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

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ABSTRACT

Beach nourishment is a popular policy beach management option in many parts of the US Atlantic and Pacific Coasts. The value of beach width is an important factor that enters the benefit-cost calculus of beach replenishment decisions. Previous studies have consistently shown a positive influence of beach width on the value of coastal property but have not considered the econometric implications of policy interventions in the coastal system and the feedback that beach nourishment has on the rate of shoreline retreat. This paper incorporates the endogeneity of beach width in a first-stage hedonic property value model. Relying on knowledge of coastal geomorphology, we use instrumental variables to recover an unbiased and consistent estimate of the coefficient on beach width. We find that the coefficient on beach width more than twice as large as the OLS estimate, suggesting that beach width is a much larger portion of property value than previously thought. This paper also begins to bridge the gap between empirical hedonic models and conceptual resource economics models of coastal management decisions. We use results from the hedonic model to parameterize a dynamic capital-theoretic model of beach nourishment decisions. Our simulation results show that the predicted interval between nourishment projects using hedonic value of beach width accounting for endogeneity is closer to the observed data for beaches that have undertaken more than ten nourishment projects. In scenarios with increased baseline erosion and increased variable costs of nourishment sand (due to scarcity) we find that the long-term net value of coastal residential property can fall by as much as 56% when the baseline erosion triples and cost of sand quadruples.

Keywords: beach width, beach nourishment, erosion, hedonic, morpho-economics, non-market valuation

JEL Codes: Q24, Q51, Q54

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 eighty to ninety percent of the sandy beaches in the United States are receding (Leatherman 1993; Kreisel, Landry, and Keeler 2005). Simultaneously, there has been an increase in the population density in coastal towns in the United States (Pilkey *et al.* 1998). Recent population reports estimate that coastal counties covering 17% of the land area – excluding Alaska – account for 53% of the US population, and the population in US coastal counties grew by 33 million between 1980 and 2003 (NOAA 2004). These two trends lead to a natural conflict that requires 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 policy beach management option and is used to combat erosion in many parts of the US 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 ocean front 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 relatated to views of the beach (Brown and Pollakowski 1977; Edwards and Gable 1991; Parsons and Wu 1991; Parsons and Powell 2001; Bin *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, and Keeler 2005). Others estimate the diminution of property value from erosion risk in a hedonic framework (Kriesel, Alan, and Lichtkoppler 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 not considered how policy interventions feed back on the rate of shoreline retreat and, in turn, on property values. Our paper focuses on this interaction between housing markets and physical coastal processes. If coastal property prices

[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 comparing the value of increased beach width and with the costs of nourishment (Edwards and Gable 1991; Parsons and Powell 2001). 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.

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. Ignoring this endogeneity due to the coastal dynamics in the implicit price function will give biased estimates of the coefficient on beach width (or coefficients on hazard risks that are functions of beach width). This econometric bias will then bias benefit-cost analyses of erosion control strategies.

In contrast to previous hedonic studies of coastal property, this paper incorporates the endogeneity of beach width using instrumental variables. We construct a unique data set that combines real estate data on residential property in ten coastal North Carolina towns and physical beach quality attributes that we collected. We estimate the value of beach width using a hedonic model and instrument for beach width using variation in the physical coastal system, accounting for spatial heterogeneity with beach-specific fixed effects. We find that the beach width coefficeint in the naïve specification in which beach width is exogenous is comparable to other estimates in the literature. However, accounting for endogeneity approximately triples the coefficient on beach width.

A parallel line of research to hedonic models of beach valuation uses dynamic models to study the interactions of complex physical process and economic decisions made by humans who depend on coastal resources (Landry 2007; Smith et al. 2009; Yohe, Neumann, and Ameden 1995). 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 re-nourishment and the rate at which future costs and benefits are discounted (Smith *et al.* 2009). Our paper begins to bridge the gap between empirically based non-market valuation studies of beaches and the conceptual resource economics models of dynamic decisions in the coastal zone. We use the results of from the hedonic model to parameterize a dynamic capital-theoretic model of beach nourishment decisions (Smith *et al.* 2009). We run the model for a range of scenarios with estimates for the value of beach 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 ten nourishment projects since 1950. Moreover, our results tell a cautionary tale about relying on beach nourishment as a long-run strategy to combat coastal erosion.

Furthermore, when beach stabilization via replenishment is an available option, beach width at any given time depends on the time of the most recent nourishment activity and the length of the nourishment interval, which depends on the erosion rate at the given location. The hedonic price function associates the value of coastal property with a measure of the average beach width at the location where the property is situated. When the width of the beach is measured at any given time, we do not observe where it lies within a nourishment interval. This leads to an econometric bias similar to attenuation bias due to erros in variables when the model is estimated using OLS. We find that two-stage least squares (TSLS) approach instrumenting for beach width corrects for the attenuation bias and endogeneity.

The following section describes the econometric model used to estimate the hedonic value of beach width and briefly describes the dynamic model for beach nourishment. 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 and a series of policy simulations to determine optimal nourishment interval in a representative coastal community. Finally, we conclude with policy implications of this study and directions for future research.

