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Adaptation, Sea Level Rise, and Property Prices in the Chesapeake Bay Watershed

Patrick Walsh[*],
Manaaki Whenua-Landcare Research, 231 Morrin Road St Johns, Auckland 1072, New Zealand

Charles Griffiths,
US EPA, 1200 Pennsylvania Ave, N.W., Washington, DC 20460

Dennis Guignet, and
US EPA, 1200 Pennsylvania Ave, N.W., Washington, DC 20460

Heather Klemick
US EPA, 1200 Pennsylvania Ave, N.W., Washington, DC 20460

Abstract

Coastal communities are facing the dual threat of increasing sea level rise (SLR) and swelling populations, causing challenging policy problems. To help inform policy makers, this paper explores the property price impact of structures that help protect against SLR using a novel and spatially explicit dataset of coastal features. Results indicate that adaptation structures can have a significant positive impact on waterfront home prices, with the most vulnerable homes seeing the largest impacts. The Chesapeake Bay is facing increasing pressure from SLR, and this is one of the first papers to report that local property markets are incorporating that threat.

Keywords

Sea level rise; hedonic regression; coastal resources; environmental economics; benefit cost analysis; valuation

I. INTRODUCTION/BACKGROUND

Coastal areas are facing two transformative forces. On the one hand, global sea level has climbed by an average of 3.2 mm/year since 1993, and is projected to increase by close to two meters by 2100 (DeConto and Pollard 2016). On the other hand, the projected increase in US coastal shoreline population density from 2010–2020 is 37 additional people per square mile (sq mi), compared to 11 people/sq mi in the US as a whole.[1] So there will be more people living in a shrinking area. The real estate firm Zillow estimated that almost 1.9

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[*] Corresponding author: WalshP@landcareresearch.co.nz, +64 09 574 4164.

[1] NOAA's State of the Coast: http://stateofthecoast.noaa.gov/population/welcome.html, accessed Jan. 2014.

million American homes, valued collectively at $880 billion, will be flooded if these projections materialize (Allison 2016).

Accelerating sea level rise (SLR) is causing novel challenges along the US coast for local planners considering how their communities will adapt. While cities such as Miami Beach and Manhattan are investing in infrastructure to arm their coastlines (Allison 2016), other jurisdictions are hesitant to plan for long-range impacts. For instance, businesses in North Carolina lobbied aggressively to block any state zoning or planning policy that used the 39 inch SLR zone projected by state scientists for the year 2100. Residents within that zone described it as a “death sentence for ever trying to sell your home.”[2] The state then tasked its scientists with developing only 30 year forecasts rather than projections for 2100 for planning purposes (NC Coastal Resources Commission Science Panel 2015).

This paper examines some of the economic impacts of adapting to SLR and related challenges such as storm surges and flooding in the Chesapeake Bay region. Adaptation is an important topic in this area because SLR in the Bay has been double the global average of 3.2 mm/year, and is believed to be increasing (Pyke et al. 2008, Sallenger et al. 2012). Zillow has estimated that a two-meter sea level rise would submerge around 64,000 Maryland properties worth almost $20 billion, representing three percent of the state’s housing stock (Rao 2017). Our focus is on Anne Arundel County, MD, which is about 15 miles east of Washington, DC, and is bordered by the Chesapeake Bay on the East and the Patuxent River on the west, resulting in approximately 530 miles of shoreline. In fact, almost two-thirds of the County’s residents live within two miles of the Bay’s tidal waters (Nuckols et al. 2010).

The results of a survey (Akerlof 2012) in Anne Arundel County indicate that 55% of county residents believe that sea-level rise is occurring and that coastal flooding has become more of a problem in recent years. Furthermore, a report (MD DNR 2011) estimates that 2,193 acres in Anne Arundel, valued at almost $3 billion, would be threatened by a SLR of 2 feet.[3] Maryland homebuyers also have access to a wealth of freely available reports and tools that allow them to obtain parcel-specific information about the risk of sea level rise.[4] Nuckols et al. (2010) project that, given the amount of urbanized and high-value land in Anne Arundel, as well as current coastal policies, development trends, and shoreline practices (Appendix Figure A1), 68% of the shoreline is “almost certain” to be protected from SLR using approaches such as shoreline armoring, elevating land, or beach nourishment.[5]

Given the amount of future adaptation projected in this area, as well as the broader coastal areas in the US, it is important to examine the associated economic impacts. Indeed, the

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[2] *The Washington Post* “On NC’s Outer Banks, Scary Climate-Change Predictions Prompt a Change of Forecast.” June 26, 2014.

