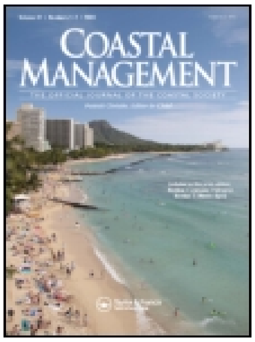

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Measuring the Cost of Beach Retreat

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We estimate the cost over the next 50 years of allowing Delaware's ocean beaches to retreat inland. Since most of the costs are expected to be land and capital loss, especially in housing, we focus our attention on measuring that value. We use a hedonic price regression to estimate the value of land and structures in the region using a data set on recent housing sales. Then, using historical rates of erosion along the coast and an inventory of all housing and commercial structures in the threatened coastal area, we predict the value of the land and capital loss assuming that beaches migrate inland at these historic rates. We purge the losses of any amenity values due to proximity to the coast, because these are merely transferred to properties further inland. If erosion rates remain at historic levels, our estimate of the cost of retreat over the next 50 years in present value terms is about $291 million (2000$). The number rises if we assume higher rates of erosion. We compare these estimates to the current costs of nourishing beaches and conclude that nourishment make economic sense, at least over this time period.

Keywords beach, economics, retreat

Introduction

Coastal communities have three basic strategies for managing beach erosion: nourishment, hard structures, and retreat. Nourishment replaces lost sand periodically with sand from another source. Hard structures are engineering solutions such as bulkheads, groin fields, and offshore breakwaters. Retreat means removing houses, stores, boardwalks, and infrastructure as a matter of policy, thus, allowing a beach to migrate inland naturally. Mixes of these strategies are also possible, such as nourishment and groin fields used simultaneously.

Each strategy is costly. With nourishment, society incurs the labor, capital, and raw material cost of importing and placing sand on the beach. The cost is almost always

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reoccurring as the imported sand is itself someday washed away. With hard structures, society has the construction cost (labor, capital, and raw materials) and maintenance cost of keeping these structures effective. Again, the cost is reoccurring. Finally, with retreat, society has a loss of land, a loss of housing and commercial services if present, and even a loss of proximity by structures that would otherwise have been located near the coast.

Which of these strategies is least costly for a given coastal community is an empirical question and is certain to vary from one beach to the next. Retreat, for example, is an obvious pick for a natural coastline with few or no housing and commercial structures. Hard structures, on the other hand, may make sense for a densely developed waterfront in an urban area.

Delaware, for the most part, has adopted a strategy of nourishment for its ocean beaches. The state has been nourishing portions of its 25 miles of beaches for several decades (see Figure 1 for a map of Delaware and its ocean beaches). Over the past 10 years, that has come at an approximate cost of $15 to $20 million (2000$). Some, including a past governor of the state, have questioned whether this policy makes economic sense and have suggested that the state consider beach retreat as a possible long-run strategy. Many view it as simply a matter of time before such a policy is adopted.[1]

In this article we estimate the economic costs of beach retreat for the state of Delaware over the next 50 years. If the retreat option is to receive serious consideration and be done in a rational way, the cost of retreat must be compared with the cost of other options. While the state compiles estimates of its nourishment and occasional hard structure costs, there is limited information on retreat costs. We present some estimates here and compare them with current estimates of nourishment costs.

In the next section, we present a discussion of retreat costs, defining in economic terms what they entail. We subsequently present our method for estimating the cost, the assumptions we have made to arrive at our estimates, and the data set we use. We then present the results, and we close with a summary and general discussion.

The Economic Losses due to Beach Retreat

Throughout our discussion of beach retreat the counterfactual is a stable beach. That is, the baseline against which we estimate the retreat cost is a beach identical to the Delaware coastline in every respect except that it is stable, undergoing seasonal change but largely maintaining its location and width over the next half century. For this reason our estimates may be viewed as the cost of sea rise to Delaware coastal communities should they adopt a strategy of retreat.[2] Our analysis extends over 50 years.