2. METHODS

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

We use the hedonic pricing model of (Rosen 1974) to estimate the value of beach width that is capitalized in property values. Price of residential coastal property (P_i) is a function of property characteristics (X_i), physical beach quality attributes (Z_i), distance from oceanfront

(d_i), width of the beach at the property location (W_i) and the location specific dummy variables (L_i).

We start with the following model:

$$\ln(P_i) = \alpha X_i + \beta Z_i + \gamma d_i + \omega W_i + \mu L_i + \varepsilon_i$$

where:

X_i is a vector of structural characteristics of the property including

X1 = Built-up Area (in 100s of sq ft.)

X2 = Number of bedrooms

X3 = Number of baths

X4 = Dummy variable for Multi-storied property (=1 if multi-storied)

X5 = Dummy variable for property type (=1 if condo/ =0 if Single Family Unit)

X6 = Age of the property (years)

X7 = Month of sale (Jan 2004 (=1) to Dec 2007 (=48))

d_i = Distance from ocean front (feet)

W_i = Beach Width at property location (feet)

Z1 = Presence of a Vegetated Dune

Z2 = Presence of shells on the beach

L_i is a dummy variable representing the beach location

We estimate four first stage 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 to account for spatial heterogeneity. In the semi-log model specification, the coefficient on beach width can be interpreted as the percentage change in the property value due to a unit (one foot) increase in the beach width. With a double-log specification, the coefficient on beach width can be interpreted as the percentage change in property value resulting from a one percent increase in the width of the beach.

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 (Kriesel, Alan, and Lichtkoppler 1993; Pompe and Rinehart 1995; Edwards and Gable 1991; 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 or the potential damage due to loss of property, 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 unbiased and consistent estimates of the coefficients in the equation. This method has been applied in previous works to recover endogenous site attributes like 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:

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). We use distance from shore to the continental shelf at a depth of 20m as an instrument for the erosivity of the coastal environment.

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 re-growth. Scarps are indicative of prolonged erosion (Davis and Fitzgerald 2004). 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 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.

2.2. 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 in (Smith *et al.* 2009). The problem faced by coastal managers is to choose an optimal beach re-nourishment 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.* (2009) present a positive model of a sandy beach facing erosion as a renewable resource that is periodically re-nourished to return to an initial width. Following the Hartman model for forest resource management, the model treats nourishment 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 re-nourishment 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. Analytical details of the dynamic beach nourishment model are described in Appendix A.

3. DATA

We use a unique dataset that combines real estate data on residential property in ten coastal towns in North Carolina with data on physical beach quality attributes that we collected. The data covers three counties along the coast of North Carolina, including Atlantic beach, Emerald Isle, Indian Beach and Pine Knoll Shores in Carteret county; Nags Head, Kill Devil Hills and Kitty Hawk in Dare County (Outer Banks); and Carolina Beach, Kure Beach and Wrightsville Beach in New Hanover County. Figure 1 presents a map of the areas covered in the study.

Sales records for residential properties, which include single-family property (SFP) and condominiums, were collected for ten coastal towns in North Carolina. These records were acquired from the public records at County Tax Assessors Office and supplemented with records purchased from First American Real Estate Solutions. The data include property characteristics such as the number of bedrooms, bathrooms, area, type of heating, flooring, built up area (in square feet), lot size (in acres), 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 trasaction and adjust all sale prices to 2004 USD. We also include only properties that are located within the first four rows from the ocean. We used Google Earth to identify properties that were within this spatial domain. Table 1 contains the summary statistics of the variables used in the analysis.

Data on beach attributes were collected at cross street transects that were approximately 400 meters apart and aligned with the public access points on the beach. Beach width was

measured via GPS [2] from the high-tide line to the dune line. The horizontal error reported by the GPS unit ranged between 13ft and 18ft 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, 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 individual property was interpolated using a distance-weighted average of the two closest measurement points.

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, were noted 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 at which beach width is measured, the continental-shelf at 20m depth is identified using bathymetry data (US 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. The distance is measured using the GIS Spatial Analyst tool to measure the Euclidean distance from point to line.

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

[2] Garmin GPSmap 76S using the '3-D GPS' mode

4. RESULTS AND DISCUSSION

4.1. ECONOMETRIC RESULTS

The results from the four first-stage hedonic models are shown in Table 2. The dependent variable in all four models is the natural log of the sale price adjusted to 2004 USD values. 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, number of bedrooms, number of bathrooms and multi-storied have positive coefficients and are significant at the 1% level. The coefficients on age of the property and time of sale are both negative but are not statistically significant. The coefficient on Condo is negative and significant at the 5% level, indicating that the value of condominiums is less than that of single-family residential properties. A negative coefficient on the month of sale suggests a declining trend in real property values, but it is not statistically significant. The coefficient on the interaction of distance to ocean and the width is very close to zero but has a negative sign. The coefficient on beach width in this model is 0.002, which can be interpreted as a 0.2% increase in the value of a property resulting from one foot increase in the beach width. This estimate is larger but of comparable magnitude to an estimate (0.001) found in the literature from a study with the same model specification for another location (Kreisel, Landry, and Keeler 2005). We also include two physical beach quality attributes – the presence of vegetated dunes and the presence of shells – as explanatory variables. We find that the presence of dunes does not have a statistically significant influence on property value, whereas a shelly beach increases property value.