[3] Of course this $3 billion figure is not necessarily the value lost from a 2-foot rise in SLR. Making such claims would require assumptions that inundated lands have zero value, current land uses and assessed values remain constant given no SLR, and that the hedonic equilibrium does not adjust (for example, inland parcels that become waterfront do not change in value). The actual net loss could be greater or less.

[4] For instance, Anne Arundel County and the State of MD regularly produce reports on SLR threats, which contain location-specific information (Michael et al. 2003, Boesch, 2008, MCCC 2008). The Chesapeake Bay has had a widely-publicized history of SLR, as 13 notable islands have been lost (http://www.umces.edu/climate-change). Popular housing websites, such as Zillow and Trulia, contain information about a home’s elevation.

[5] For a color version of the planning Figure, go to http://ccrm.vims.edu/climate_change/slr_maps/MD_maps/Anne%20Arundel%20County.jpg

effectiveness of adaptation strategies in mitigating the damages associated with SLR remains a major source of uncertainty in estimating the social costs of climate change. Recent research using a global coastal modeling framework suggests that cost-effective adaptation can reduce the economic costs of SLR by roughly an order of magnitude (Diaz 2016). Empirical estimates of the costs and benefits of adaptation strategies are critical inputs into such global simulation models that project the range of potential climate damages, but such inputs remain sparse.

This study contributes to the literature by examining the property value impacts from a subset of adaptation structures. We hypothesize that if local residents perceive risks from SLR, then the potential for adverse outcomes should be capitalized in property values. Further, if local residents believe that such risks are mitigated by the presence of adaptation structures, all else constant, protected property values should reflect a premium.

There are a wide variety of ways to protect shoreline from flooding, storm surge, and SLR, including both structural and non-structural approaches (such as wetlands). We focus on the structural measures used most commonly in the Chesapeake Bay area: bulkheads, ripraps, and groinfields. Bulkheads and ripraps in particular are widely deployed in Anne Arundel County, and these and other structures will likely play a part in future protection, particularly in developed areas. We utilize a novel and spatially explicit GIS dataset of structural adaptation measures in the Chesapeake Bay that was jointly developed by the Virginia Institute of Marine Science (VIMS), the Maryland Department of Natural Resources (MD DNR), and the National Oceanic and Atmospheric Agency (NOAA). Adaptation structures were mapped and catalogued using GPS units and cameras during detailed surveys conducted from boats traveling along the entire shoreline. These features were then verified and augmented using satellite imagery.

Our results suggest that certain types of adaptation structures can yield a significant property price increase. The price premium from adaptation structures likely reflects the multiple types of amenities they provide; in addition to mitigating threats from SLR, they also offer protection from existing threats like flooding and storm surge, and they support boating and the capacity to build out a dock. However, these impacts are strongest in areas most threatened by SLR. This result provides suggestive evidence that the property market appears to be incorporating both the threat of future SLR and mitigation approaches. Although previous literature has examined flood zone and hurricane-related impacts on property values (Hallstrom and Smith 2005, Bin et al. 2008), this is the first study to specifically examine adaptation to SLR.

II. LITERATURE REVIEW

Sea level rise and other impacts of climate change have received some attention in the hedonics literature. Beach erosion, flood zones, and general climate conditions have been examined, and large shoreline protection structures (dikes) have been analyzed at the regional level. However, our paper is the first to examine the impact of adaptation structures and the risk of SLR on individual homes.