We follow a method similar to that developed by Yohe (1989). Using sea rise projections and data on the density and value of development on Long Island Beach, New Jersey, he estimated the economic loss of sea rise to the year 2100. He provided national estimates using the same methodology in Yohe (1990). Our method uses the same reasoning but employs a more disaggregated or micro data set. Yohe's unit of observation is an aggregate measure of development over a 500 m^2 block, while ours is an individual structure (a house or business). Also, where Yohe uses tax record data (corrected for inflation and adjusted for percentage of market value used by assessors), we use market-based data directly.

We group the costs of retreat into four categories: *land loss, capital loss (structures), proximity loss,* and *transition loss*. As sea level rises, a beach migrates inland under a policy of retreat and productive land is lost. The difference between the value of that land today in the absence of beach migration and the value of that land today in the presence of beach migration is our first economic loss (land loss). Interestingly, from an

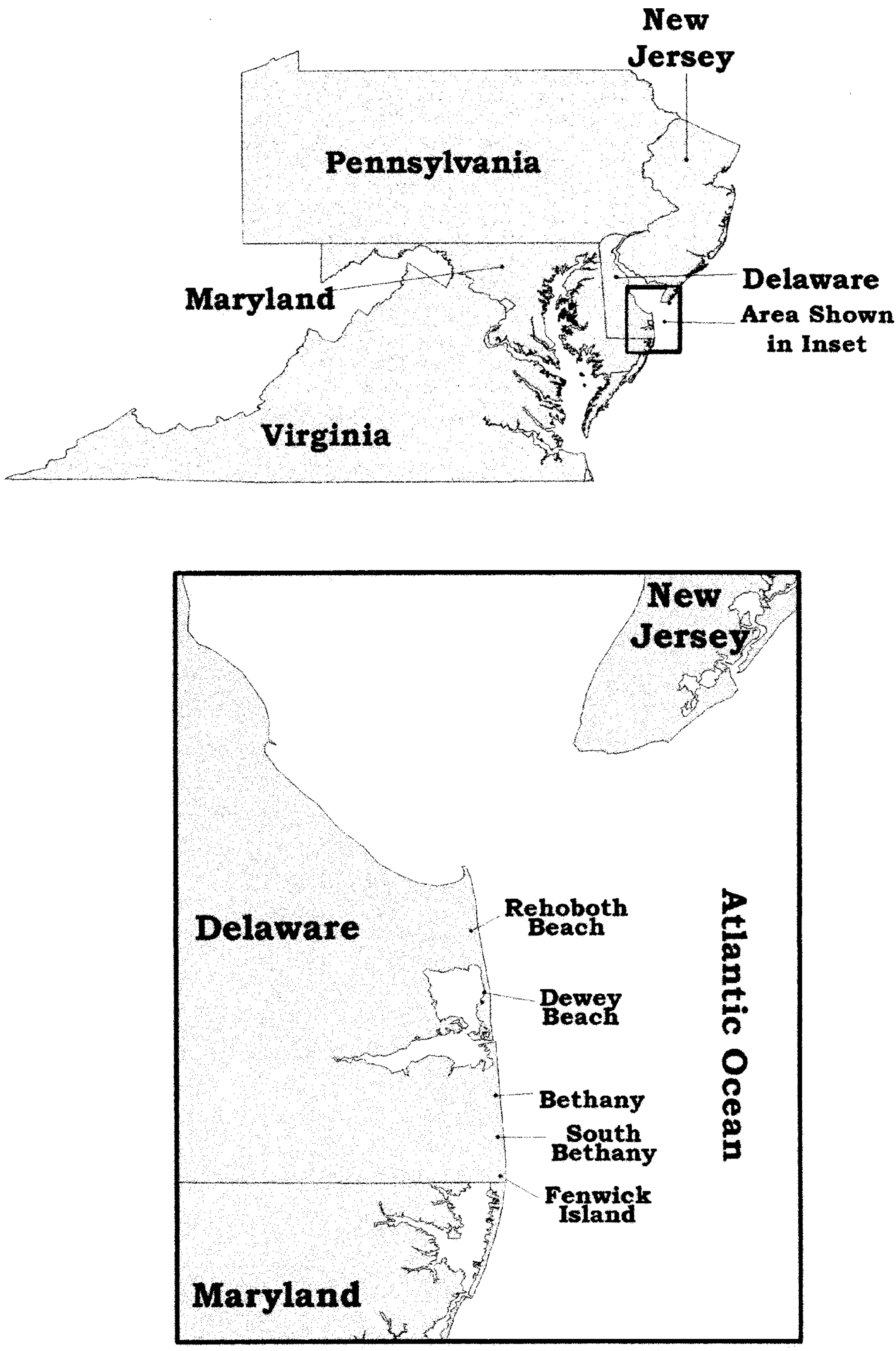

Figure 1. Map of Delaware and its beaches.