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 the coefficients on the property characteristics have the expected signs and are significant at the 1% level. The coefficients on the discrete explanatory variables are similar to Model (1). The coefficient on beach width is 0.19 indicating that a one percent increase in beach width leads to a 0.19% increase in the value of the property. This estimate is comparable to the results in

(Pompe and Rinehart 1995), where a double-log specification is used and the coefficient beach width was reported as 0.25.

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. 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 is 0.006, which is three times as large as the coefficient in Model (1). We find that the coefficients on all other explanatory variables do not change significantly compared to the OLS estimates, and the TSLS estimation corrects for the bias due to the endogeneity of the width.

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 0.485, which is also more than twice as large as the estimated coefficient in Model (2). We find that incorporating the endogeneity of beach width and correcting for the bias in 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 (50-400%).

At first glance, the results seem counter-intuitive. We would 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. However, in this case the endogeneity enters dynamically through the effect of the erosivity of the coastal environment on nourishment decisions. 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). Furthermore, when beach stabilization via replenishment is an available option, beach width at any given time depends on the time of the most recent nourishment activity and the length of the nourishment interval, which 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. This leads to an

econometric bias similar to attenuation bias due to errors in variables when the model is estimated using OLS. To understand the underlying physical-economic dynamics, we also conducted a Monte Carlo simulation experiment (Appendix B). We simulate the discounted value of an infinite stream of benefits for a randomly choosen a baseline erosion rate between 1ft and 10ft per year, which determines the beach width at any time. The beach is nourished (returns to initial width) every T years, derived by solving the dynamic optimization problem for each erosion rate. Baseline property values (property attributes other than beach width) are collapsed into a single parameter. We run the model 1000 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 regress the value on width using OLS and IV (instrumenting for width using the erosion rate). The simulation results also indicate that the value of beach width is underestimated when the model is estimated using OLS. Figure 2 shows the distributions of the estimated coefficient of beach width under OLS and IV when the true value is 0.48 (value from the empirical model using IV) We find that the MonteCarlo experiment recovers the true value using IV and that the magnitude of the OLS estimate of the coefficient on beach width is approximately three times smaller than the TSLS estimate, which is similar to our empirical result.

We include location specific fixed effects for the two models with endogenous beach width. We find that all locations except Nags Head in the Outer Banks have higher property values relative to Kill Devil Hills. The coefficient on Wrightsville Beach, which has undertaken 23 nourishment projects since 1939, is the largest indicating that the average value of coastal property in Wrightsville beach is 60% higher than at Kill Devil Hills. The geographical coverage of each beach is small and the location fixed effects absorb factors that lead to variation in property values at the zipcode level. We do not include other common neighborhood characteristics such as school district because there is no variation within each beach town. In Models (1) and (2) we do not include location fixed effects but include a dummy variable for whether the beach has ever been nourished. In both models (1) and (2) the coefficient on

Nourish is positive and significant at the 1% level, indicating that the value of properties in locations that have undertaken beach nourishment projects at least once is approximately 45% higher than the value of property in the Outer Banks where there have been no coastline stabilization policies.

Two model specification tests were conducted to test for the endogeneity of beach width. The Wu-Hausman (F-statistic 9.972 ; P=value 0.002) and the Durbin-Wu-Hausman (Chi-squared statistic 10.055 ; P=value 0.002) 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).

The validity of the instruments used for the endogenous variables can be tested using the first stage regression. To recover unbiased estimates of the coefficients in the equation, the instrumental variables need to satisfy two conditions – relevance (the instruments must be correlated with the endogenous variable) and exogeneity (instruments must not be correlated with the error terms). The partial R-squared 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 (Hahn and Hausman 2002; Shea 1997; Baum 2003). A high value (F > 10) of the F-statistic in the first stage regression (test for excluded instrument) indicates that the instrumental variable is not a weak instrument when there is a single endogenous variable. Davis and Kim (2002) show that the Shea Partial R^2 measure and the Likelihood Ratio test statistic can be derived from a single auxillary regression to test for instrument relevance in the case of a single endogenous regressor. In the first stage the predicted value of the endogenous variable is derived (by estimating $\ln(W_i) = \alpha_1 X_i + \alpha_2 I_i + \varepsilon_i$ where W_i is the beach width, X_i is the vector of all exogenous explanatory variables and Z_i is the vector of instruments for each observation). In the second stage we regress the predicted beach width on all explanatory variables of interest ($\ln(\hat{w}_i) = \theta_1 X_i + \theta_2 \ln(W_i) + u_i$). The coefficient on the endogenous explanatory variable in the

auxillary regression (θ_2) is the measure of instrument relevance. If $\theta_2 > 1 - e^{-C.V/N}$ (C.V(=3.83) is the critical value for a χ^2 distribution with one d.f, N = number of obs.) then we can reject the null hypothesis that the instruments are not relevant (Davis and Kim 2002). We find that θ_2 = 0.053 which is greater than $1 - e^{-3.83/1210}$ (0.0032). The summary results from the first stage regression (Table 2) indicate that the instrumental variables are valid and pass the weak instruments test (F > 10).

