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Shoreline defense against climate change and capitalized impact of beach nourishment

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1. Introduction

Coastal climate adaptation has garnered tremendous interest from scientists and policy makers alike in the past decade. Densely populated coastal regions, covering less than 10% of the total land area (excluding Alaska), support 39% of the US population and contribute to 45% of the US GDP (NOAA, 2010). Coastal zones are, however, also most vulnerable to the impact of climate change as sea level rise and frequent storms threaten property and infrastructure. Communities respond to these risks with shoreline stabilization policies, such as the construction of sea walls or jetties and beach nourishment, to protect coastal development. The value of recreational amenities and storm protection benefits justify capital investments along the coast, and ultimately determine future responses to coastal risks. Beach nourishment – the process of replacing an eroding section of a beach with sand dredged from inlets or offshore sand reserves – first introduced in the United States in the 1920s, is now the dominant coastal management policy for sandy beaches along the US Atlantic and Gulf Coast.

Over the past 50 years, U.S. federal expenditures on beach nourishment alone have exceeded $2.9 billion (Coburn, 2009). Between 1950 and 2006, the U.S. Army Corps of Engineers (ACE) implemented beach nourishment on approximately 350 miles of U.S. shoreline, largely along the Atlantic and Gulf coasts (USACE, 2007). Nourishment costs, including fixed costs of infrastructure and project engineering, and variable costs of nourishment sand, are estimated between one and three million dollars per mile of shoreline (Dean, 2002). With a steady increase in nourishment activity, sand costs have increased exponentially; the cost per cubic yard of nourishment sand increased from less than $1 in 1950 to almost $12 in 2013 (Gopalakrishnan et al., 2018). Historically, approximately two-thirds of the nourishment costs have been paid through federal spending (Ludden, 2013; McNamara et al., 2015). However, as climate change intensifies the demand for shoreline defense, federal funding may not grow at the same rate. Potential cutbacks in federal contributions toward beach nourishment (Coburn, 2009; U.S. Senate Amendment #815) will increase the need for local funding for shoreline stabilization. Investments in natural capital through beach nourishment directly influence coastal housing markets, and are, at least partly, capitalized in coastal property values. Therefore, reliable estimates of the impact of shoreline stabilization policies on coastal housing markets provide a first step to examine the viability of beach nourishment as a long-term adaptation strategy.

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Wide beaches can be characterized as impure public goods that generate value through recreational amenities and storm protection. Recreational amenities such as beach views and increased access to the beach are generally available to property owners and to beachgoers who may not directly pay for shoreline stabilization policies that maintain beach width. Benefits from storm protection, however, are inherently tied to the section of the coastline protected through shoreline stabilization policy. In this paper, we combine data on housing sales between 2008 and 2014 in Dare County, North Carolina with geospatial information on the timing and location of the first beach nourishment project. We estimate a series of triple difference (DDD) models to recover the amenity and risk-reduction effect of beach nourishment along the northern barrier islands in North Carolina using the occurrence of Hurricane Sandy as a natural experiment to estimate the perceived risk-reduction capitalized in housing values. Hurricane Sandy was the most destructive coastal hazard in 2012, which affected large regions of the Atlantic Coast. While damages from Hurricane Sandy were largest in the states of New Jersey and New York, its impact was felt as far as North Carolina (National Hurricane Center, 2013). Though accurate damage estimates are not available for individual towns, reports in the popular press documented damage to infrastructure and property from Hurricane Sandy at both ends of the Outer Banks of North Carolina. Local news reports further indicated that the storm surge from Hurricane Sandy caused significant damage to the U.S. Highway 158 and property damage as far as three rows back from the shoreline in the town of Kitty Hawk (WRAL, NPR),[1,2] whereas the relatively minor damage in Nags Head was attributed to the recent beach nourishment investment.[3] We use Hurricane Sandy as a natural experiment to estimate the perceived risk-reduction value of shoreline stabilization. Triple difference estimates reveal that investment in nourishment results in a price premium of 11.7%–16.5% for oceanfront homes located on a nourished beach. We control for aggregate effects at the beach-level, storm risk information provided by Hurricane Sandy, and unobservable price trends unrelated to nourishment. Our results are robust to a range of specifications. Our findings show that gains from beach nourishment are heterogeneous over space and are disproportionately capitalized by beachfront properties. Converting the average treatment effect of 13.4% from our preferred DDD model to aggregate benefits capitalized by oceanfront homes in Nags Head suggests that the value of beach nourishment exceeds $16 million. Our analysis provides supporting evidence for spatially targeted policies, such as the formation of special tax districts, which follow a graduated approach to provide local funding for shoreline management.