economic perspective, the lost land is not acreage at the beachfront; rather, it is inland acreage. The reasoning is simply that as the beach migrates inland, there will always be beachfront land. Total acreage, however, is reduced by the extent of the migration. This effect is quite noticeable on a small island country with a migrating beach; the beach is never lost, but the amount of useable inland land steadily shrinks.

To the extent that beachfront structures are lost, removed from the shoreline as the beach migrates inland, this constitutes the second economic loss (capital loss). The difference between the value of these structures today in the absence of beach migration and the value of these structures in the presence of migration is the capital loss. These structures include housing, commercial buildings, and public infrastructure such as boardwalks and parking lots. The difference is not merely the value of the structure over the years after it is lost. It should account also for any adjustment in use and maintenance in the interim years that serves to alleviate some of the loss.

If a coastal community adopts a strategy of beach retreat it is apt to realize a different pattern of future development along its coast. There will be less development near the beach and greater development further from the beach. To increase the longevity of a structure people build houses further from the beachfront. How far will depend on preferences for proximity versus housing longevity. A community that values proximity less will develop long-lived structures far from the beach. A community that values proximity highly will develop short-lived (and perhaps mobile) structures near the beach. In either case there is a welfare loss associated with the loss of proximity that new structures would enjoy if the beach were stable. This is our third economic loss (proximity loss).

In our scenarios, we assume that all housing and commercial structures are removed as the beach moves inland and that the beach itself is maintained as a recreation site. The labor, capital, and raw materials used in removal are economic losses associated with retreat (transition loss). This loss includes the cost of the removal of the structure itself as well as its foundation, posts, roadways, and any public infrastructure such as pipes, public roadways, power and phone lines, and so forth. It is worth noting that relocation of structures in some circumstances may be the optimal (least costly) response. In this case, the economic loss is not lost structures and cost of removal; instead, it is the cost of relocating structures. To the extent that removal of structures is the responsibility of the owner of the structure, we would expect it to be included (capitalized) in the value of the structure in the presence of beach retreat, in effect reducing that value.

Finally, while there may be an inclination to add recreation losses to our list of retreat costs, this is incorrect. We assume that the basic characteristics of the beach in our counterfactual are the same as the beaches in our retreat strategy. The beach merely changes its location, moving inland. We assume there are no changes in the recreation use of the beach, or at least that the differences are minor.

Measurement and Method

The vast majority of developed land in coastal Delaware is residential housing. For this reason, our focus is on the residential land and housing market. In our judgment, this is far and away where most of the losses would be if a retreat strategy were actually adopted. Public infrastructure losses and proximity losses are likely to be a small fraction of the total over the next 50 years.

The economic loss associated with losing a parcel of coastal property in year t due to retreat is

$$W = \{A_{\text{without}} - A_{\text{with},t} + d_t - a_t\},$$

where A_{without} = the asset value of the coastal property today in the absence of beach retreat (without case), $A_{\text{with},t}$ = the asset value of the coastal property today in the presence of beach retreat and assuming the property would be lost in year t (with case), d_t = the present value of dismantling the structure in year t (assuming it is not capitalized into $A_{\text{with},t}$), and a_t = the amenity value transferred to neighboring inland land in year t.

For example, consider a house that would be lost in the first year of a beach retreat strategy. All of the structural and land services of that piece of property would be lost immediately. In this case $A_{\text{with},t} = 0$. That is, the value of the property (land loss and structural loss) with retreat is zero. Asset theory tells us that the value of that property is just the present value of the expected services of the land and structure in a world without retreat (with a stable beach). Since the beaches along the coast of Delaware have been protected for several decades and there would appear to be every reason to expect that to continue (despite speculation to the contrary by this study), we assume that current market value for the property is a good proxy for A_{without}. So, the lost land and structure value is $A_{\text{without}} - 0$, which is just the current market value of the house and its land. From this value we need to subtract the amenity or proximity value of property (a_t). This value is merely passed to the next closest property to the shore.[3] Again, inland, not coastal, land is lost. Finally, we add the cost of demolition and removal of the house (d_t) to the total loss, assuming it is not capitalized into our measure of $A_{\text{with},t}$.