Finally, we conducted the Sargan Test for over identification of the two instruments. To be valid instruments we need the instruments to not be correlated with the error term in the system. The null hypothesis is that all the instruments are exogenous and influence the dependent variable (sale price) only through the endogenous variable (beach width). The Sargan test statistic under the semi-log model (Model 3) was 0.442 with a P-value of 0.51 for the Chi-squared distribution. For the double log model (Model 4) the Sargan test statistic was 1.203 with a P-value of 0.27 for the Chi-squared distribution. For both models we find that the instruments pass the over-identification test becaues we fail to reject the null hypothesis that the instruments are exogenous.

4.2. DYNAMIC POLICY SIMULATIONS

The hedonic values of beach width estimated using OLS and TSLS using a double-log model specification (Model (2) and Model (4)) were 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 nourished portion of the beach to return to the equilibrium profile. The exponential decay rate is 10% per year. The benefits from nourishment are an exponential function of the beach width. We use the OLS and TSLS coefficients on beach width from the two double-log models to parameterize the benefit

function. The nourishment costs include two components. Fixed costs 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 $2000 and a variable cost of $300 per cross-shore foot of beach build-out[3] (costs normalized to an individual property with average alongshore width). See Smith *et al.* (2009) and (Slott, Smith, and Murray 2008) for a discussion of the parameters.

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. Table 4 presents the simulation results for the predicted optimal nourishment interval for a range of values for the baseline property value and the hedonic coefficient of the value of beach width. The baseline property values range from $50000 to $300000 and the hedonic beach values range from 0.15 to 0.55. As we would expect, the optimal nourishment interval reduces with an increase in the beach value 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 is proportional to the hedonic coefficient on beach width and we find that the long-run net value with optimal nourishment strategy increases the baseline property value by approximately ten times the hedonic coefficient (Table 5).

We ran 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

[3] We follow Slott *et al.* (2008) to calculate the cost of nourishment sand needed to build out the beach by w_n ft using $V_n = w_n LD$. 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 100000 cubic meters of sand $[1m \times 10000m \times 10m]$. Cost of nourishment sand is $5 per cubic meter. Assuming that there are 50 properties (ocean front) 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 $\left[\frac{(33000 \times 33 \times 1) \times (5/35.31)}{500}\right]$. Fixed cost is assumed $100000 normalized over individual properties.

estimates of the hedonic value of beach width. Nourishment data are from the online Beach Nourishment Database maintained by the Program for the Study of Developed Shorelines, Western Carolina University (PSDS). Table 6 presents a comparison of the predicted nourishment interval with the TSLS estimate of beach value 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 2.12 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 a more accurate measure of the value of beach width. The numerical simulations are indicative of the broad implications of combining the empirical non-market 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 does not 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 for our model.

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 7 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 were conducted with baseline property values for three representative beaches in our dataset – Carolina Beach, Emerald Isle and Wrightsville Beach – that have been re-nourished more than ten times since 1950. 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 $1500 per cross-shore foot of beach build-out (Footnote 3).

Table 7A shows the results for a community with a baseline property value (A) of $40000 (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 $40000 (representative of Carolina Beach) we find that, compared to the baseline scenario, the cumulative value at the optimal rotation decreases by 56% when the erosion rates triple (from 2ft/year to 6ft/year) and the cost of nourishment quadruple (from $300 to $1200 per cross-shore ft of beach build-out).

Table 7B and 7C present similar results for communities with baseline property values of $60000 and $70000 (value of beach width not included). We find that the discounted value of cumulative net benefits can decrease by as much as 36% in a community with mean property value $60000 (Emerald Isle) and by up to 31% in a community with mean property value $70000 (Wrightsville Beach) if the costs of nourishment sand increase by a factor of four and the baseline erosion triples.

5. CONCLUSION

Beach erosion is a serious concern for coastal economies that depend primarily 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 are 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 endogeneity of beach width, which can be altered through policy intervention via beach nourishment, we correct for the bias in the model using instrumental variables and find that the coefficient on width is more than twice 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 unbiased and consistent estimates of the marginal value of beach width, which is a necessary first step for an accurate cost-benefit analysis of beach nourishment as a policy option. Our results also suggest that the value of policy interventions via beach nourishment are 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. Non-market 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 non-market 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 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 53% in places like Carolina Beach when the baseline erosion triples and variable costs of sand quadruple. Though seemingly counter-intuitive, we find that increase in

variable costs leads to more frequent nourishment for our model parameters (suggested as theoretically possible in Smith *et al.* 2009). The simulation results thus highlight the importance of sand availability in maintaining coastal property values over time.

