0004	-0.06
$\alpha 0$	**1.00**	1.157	0.037	1.157	0.941	0.045	0.941
$\beta 0$	**0.60**	0.449	0.036	0.448	0.656	0.044	0.656

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