For another example, consider a house further inland lost several years from now in year t. In this case $A_{\text{with},t}$ is the asset value of that property knowing that the property will be removed in year t. If the market (owners of the property) make no adjustment whatsoever to account for the impending future loss, $A_{\text{with},t}$ is just the value of the housing services from year 0 to t, the same housing services realized over that period if beaches were believed to be stable. The loss due to retreat then is just the present value

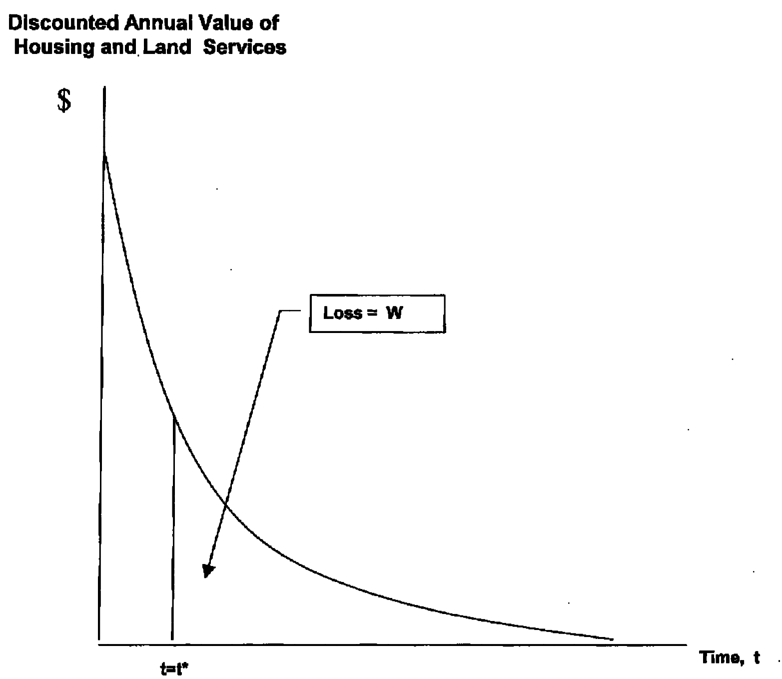

Figure 2. Annual housing and land services over time.

of the housing services from year t onward. Figure 2 shows the net annual value of the property (land and structures) over time. The loss due to retreat in this case is just the area under the curve to the right of t^*. Understandably, the further into the future the removal date is, the lower the loss. Again, amenity values must be purged from the calculation and dismantling cost added.

If the market adjusts for the impending future loss, the actual losses will be somewhat lower. Property owners will now cancel or downgrade improvements which otherwise might have been made to the properties. Public infrastructure supporting the houses would be in decline as well. This suggests that there would be some loss in the quality of housing services over the period 0 to t. The stock of housing is now poorer than in the case with a stable beach. On the other hand, the investment once made during the period 0 to t to improve housing is now devoted to other purposes, and those returns, albeit lower than the returns one could have earned on a house with a stable beachfront, are realized. These returns must be more than the interim decline in housing services or otherwise would not have been made. The net result is an expected loss lower than that reported in Figure 2. We write the loss accounting for such adjustment as

$$W' = \{A_{\text{without}} - A'_{\text{with},t} + d_t - a_t\},$$

where $A'_{\text{with},t}$ is the with-retreat case accounting for adjustment and therefore some nonhousing returns to investment. Note that $A'_{\text{with},t} > A_{\text{with},t}$, so $W' < W$.

We measure W, not W', in this article. We use a hedonic price regression on recent housing transactions along the coastline in Delaware and an inventory of housing structures along the coast that are likely to be affected by retreat over the next 50 years. In a hedonic price regression of housing one regresses the sale price of houses on the characteristics of houses such as size, age, number of bathrooms, and distance to desirable and undesirable features such as beaches and shopping areas. The estimated regression predicts the relative importance of each characteristic in determining the price of the house. Indeed, the coefficient on a characteristic in a linear hedonic price regression is interpreted as an implicit price for that characteristic in the market. For more on the application of hedonic price analysis, see Palmquist (1991) or Freeman (1993). The analysis is done in three steps.