These 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. Because use of this resource is largely unregulated, one can imagine a tragedy of 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.

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Appendix A:
Technical Summary of the Dynamic Simulation Model (based on Smith *et al.* 2009)

The value of a property is the discounted infinite stream of net benefits. Beach width (*x*) changes dynamically as a function of background erosion (g) and exponential decay from nourishment projects (q). Each time a community nourishes, it re-sets the beach at x_0 such that beach width at time *t* is:

A1 $$x(t) = (1-\mu)x_0 + \mu e^{-\theta t} x_0 - \gamma t \ .$$

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

A2 $$B(T) = \int_o^T e^{-\delta t} \delta\alpha \left[x(t)^{\beta} \right] dt \ ,$$

where a is a baseline property value, b is the hedonic coefficient on beach width, and d is the discount rate (also assumed to be the same as the capitalization rater here). The costs of a nourishment project are the sum of fixed costs (*c*) and variables costs (*f* times the amount of beach width added):

A3 $$C(T) = c + \phi\left(x_0 - x(T)\right).$$

Substituting A1 into A3 and simplifying, costs are:

A4 $$C(T) = c + \phi\left(\mu x_0 \left(1 - e^{-\theta T}\right) + \gamma T\right).$$

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:

A5 $$v(T^*) = \left(B(T^*) - C(T^*)\right) \Big/ \left(1 - e^{-\delta T^*}\right)$$

Appendix B:
Montecarlo Simulation experiment to estimate the hedonic value of beach width

We conducted a Monte Carlo experiment to understand the underlying dynamics that drive the interaction between the physical coastal system and the housing markets and the results of our hedonic analysis. Based on the optimal nourishment model descibed in Appendix A, 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:

$$V = e^{-\delta t}\alpha[x(t)]^{\beta}$$

Beach width $x(t)$ follows the state equation A1. And the beach return to initial width x_0 every T* years (Optimal nourishment interval).

Parameter Values:

δ^0 = 0.06	Discount factor (true value)
β^0 = 0.48	Hedonic coefficient of beach width (True Value)
c=2	Fixed Cost (Scale: 1000$)
phi=0.3	Variable Cost per foot of cross-shore build out (Scale: 1000s $)
x0base=100	Initial Width (Feet)
theta=0.10	Exp Erosion Rate
mu=.35	Portion of the beach that is nourished
α ~ U(50, 200)	Baseline Property Values (Scale: 1000s $)
γ ~ U(1, 10)	Baseline Erosion (Feet)

For each simulation run, we draw a baseline property value A ~ U(50, 200). We draw 50 observations of erosion rates $\gamma_j \sim U(1,10); j \in [1,50]$. The optimal nourishment interval T_j^* is calculated for each (A, γ_j) by solving the model described in A.

We then, draw a random sample of 100 time points (t_i) within each interval T_j^* and calculate beach width x_{ij} at each t_{ij}.

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

$$B(t_{ij}) = \int_{t_{ij}}^{T_j^*} e^{-\delta t_{ij}}\alpha[x_j(s)]^{\beta}\,ds + e^{-\delta T_j^*}\int_0^{t_{ij}} e^{-\delta t_{ij}}\alpha[x_j(s)]^{\beta}\,ds$$

The cumulative value from an infinite stream of benefits is $V_{ij} = \dfrac{B(t_{ij})}{1-e^{-\delta T_j^*}}$

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

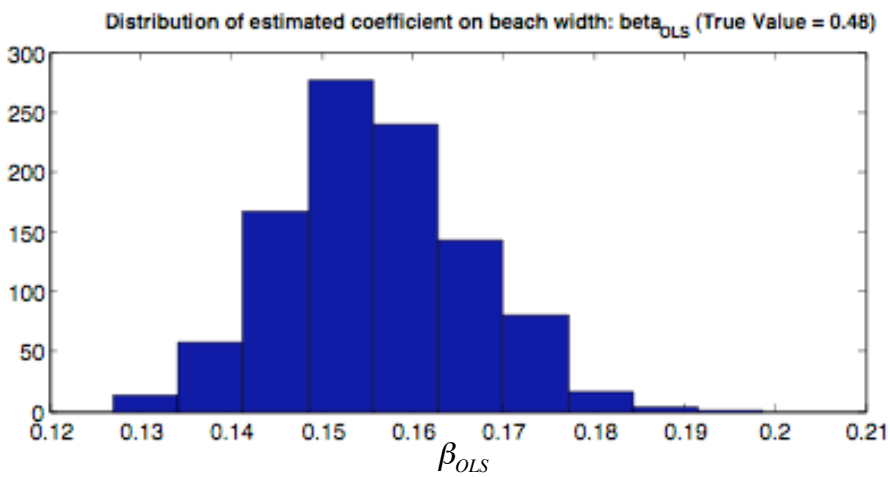
$$\ln(V_{ij}) = -\delta t_{ij} + a\ln(\alpha) + \beta\ln(x_{ij}) + \varepsilon_{ij} \text{ where } \varepsilon_{ij} \sim N(0,0.1)$$

For the TSLS estimation we use γ_j as an instrument for x_{ij} and we recover estimates of the parameters [δ^0, a^0, β^0]. The model is run 1000 times.