Several studies have examined coastal property damage using relatively simple approaches that calculate rough estimates of real estate damages using assessed values and SLR predictions or models rather than hedonic or other regression-based models (Yohe et al. 1995, Darwin and Tol 2001). A more recent paper (Bin et al. 2011) takes a spatially explicit approach to the costs of SLR in North Carolina by using satellite-based LIDAR data and the assessed values of individual homes. Fu et al. (2016) examine projected SLR damages from inundation in the Tampa Bay area of Florida using a similar approach but with home sales data instead of assessed values. Michael (2007) expands this literature by illustrating that the values of inundated properties may only be a portion of the total damages of SLR. In three Chesapeake Bay communities, he finds that episodic flooding associated with rising seas can cause 9 to 28 times more damage than the value of inundated properties, but he does not consider how adaptation can lessen such damages.

The preceding papers show that there could be substantial damages associated with living in areas threatened by SLR. However, the hedonic literature investigating residents' responses to these threats is somewhat sparse. Dorfman et al. (1996) look at the risk reduction provided by large concrete structures used to reduce erosion. They use stated preference results to calculate a measure of erosion risk that accounts for the structures, and they find that the risk variable is negatively related to home prices. Landry et al. (2003) examine erosion protection structures in a hedonic property analysis but find statistically insignificant results.[6] Finally, Hamilton (2007) examines the impact of dikes, which may deter damages from SLR and erosion, on average nearby hotel prices. The structures have a negative impact on hotel prices, but since there is a tradeoff between these structures (measured in aggregate at miles of structure) and recreational beaches, these impacts on average hotel price are not too surprising.

Another topic related to SLR is flood zones, which are projected to expand as water levels rise. Early papers found it difficult to disentangle the benefit of living close to the water from the impact of flood zones (Bin and Kruse 2006). However, later studies use more sophisticated GIS techniques to isolate individual properties, and find that, all else equal, flood zones do negatively impact home values. Bin et al. (2008) find that the capitalized price differentials from living in flood zones are approximately equivalent to insurance premiums. Daniel et al. (2009) conduct a meta-analysis on hedonic studies of flood risk, and find that an increase in flood risk of 1% in a year corresponds to a −0.6% decrease in transaction price. Finally, Bin and Landry (2013) use difference-in-difference methods to examine flood zone impacts to property values before and after hurricanes. Although they find significant impacts from hurricanes, the effect diminishes over time, suggesting that home buyers may not have full information about flood zone locations, or that the perceived risks diminish as time since a high impact event, like a hurricane, increases.

III. DATA

We use property sales data from Anne Arundel County, MD, which were obtained from MD PropertyView (a state manager of real estate sales data). These data include a wealth of

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[6] Other erosion-related studies that look at beach width include Landry and Hindsley (2011) and Ranson (2012).

information on each home, such as structural characteristics (for example, square feet and number of bedrooms), land characteristics (e.g. lot size, zoning information), as well as GIS maps that allow the parcels to be matched to a variety of other location-based attributes. Since the focus is on shoreline adaptation structures, we narrow our focus to all waterfront property sales from 2003–2008.

The data on adaptation structures comes from a joint program between the Virginia Institute of Marine Science (VIMS), the Maryland Department of Natural Resources (MD DNR), and the National Oceanic and Atmospheric Agency (NOAA). Data were obtained during 2004–2006 by navigating the entire coastline of the Chesapeake Bay and its major tributaries in small shoal draft vessels, parallel to the shore. Onboard the vessels, GPS units and cameras were used to catalog shoreline features and location; these observations were later cross checked with satellite images. This resulted in a comprehensive GIS database of the shoreline and its attributes, with several layers focusing on shoreline adaptation structures. This dataset is a particular strength of our analysis, as it contains a spatially explicit accounting of the local shoreline. The data are a snapshot of the shore during this three-year period, so we know what was in existence at that time, but unfortunately we do not know the age of the structures. We therefore limit the property sales to a window around those three years. Figure 1 contains a map of the Severna Park area in Anne Arundel County, which is the location of quite a few structures. The waterfront homes we analyze are the grey X's and the structures are represented by various types of shaded lines. Figure 1 demonstrates how each of the adaptation structures often cover several residential parcels.