First, a hedonic price regression is estimated over the houses recently sold in the area. The hedonic includes the usual set of housing characteristics as well as measures of proximity to the beach, such as frontage and feet away from the water at high tide. Second, using estimates of the average rate of erosion for seven different beach communities along the coast, we approximate the expected location of the beach in the absence of existing policies which attempt to hold the beach in place. Using that information, we predict which specific houses in our inventory would be lost to make way for retreat. We do this on a decade-by-decade basis. Third, for each house in the inventory that is lost, we predict the value of that house using the hedonic price regression. Our inventory has measures of the same set of characteristics as the houses used in the hedonic price regression. We purge from that predicted value any coastal amenity value the property has captured in the frontage and distance variables. We also purge from that value an estimate of depreciation obtained in the regression. Finally, we add our estimate of removing a house from the coastal area. The net value is then discounted to the present.[4]

This is a measure of W, not W', because the analysis presumes that the asset value of the house in year t when it is lost (designated area in Figure 2) is the same value that house would have in the absence of a retreat policy. So, it presumes no adjustment and therefore overstates retreat cost. The overstatement is larger in the later decades since more time to adjust interim investment in housing is possible.

The other components of lost value due to retreat are small relative to the loss of housing and land services. We have a rough estimate for commercial structures which approximates losses using the cost of construction. With respect to lost infrastructure, we believe much of this will be capitalized into the value of the housing structures themselves and hence be captured in our analysis. For example, utilities, quality of access, and so forth will be captured in land markets and hence revealed in our housing values. However, not all public infrastructure will be capitalized. For example, roadways and boardwalks are enjoyed by nonresidents taking day-trips whose values will not bid up housing cost and be captured in land markets. With respect to proximity losses, we miss these altogether, but given the available space near the coast and the proclivity for new development directly in the near coastal area even without retreat, we believe that these losses are also small. We also miss any impacts realized on the bay side of the barrier island and any impact on the natural environment (e.g., wetlands) caused by migration.

Data, Estimation Results, and Discussion of Findings

The hedonic price regression is reported in Table 1. It is estimated over 266 housing transactions observed during the period 1991 to 1992. The variable definitions are given in Table 2. We use the natural log of price as the dependent variable, giving our hedonic the common semilog form. The price we used is the actual transaction price recorded at the time of sale. We use a set of structural housing characteristics commonly found in hedonic regressions: square footage, number of baths, presence of fireplace, presence of garage, and presence of air conditioning. Our locational characteristics in-

Table 1
Hedonic price regression

Variable	Coefficient	T-statistic
INTERCEPT	4.090	11.762
BETHANY	–0.281	–6.368
SBETH/SEACOL	–0.535	–8.410
NBETH	–0.248	–3.300
FENWICK	–0.311	–2.698
DEWEY	–0.350	–7.318
OCEANFRONT	0.435	6.133
BAYFRONT	0.076	1.153
CANALFRONT	0.231	2.775
SQFT	0.210	4.226
FIRE	0.112	3.872
CAR	0.058	0.855
DIST	–0.004	–12.299
BATH	0.115	5.059
AGE	–0.011	–4.083
n = 266		
R^2 = .76		
Dep. Var. Mean - 5.28		

Table 2
Variable definitions

FENWICK, SBETH/SECOL, BETHANY, NBETH, DEWEY, REHOBOTH	1 if unit is located in the designated community, 0 otherwise
OCEANFRONT	1 if oceanfront property, 0 otherwise
BAYFRONT	1 if bayfront property, 0 otherwise
CANALFRONT	1 if canalfront property, 0 otherwise
SQFT	Square feet of living space in the structure
FIRE	1 if unit has a fireplace, 0 otherwise
CAR	Garage space. 0 = none, 1 = one car, 2 = two car, etc.
DIST	Distance from the beach at mean high tide; 1 = 25 feet, 2 = 50 feet, 3 = 75 feet, and so on
BATH	Number of bathrooms
AGE	Age of the structure, in years

clude a set of seven dummy variables for the different beach communities in coastal Delaware, a measure of the distance a house is located from the beach, and a set of dummy variables indicating whether the house has ocean, bay, or canal frontage.