The mean value of the estimated coefficients were:

	Estimated Parameter		
Model	δ^0 = **-0.06**	a^0 = **1.00**	β^0 = **0.48**
OLS	$\bar{\delta}_{OLS}$ = -0.046	$\bar{a}_{OLS}$ = 1.311	$\bar{\beta}_{OLS}$ = 0.156
TSLS	$\bar{\delta}_{IV}$ = -0.060	$\bar{a}_{IV}$ = 0.991	$\bar{\beta}_{OLS}$ = 0.489

Distribution of the estimates of β^0 under OLS and TSLS



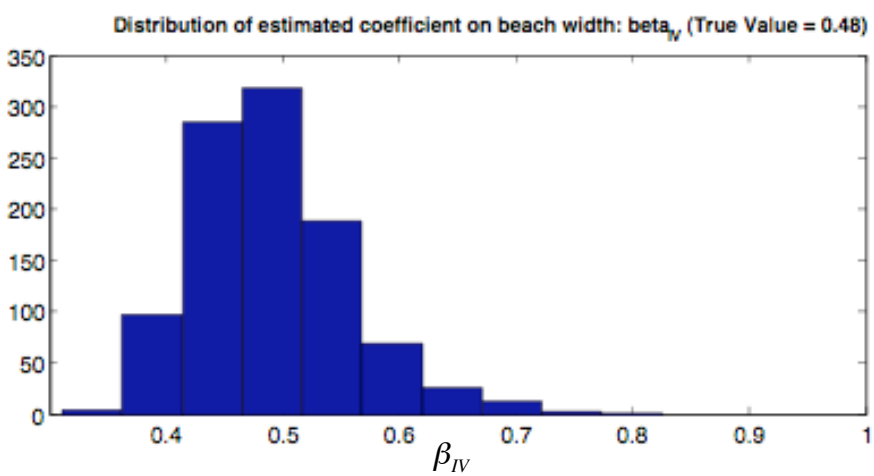


Figure 1: Study Region

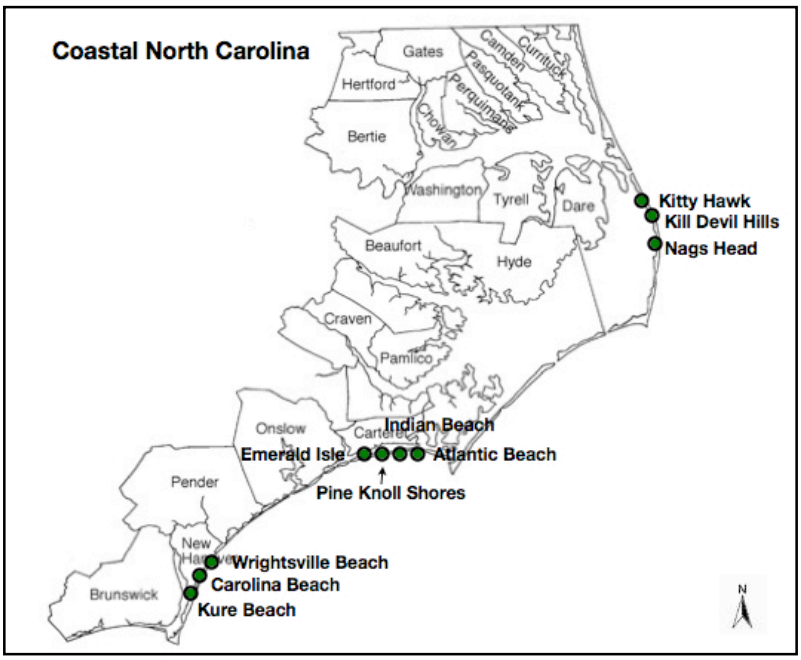


TABLE 1: Variable Description and Descriptive Statistics

Variable	Mean	Std. Dev.
Sale Price (in 1000s of 2004 $)	635.74	622.90
Age of Property	25.13	16.24
Month of Sale	24.49	10.69
(Dec '07 = 48; Jan '04 = 1)		
Built up area (in 100 sq ft)	32.53	44.03
Number of Bedrooms	3.36	1.66
Number of Bathrooms	2.70	1.53
Multi-Storied (=1 if # Stories > 1)	0.47	0.50
Distance from Ocean (in feet)	619.33	475.81
Property Type (=1 if Condo)	0.39	0.49
Beach Width (in feet)	98.10	27.51
Shells	0.10	0.27
Dunes	0.59	0.46
Scarps	0.27	0.45
Atlantic Beach	0.18	0.38
Carolina Beach	0.17	0.37
Emerald Isle	0.21	0.41
Indian Beach	0.03	0.18
Kill Devil Hills	0.03	0.18
Kitty Hawk	0.03	0.17
Kure Beach	0.09	0.28
Nags Head	0.10	0.30
Wrightsville Beach	0.10	0.30
Number of Observations = 1662		