A large part of the coastal economics literature has focused on estimating the value of environmental amenities and storm risks using a hedonic pricing framework (Rosen, 1974). The hedonic price function decomposes the market price of a residential property into a bundle of structural attributes such as the number of rooms, age, lot size; neighborhood characteristics such as school quality, crime rates, congestion effects (Brookshire et al., 1982; Gibbons and Machin, 2008; Timmins and Murdock, 2007); and environmental amenities such as air quality, water quality, proximity to agricultural land, and landscape diversity (Bastian et al., 2002; Geoghegan et al., 1997; Leggett and Bockstael, 2000; Won Kim et al., 2003). Under market equilibrium conditions, the partial derivative of the hedonic price function with respect to an attribute can be interpreted as the marginal willingness to pay for the attribute. Empirical analyses consistently show that access to wider beaches, better views, reduced flood hazards, and proximity to the shoreline (Bin et al., 2008; Brown and Pollakowski, 1977; Landry et al., 2003; Pompe, 1999) increase the value of coastal residential properties. Recent work that explores the dynamic nature of beach amenities tied to coastal geomorphology suggests that, when beaches are actively managed through periodic renourishment, property values that reflect benefits from widened beaches may also simultaneously affect nourishment decisions and the maintained beach width (Landry and Allen, 2016; Gopalakrishnan et al., 2011).

Housing markets also reflect gradients in the price-risk schedule for storm hazards, and hedonic price functions estimate the effect of storm and flood risks on coastal housing markets (Smith, 1985; MacDonald et al., 1987; Bin et al., 2008; Rambaldi et al., 2012; Gopalakrishnan et al., 2016). Risks from wind, water, and storm hazards are particularly acute in communities along the coast. Quasi-experimental analyses to examine the effect of risk information provided by hazard events have shown that price discounts for properties located in floodplains increase after a hurricane (Bin and Polasky, 2004; Hallstrom and Smith, 2005; Kousky, 2010; Atreya and Ferreira, 2015), and the associated risk discount attenuates over time in the absence of additional natural hazard events (Bin and Landry, 2013; Atreya et al., 2013). Furthermore, household investments in repair and reconstruction of residential buildings after a severe hurricane vary significantly across homes located in the flood zone and homes that faced similar damages but were located outside the flood zone (McCoy and Zhao, 2017). Housing markets also capitalize the value of risk mitigation measures such as increasing elevation of the structure, construction of seawalls, and windstorm resistance measures (Jin et al., 2015; Rambaldi et al., 2012; Simmons et al., 2002). Because seawalls and other hardened structures tend to exacerbate erosion in other alongshore locations (Ells and Murray, 2012; Kraus and Pilkey, 1988), towns along sandy beaches are shifting to natural capital investments such as vegetated dunes and beach nourishment. Vegetated dunes provide amenities that increase coastal housing values but also generate ancillary costs due to reduced ocean views (Dundas, 2017). Coastal adaptation measures also have broader impacts beyond housing markets. In small economies that rely on tourism, such as Barbados in the Caribbean Islands, investment in coastal infrastructure and shoreline stabilization can increase local GDP by as much as 11.7% in the short term (Corral and Schling, 2017).

We build on existing literature and examine how coastal housing markets capitalize amenities and risk-reduction benefits from shoreline stabilization. Using the information on the timing and spatial extent of the first beach nourishment project in

[1] http://www.wral.com/soundside-flooding-possible-as-sandy-trudges-along-outer-banks/11713760/.
[2] https://www.npr.org/sections/thetwo-way/2012/10/29/163903064/hurricane-sandy-the-scene-from-kitty-hawk-n-c.
[3] http://www.northbeachsun.com/outer-banks-thoughts-on-hurricane-sandy/.