The structural characteristic data are from the property record files maintained by the Sussex County Delaware Tax Assessment Office. The location of each property was cross-referenced with aerial photographs taken in the beach communities and verified individually on-site. Using this information we measured the distance to the beach and frontage (yes or no) for all properties.

The coefficient estimates reported in Table 1 are for the most part significant and in all cases have the expected signs. Ocean, bay, and canal frontage have a large effect on property values, as expected. For example, a $300,000 house with ocean frontage can attribute nearly $132,000 of its value to having that frontage. Bay frontage would contribute $24,000 to a $300,000 house, and canal frontage, $63,000. Distance from the ocean coast was statistically the most significant variable in our regression. Each 25 feet from the coast for a house inside a half-mile from the beach is worth about $1200 for a $300,000 house. These amenity values are reasonable and in line with past coastal studies.[5] Recall that these values are particularly important in our application. We purge them from the value of the lost property when a house is removed due to retreat.

The coefficient estimates on the structural attributes for fireplace, garage, number of baths, and square footage are all positive and significant. The implicit prices of each, once again, are in line with research in the hedonics literature. The coefficient on fireplace is rather large, suggesting that a fireplace contributes $33,000 to a home worth $300,000. Fireplace appears to be a proxy for a variety of structural attributes excluded from the regression and correlated with the presence of a fireplace, probably signaling a somewhat more upscale housing unit.[6]

An obvious explanatory variable missing from our regression is lot size. It was missing and measured with inaccuracy at so many sites in the data set that we choose to drop it instead of reducing our sample size. Furthermore, the housing inventory had fewer than half of the houses reporting lot size. We assume that square footage and perhaps fireplace is picking up the effect of lot size.

We use the coefficient on age of the house to depreciate the housing unit over time in our analysis, so accuracy in that estimate is also important. Here, we found a negative and significant coefficient, as expected. All else constant, the value of a house declines about 1% for each year of age in our data set.

The coefficients on the community dummies allow us to control for variation across the different coastal towns that is not accounted for in our attribute list. The excluded community in our regression is Rehoboth, so the coefficients are interpreted relative to that town. As shown, houses in Rehoboth, all else constant, have a higher value. This was expected. South Bethany and Dewey had the lowest values, controlling for other characteristics.

The hedonic price function is used to simulate the land and capital (structures) loss as described in the previous section. In addition to our data on housing transactions (n = 266), we also have a data set on housing structures in Delaware in the near coastal area (n = 1824). For that inventory of houses we have exactly the same characteristic data used in our hedonic regression. That enables to us to simulate the losses due to retreat using the hedonic price regression as a predictor of loss property values. The mechanics of our simulation model work as follows.

The model simulates beach migration using a specified erosion rate. We assume that the beach would migrate at approximately the specified erosion rate under a policy of retreat. The simulation program marks how far inland the beach moves each decade using these rates. After marking the distance moved in a decade, the program then identifies all structures that must be removed to make way for the beachfront in that decade. Then, using the hedonic price function estimated above, the program predicts the value of each lost property in the inventory of coastal houses.[7] The predicted value from that regression is inflated to 2000$.[8] In that prediction equation, we assume each lost house has no ocean frontage (OCEANFRONT = 0 in the prediction equation) and that it is located 600 feet from the coast (DIST = 24). This accounts for our amenity transfer.

The results are shown in Table 3 for the entire coastline. We present the losses under different assumptions for the rate of erosion, ranging from 1 ft/yr to 8 ft/yr. In all

Table 3

Present value of losses due to retreat in millions of dollars (2000$), discount rate = 3%

