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Beach nourishment as a dynamic capital accumulation problem

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ABSTRACT

Beach nourishment is a common coastal management strategy used to combat erosion along sandy coastlines. It involves building out a beach with sand dredged from another location. This paper develops a positive model of beach nourishment and generates testable hypotheses about how the frequency of nourishment responds to property values, project costs, erosion rates, and discounting. By treating the decision to nourish as a dynamic capital accumulation problem, the model produces new insights about coupled economic geomorphological systems. In particular, determining whether the frequency of nourishment increases in response to physical and economic forces depends on whether the decay rate of nourishment sand exceeds the discount rate.

1. Introduction

Most US coastlines are either moderately or severely eroding [14,22]. Both wave-driven alongshore sediment transport and sea-level rise contribute to coastal erosion, and climate change is likely to intensify both of these forces [30]. At the same time, more humans are living in the coastal zone [16,31]. Cost estimates of avoiding inundation from a 1 m rise in sea level are between $270 billion and $475 billion [32]. A recent Heinz report suggests that over the next 60 years, erosion will affect 25% of US structures within 500 ft of the coastline, and the lost property value without any further build-out on vacant lots would be between $3.3 billion and $4.8 billion [14]. These estimates reflect diminished property values from erosion without accounting for any potential damages to structures or lost recreational amenities that are not fully capitalized into land values.

Trends in the coastal zone point to an inevitable conflict between coastal developments and an encroaching shoreline. As coastal erosion takes place, residential and commercial properties as well as coastal infrastructure are threatened. Humans can, and do, intervene in the coastal zone to defend against shoreline changes. To address erosion, coastal managers and engineers can pursue beach nourishment,[1] build hard structures like sea walls, or simply move or abandon coastal property [17,25].

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[1] Nourishment is also referred to as re-nourishment or replenishment to reflect the need for repeated applications of sand if this strategy is pursued.

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Increasingly, communities are relying on beach nourishment to hold back the sea. Beach nourishment is the practice of building out a beach with sand that has been dredged from another location [6]. It is a common beach management strategy in the United States for sandy coastlines along the Atlantic coast and in the Gulf of Mexico [33,34]. At least $2.5 billion ($2002) was spent on nourishment projects between 1950 and 2002 in the US, and the frequency of nourishment has increased dramatically in recent years with federal appropriations of $787 million from 1995 to 2002 [23]. Beach nourishment only defends the shoreline temporarily and must be re-done periodically [24]. In this paper, we develop a model that explains this Sisyphean pattern and suggests what we might expect to see in the future if sea-level continues to rise and beach erosion accelerates.

We specifically develop a capital-theoretic model of a representative community that decides how often to nourish its beach. We adapt a Faustmann–Hartman model from the rotational forestry literature to characterize the continuous flow of amenities from beaches and the periodic nature of beach nourishment interventions [9,13]. As in Faustmann, the choice of nourishment frequency depends on balancing the marginal net benefits (*NB*) of a single rotation with the interest lost from delaying all future rotations.

Our model effectively endogenizes the depreciation rate of natural beach capital because nourishment changes the short-run morphodynamics of the beach. The model generates both expected and surprising predictions. Specifically, we find that communities will nourish more often if (1) the baseline property values are higher, (2) un-nourished beaches erode faster, (3) the hedonic price of beach width is higher, (4) fixed costs of nourishment are lower, or (5) the discount rate is higher. However, a higher variable cost of nourishment sand could result in increased or decreased frequency of beach nourishment. It is thus possible that the input demand for nourishment sand could slope upwards. This result is particularly striking in light of the scarcity of nourishment-quality sand and the possibility of greater scarcity in the future [10,15,27]. Similarly, a higher decay rate of nourishment sand could lead to higher or lower rates of nourishment. These latter results lead to new insights about linked economic and geomorphological models. Signing the change in nourishment frequency hinges on whether the rate of foregone interest (financial capital depreciation) exceeds the rate of sand loss (natural capital depreciation).

2. Background

Beaches provide economic value through storm protection and amenity flows, and the economic literature has focused on quantifying these values. While hedonic models reflect storm risks generally [12], some studies specifically show that threats from coastal erosion are capitalized into housing values [7,18]. Amenity flows can also be capitalized into housing prices; hedonic studies consistently find a positive price for coastal properties being on the waterfront, in close proximity to water, or having a view of the water [2–4,20,25]. In addition, there is empirical support that beach width has a positive hedonic price [20,21,28], which could reflect a combination of amenity and storm protection values. Nevertheless, not all amenity flows are capitalized directly into beachfront properties. Recreation demand studies find positive values for beach trip days using revealed preference [2,3] and stated preference methods [20].[2] Thus, beach communities have an incentive to preserve beach quality and width to support local tourism.

Several economic studies conduct normative analyses of coastal management strategies. Edwards and Gable [8] compare amenity values from a hedonic model to costs of periodic beach nourishment and find support for the efficiency of beach nourishment. Yohe et al. [36] formulate a dynamic model to ask how long coastal communities should defend against sea-level rise with an application to Charleston, South Carolina. The model incorporates continuous depreciation of capital—both land values and structures—as a function of rising sea level, and costs of protection are incurred in continuous time. Parsons and Powell [25] compare the benefits and costs of nourishing beaches versus beach retreat for Delaware and find that nourishment provides net benefits over a 50-year horizon. Landry et al. [20] combine property benefits from a hedonic model with stated preference data on recreational use to estimate benefits of retreat and nourishment strategies on Tybee Island, Georgia. With an application to Seabrook Island, South Carolina, Woglom [35] compares the costs of nourishment with the costs of allowing natural shoreline change and moving structures. She finds that nourishment is a preferred strategy when the interval between nourishments is long (>10 years), but the preferred strategy reverses when the interval between nourishments is short (<5 years). This result leaves open the question of whether nourishment will be a dominant strategy if communities choose the nourishment interval optimally. Finally, Landry [19] combines empirically driven benefit and cost estimates with the insights from [36] to analyze optimal beach nourishment on Tybee Island using dynamic programming. Consistent with real-world practices, Landry finds that the optimal nourishment control is periodic. Landry's model also illustrates how to determine optimal beach width in a dynamic context.

Taken together, these normative analyses and valuation studies highlight factors that will influence coastal management. However, they do not generate specific testable hypotheses about coastal management decisions across communities and across time. Our paper aims to fill this gap in the literature by providing a positive analysis of nourishment decisions. We propose that choosing whether to nourish a beach and when can be viewed as a dynamic

[2] In a discrete choice recreation demand model, Parsons et al. [26] find that wider beaches are preferred up to a point. Eventually, beachgoers receive disutility from wider beaches, suggesting that the recreational value of beach width may have an inverted U-shape. Combined recreational and storm protection benefits of wider beaches are unclear, but it seems reasonable to assume that overall benefits are concave in width.