TABLE 2:
Hedonic Pricing Model
Dependent Variable: ln(Inflation adjusted Sale Price)

	(1)	(2)	(3)	(4)
VARIABLES	OLS (Semi-log)	OLS (Double-log)	TSLS (Semi-log)	TSLS (Double-log) Robust SE
Built-up Area (100s sq ft)	0.004***	0.003***	0.005***	0.005***
	(-0.001)	(-0.001)	(-0.001)	(-0.001)
Number of Bedrooms	0.060***	0.063***	0.081***	0.087***
	(-0.022)	(-0.022)	(-0.018)	(-0.023)
Number of Bathrooms	0.145***	0.148***	0.125***	0.123***
	(-0.025)	(-0.025)	(-0.02)	(-0.027)
Multi-Storied	0.093***	0.112***	0.006	0.013
	(-0.036)	(-0.036)	(-0.036)	(-0.037)
Property Type (=1 if Condo)	-0.230***	-0.205***	-0.202***	-0.215***
	(-0.037)	(-0.037)	(-0.040)	(-0.043)
Age	-0.000	-0.001	-0.002*	-0.002
	(-0.001)	(-0.001)	(-0.001)	(-0.001)
Month of Sale (=1 if Jan 2004; = 48 if Dec 2007)	-0.000	-0.000	-0.001	-0.001
	(-0.001)	(-0.001)	(-0.001)	(-0.001)
Beach Width (Feet)	0.002***	0.190***	0.006**	0.485**
	(-0.001)	(-0.058)	(-0.003)	(-0.243)
Distance to Ocean (Feet)			-0.000***	-0.110***
			(-0.000)	(-0.02)
(Distance to ocean)x(Width)	-0.000***	-0.127***		
	(-0.000)	(-0.019)		
Dunes	-0.053	-0.044	0.089**	0.117**
	(-0.032)	(-0.033)	(-0.045)	(-0.055)
Shells	0.372***	0.406***	0.338***	0.319***
	(-0.066)	(-0.067)	(-0.086)	(-0.084)
Constant	11.95***	12.17***	11.63***	10.58***
	(-0.096)	(-0.27)	(-0.24)	(-1.057)

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

TABLE 2 (Cont.)– Location Fixed Effects and First Stage Regression Statistics

	(1)	(2)	(3)	(4)
VARIABLES	OLS (Semi-log)	OLS (Double-log)	TSLS (Semi-log)	TSLS (Double-log) Robust SE
Atlantic Beach			0.223**	0.217***
			(-0.088)	(-0.083)
Carolina Beach			0.12	0.050
			(-0.096)	(-0.096)
Emerald Isle			0.310***	0.309***
			(-0.083)	(-0.0721)
Indian Beach / Pine Knoll Shores			0.174	0.253*
			(-0.149)	(-0.143)
Kure Beach			0.248**	0.242**
			(-0.109)	(-0.112)
Nags Head			-0.321***	-0.286***
			(-0.085)	(-0.087)
Wrightsville Beach			0.562***	0.607***
			(-0.131)	(-0.128)
Nourish (=1 if ever nourished)	0.471***	0.452***		
	(-0.059)	(-0.059)		
Observations	1210	1210	1210	1210
R-squared	0.507	0.495	0.491	0.507
First Stage Partial R^2			0.06	0.05
First Stage F Statistic			34.82	51.6

*** p<0.01, ** p<0.05, * p<0.1

Robust standard errors in parentheses

DYNAMIC POLICY SIMULATIONS

Table 3: Parameter Values

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 $)
β		Hedonic Value of beach width

Table 4
Optimal Nourishment Interval (Years) for different Baseline Property Values and Hedonic Values of Beach width

	Baseline Property Values (Excluding value of beach width)												
	50	70	90	110	130	150	170	190	210	230	250	270	290
beta													
0.15	8.49	7.55	6.83	6.26	5.81	5.43	5.11	4.84	4.61	4.41	4.23	4.07	3.92
0.20	7.07	6.11	5.44	4.93	4.54	4.23	3.97	3.75	3.56	3.40	3.26	3.13	3.02
0.25	5.82	4.95	4.37	3.95	3.62	3.36	3.15	2.98	2.83	2.70	2.58	2.48	2.39
0.30	4.79	4.04	3.55	3.20	2.94	2.73	2.55	2.41	2.29	2.18	2.09	2.01	1.94
0.35	3.96	3.32	2.92	2.63	2.41	2.24	2.10	1.98	1.88	1.79	1.72	1.65	1.59
0.40	3.29	2.76	2.42	2.18	2.00	1.86	1.74	1.64	1.56	1.49	1.43	1.37	1.32
0.45	2.75	2.31	2.02	1.82	1.67	1.55	1.46	1.38	1.31	1.25	1.19	1.15	1.11
0.50	2.31	1.94	1.70	1.54	1.41	1.31	1.23	1.16	1.10	1.05	1.01	0.97	0.93
0.55	1.96	1.64	1.44	1.30	1.19	1.11	1.04	0.98	0.93	0.89	0.85	0.82	0.79