Decade	Historic	1 ft/yr	2 ft/yr	3 ft/yr	4ft/yr	5 ft/yr	8 ft/yr
2000–2009	43.30	0	0	43.30	43.30	73.17	361.39
2010–2019	29.89	0	32.21	22.23	236.69	281.56	142.50
2020–2029	139.41	23.97	16.54	159.58	49.93	56.10	61.67
2030–2039	49.60	0	118.75	37.15	41.74	31.65	52.33
2040–2049	29.24	9.16	27.64	31.07	23.54	41.97	54.50
Total							
2000–2049	291.45	33.13	195.14	293.32	395.22	466.86	672.18
2000–2999	318.57	49.16	214.23	320.24	432.97	518.57	722.45

cases we use a real discount rate of 3% and present the numbers in 2000$. The losses are quite sensitive to the assumed rate of erosion, reflecting the density of development along the coast. At the lowest rate of erosion (1 ft/yr) the present value of the losses is $33 million. At the highest rate (8 ft/yr) the loss is $622 million. Neither of these extremes is likely. We also presented estimates of the losses in Table 3 based strictly on historic rates of erosion for each community. Using these rates for each community, we get the losses reported in the column titled "Historic." That estimate is $291 million. All of these numbers include an estimate of the loss of commercial structures using Marshall and Swift's property appraisal method. While less than ideal, it gives a value relative to housing losses that seems plausible. The estimate also includes transition loss, which is largely the dismantling of structures as the beach moves inland. Here we simply use $25,000 per structure based on information provided in discussions with a number of local businesses. Commercial structures and transition losses account for about 15% of the total loss.

Table 4 shows how the losses are distributed across the different communities. Over 75% of the loss is concentrated on the southern beaches, those south of the Delaware Seashore State Park. These include North Bethany, Bethany, South Bethany, Sea Colony, and Fenwick Island. (See the map in Figure 1.) This result is not surprising. Erosion rates are higher and houses are closer to the beach in the south. It is also worth noting that most of the costs are incurred in the second decade, assuming historic rates of erosion. This reflects both the pattern of development along the coast and discounting.

To see the effect of discounting on our estimates we conducted a sensitivity analysis over the discount rate for the "Historic" scenario. Over the next 50 years the estimated losses at discount rates of 1%, 3%, and 5% are $439 million, $291 million, and $204 million. As usual the choice of discount rate has a sizable effect on the cost estimates.

Much of the literature on the effects of sea rise on coastal communities projects losses to the year 2100. For this reason, Table 3 also includes estimates over the period 2000–2099 along with our projection over 2000–2049. In our "Historic" scenario the losses over the next hundred years at discount rates of 1%, 3%, and 5% are $549 million, $319 million, and $212 million. The effects of discounting are evident in the much lower numbers for losses over the second half of the century.

Finally, it is natural to inquire how the cost of retreat compares with the cost of

Table 4
Present value of losses by community in millions of dollars (2000$), 2000–2049, discount rate = 3%

	Historic	1 ft/yr	2 ft/yr	3 ft/yr	4ft/yr	5 ft/yr	8 ft/yr
Fenwick Island	29.71	.72	17.70	29.71	40.85	53.51	79.49
South Bethany	43.71	17.80	31.95	43.71	52.33	64.03	81.03
Sea Colony	95.44	0	71.02	95.44	128.27	128.27	172.38
Bethany	24.89	8.12	16.15	24.89	29.78	38.27	53.04
North Bethany	44.59	2.54	23.98	44.59	61.32	78.44	119.93
Dewey	33.34	3.94	14.55	24.25	33.34	45.55	72.10
Rehoboth	19.78	0	19.78	30.72	49.35	58.81	94.22

other beach management strategies. In Delaware, the current practice is beach nourishment. Nourishment cost currently runs at about \$15–20 million per decade (2000\$). It is difficult to judge how much these costs will rise in real terms. With accelerated sea rise there is likely to be some increase. On the other hand, this may be offset somewhat by technological advance. Take the higher end of the nourishment cost estimates (\$20 million/decade) and assume that the costs remain fairly stable. The present value of \$20 million dollars occurring in each of the next five decades gives a present value cost of \$60 million (2000\$)—the cost of maintaining Delaware's beaches in their current state for the next half century.[9] This is substantially below the retreat estimates for the same period assuming historic rates or erosion. Nourishment cost would have to increase by a factor of more than 4 before the nourishment option looks feasible in this model over the next 50 years.

Conclusions

We have suggested a methodology for measuring retreat losses based on a more disaggregated unit of observation than existing studies in the literature and have relied on market-based data for the largest portion of losses in our application. Using this methodology we estimate the cost of beach retreat in Delaware over the next 50 years to be about \$291 million in present value (2000\$). These costs are estimated assuming that

- the beach migrates inland at current rates of erosion;
- adjustment made by households to the existing stock of houses in this time frame are not likely to alleviate much of the cost;
- proximity losses, public infrastructure losses, and other land asset losses such as the services of lost wetlands are small in comparison to the land and housing service losses;
- current housing markets are good proxies for the future value of lost housing services on the coast;
- recreation uses of the beaches are the same under retreat or nourishment policies.

While we believe that these are fairly reasonable assumptions in our setting, caution is warranted. The configuration of the migrating beach may change in unexpected ways, giving rise to recreation losses or gains; adjustments made by households in response to retreat may exceed our expectations; erosion rates may change; and the statistical accuracy of the hedonic may or may not hold up upon replication. Furthermore, and not surprisingly, we found the estimated loss to be extremely sensitive to the rate of erosion used in our model. If low rates are assumed (1 ft/yr) the losses are as low as \$33 million. At higher rates (8 ft/yr) the losses reach \$672 million. The estimates are far from being the final word and, as always, skepticism of the assumptions is warranted.

Also note that the methodology works in the state of Delaware because most of the costs of retreat are concentrated on the housing and land markets. This allows us to use a hedonic price simulation model to estimate what we expect will be the lion's share of the total retreat costs. The methodology is transferable to other settings but the numbers are not. The numbers in other regions will depend on the density of housing, specifics of that housing market, and the rate of erosion. Furthermore, to the extent that other coastal regions have losses concentrated over commercial structures, public infrastructure, or wetlands, our method will provide limited coverage of the full losses.

Notes

1. The practical feasibility of a retreat policy is a matter worth noting. Does the state compensate owners for the removed structures? Who pays for the dismantling? How is the periodic

retreat line set? How are existing land use rules integrated with such a policy? Needless to say, it raises some rather thorny issues. See Titus (1998) for a discussion of some of these and other related issues.

2. For excellent discussions of the impacts of sea rise on coastal resources, economic and otherwise, see Neumann et al. (2000) and Yohe, Neumann, and Marshall (1999). Also, see Cline (1992) for a broader look at the effects of climate change and Edwards (1987) for a entirely different method to measure losses.

3. Strictly speaking, the amenity may not be fully or exactly passed back to the next residence. The density and type of housing may differ or there may instead be a crossroad or marsh behind the just lost residence. Development along the Delaware coast is uniform enough to make this assumption reasonable, but it is far from ideal.

4. Our retreat cost model assumes, at least implicitly, that the beach migrates inland at a steady pace. In reality, migration would not follow a steady pattern of retreat. Instead, we would expect large discrete movements inland following major storms and would expect little or no migration during calmer years. In this sense, our estimates are capturing something like expected values of retreat and have not dealt with risk preferences in any way. If retreat occurs in jumps dictated by uncertain storm events, property values would also capture a risk premium, reflecting the uncertainty of the coming retreat date. We experimented with a simulation that allowed for large discrete jumps using storm probabilities along with our erosion rates and then repeating these estimates to arrive at expected values. It had little affect on our estimates, so we stayed with the simplest model.

5. For some examples of coastal hedonic studies, see Pompe and Rinehart (1994), Milon, Gressel, and Mulkey (1984), Parsons and Wu (1991), and Edwards and Anderson (1984).

6. The coefficient on square footage is a bit smaller than expected. It implies that doubling footage increases the price of a house by 21%. At first blush this may seem unrealistic, but it must be kept in mind that the coefficient implicitly holds the number of bathrooms (a proxy for total rooms) fixed. Increasing size while holding number of rooms constant is entirely different than increasing size while adding rooms and other features. Furthermore, housing configurations that double or increase housing size in a significant way without commensurate changes to other attributes is almost certain to predict outside the range of observable data. In our application, there is no such projection.

7. The loss estimate is likely to be understated somewhat due to the availability of federal flood insurance in this area. To the extent that subsidized premiums are capitalized into housing prices, the true market value of the properties will be understated.

8. We created a simple index: the average sale price of houses sold in the coastal area in 2000 divided by the same for 1991–1992. That gave us a value of 1.639 for inflating the 1991–1992 predicted values to 2000 dollars.

9. This assumes that the costs are incurred at the beginning of each decade, consistent with our retreat cost estimates.

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