Table 5
Value Function for predicted Nourishment Interval (Scale: 1000 $)

	Baseline Property Values (Excluding value of beach width)												
	50	70	90	110	130	150	170	190	210	230	250	270	290
beta													
0.15	61	100	139	178	217	256	295	334	373	412	451	491	530
0.20	85	134	182	231	280	329	379	428	477	526	576	625	675
0.25	115	176	238	299	361	423	485	547	609	671	733	795	857
0.30	154	231	308	385	463	541	619	697	775	853	932	1010	1088
0.35	202	299	396	494	592	690	788	887	985	1084	1182	1281	1380
0.40	263	386	508	632	755	879	1002	1126	1250	1375	1499	1623	1747
0.45	341	495	650	805	961	1117	1273	1429	1585	1742	1898	2055	2211
0.50	439	634	829	1025	1221	1417	1614	1811	2007	2205	2402	2599	2797
0.55	563	809	1055	1302	1549	1796	2044	2292	2540	2789	3037	3286	3535

Table 6
Comparison of Predicted Optimal Rotation Length and Observed Nourishment Frequency

Description	Pooled	Atlantic Beach	Carolina Beach	Emerald Isle	Indian Beach /Pine Knoll Shores	Kure Beach	Wrightsville Beach	Outer Banks
Observations	1138	216	212	191	149	122	90	154
Mean Property Value (1000s of 2004 $)	472.20	337.95	353.26	482.88	438.45	544.12	676.48	672.36
Mean Predicted Value (TSLS)	469.60	322.35	337.40	468.36	410.58	543.56	723.44	713.73
Baseline Values 1 (w/o beach value) OLS Estimate	198.68	143.65	147.34	205.85	176.28	224.99	274.05	296.61
Baseline Values 2 (w/o beach value) TSLS Estimate	52.20	38.29	37.95	54.97	43.05	57.19	67.52	84.40
Mean Width	100.87	91.94	101.37	92.45	126.83	107.16	120.11	81.85
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 = 0.19)		4.53	4.48	3.78	4.09	3.61	3.26	
Optimal Rotation w/TSLS (beta = 0.48)		2.85	2.86	2.36	2.68	2.31	2.12	

Table 7
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

7A: Baseline Property Value = 40000 (Carolina Beach

Gamma =	2	2.5	3	3.5	4	4.5	5	5.5	6
phi = 0.3	0.0	1.3	2.5	3.7	4.9	6.1	7.2	8.4	9.5
phi = 0.45	4.4	6.1	7.8	9.4	11.0	12.6	14.2	15.8	17.3
phi = 0.6	8.8	10.9	13.0	15.1	17.1	19.2	21.2	23.2	25.1
phi = 0.75	13.2	15.8	18.3	20.8	23.2	25.7	28.1	30.5	32.9
phi = 0.90	17.6	20.6	23.5	26.5	29.4	32.2	35.1	37.9	40.7
phi = 1.05	22.0	25.4	28.8	32.2	35.5	38.8	42.0	45.3	48.5
phi = 1.2	26.4	30.3	34.1	37.8	41.6	45.3	49.0	52.6	56.3

7B: Baseline Property Value = 60000 (Emerald Isle)

Gamma =	2	2.5	3	3.5	4	4.5	5	5.5	6
phi = 0.3	0.0	0.8	1.7	2.5	3.3	4.1	4.9	5.6	6.4
phi = 0.45	2.8	3.9	5.0	6.1	7.2	8.2	9.3	10.3	11.4
phi = 0.6	5.6	7.0	8.4	9.7	11.1	12.4	13.7	15.0	16.3
phi = 0.75	8.4	10.1	11.7	13.4	15.0	16.6	18.1	19.7	21.3
phi = 0.90	11.2	13.2	15.1	17.0	18.9	20.7	22.6	24.4	26.2
phi = 1.05	14.0	16.3	18.4	20.6	22.7	24.9	27.0	29.1	31.2
phi = 1.2	16.9	19.3	21.8	24.2	26.6	29.0	31.4	33.8	36.1

7C: Baseline Property Value = 70000 (Wrightsville Beach)

Gamma =	2	2.5	3	3.5	4	4.5	5	5.5	6
phi = 0.3	0.0	0.7	1.5	2.2	2.9	3.5	4.2	4.9	5.5
phi = 0.45	2.4	3.3	4.3	5.2	6.1	7.1	8.0	8.8	9.7
phi = 0.6	4.8	5.9	7.1	8.3	9.4	10.6	11.7	12.8	13.9
phi = 0.75	7.1	8.6	10.0	11.3	12.7	14.1	15.4	16.8	18.1
phi = 0.90	9.5	11.2	12.8	14.4	16.0	17.6	19.2	20.7	22.3
phi = 1.05	11.9	13.8	15.6	17.5	19.3	21.1	22.9	24.7	26.5
phi = 1.2	14.3	16.4	18.5	20.5	22.6	24.6	26.6	28.7	30.7