The four types of adaptation structures used in this area are breakwaters, groinfields, riprap revetments, and bulkheads. Breakwaters are structures that sit parallel to the shore and generally occur in a series, looking like a dashed line along the shore from overhead, as illustrated in the Appendix, top left picture in Figure A2. However, due to their extremely low number in our sample, we are not able to analyze this structure.

Groinfields sit perpendicular to the shore and also normally occur in a series, as shown in the top right picture of Figure A2. They are designed to trap sediment moving along the shore, and they can offer protection to the area behind the system. Individual parts of groinfields can resemble stone jetties. Their effectiveness is heavily dependent on proper setup and local conditions (Barnard 1993). Also, in many cases the immediate downstream area next to the groinfield experiences a net loss of beach, as seen on the bottom of the groinfield picture in Figure A2.

Riprap revetments sit directly along the shore and are typically composed of large rock deposits, and look like stream armoring projects common in many rural areas. They are meant to withstand wave energy and prevent erosion. Riprap also provide habitat benefits, as several species of crab, fish, and other animals are known to use them as shelter (Barnard 1993).

Finally, bulkheads are wood, steel, or plastic walls designed to withstand incoming waves. The bulkhead pictured in Figure A2 is a smaller wood variation. They are vertical structures built slightly seaward and backfilled with suitable fill material. Bulkheads are designed to prevent erosion and related problems. Although some variations of bulkheads in high wave areas can cause erosion on neighboring shoreline, it is common to build them with “return walls” on the sides to minimize this problem. A wooden bulkhead has an average lifespan of 20–25 years, although steel and concrete versions can last much longer (Barnard 1993).

All four adaptation structures are classified by hydrologists and ecologists into two categories. Breakwaters and groinfields are considered offensive structures, while ripraps and bulkheads are classified as defensive structures. Generally speaking, defensive structures are designed to armor or protect the shoreline from the rising water and incoming waves, whereas offensive structures are designed to work with the natural currents to reduce erosion and adverse impacts. It is difficult to compare the effectiveness of the various structures since that depends on a complex interaction of local water currents, soil, elevation, and other conditions, as well as proper construction parameters. Offensive and defensive structures can also be used in tandem to protect the same sections of shoreline.

Bulkheads are probably the least environmentally preferred, as they fix the shoreline and provide minimal habitat. Ripraps, which also fix the shoreline, have habitat benefits, and tend to absorb wave energy, as compared to bulkheads, which reflect it. However, bulkheads can support boating and attached docks, whereas the other types of structure do not. Breakwaters are also environmentally preferred, since they provide habitat, can create marshes behind them, and extend the shoreline.

These structural shoreline protection approaches contrast nonstructural approaches like planting native wetland vegetation. Structural approaches, particularly bulkheads and seawalls[7], can exacerbate erosion at nearby shore areas by disrupting sediment transport and increasing wave reflection (NRC 2007). The cumulative impacts of regional-scale shoreline “hardening” are understudied but can include loss of intertidal and beach habitat (NRC 2007). Groinfields and breakwaters can be designed to allow some movement of sand along the shore and to minimize habitat destruction. Structural approaches typically have higher upfront costs than non-structural methods, though ongoing maintenance costs may be lower. Despite their drawbacks, structural approaches are more effective than non-structural at protecting shorelines in areas with greater wave energy, deeper water, and higher rates of erosion (Luscher and Hollingsworth 2007).[8]

Structural approaches were most common during the 20th century, but state policies have promoted non-structural approaches in recent decades because they offer benefits such as riparian habitat protection and reduced sediment runoff. Maryland issued regulations effective in 2013 implementing the state’s Living Shorelines Protection Act of 2008 (Annotated Code of MD 2013). While the state previously encouraged the use of tidal wetland vegetation for shoreline stabilization, the new regulations now require it wherever technologically and ecologically feasible. Structural approaches are now only allowed in

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[7] Seawalls are similar to bulkheads but can withstand greater wave energy and are typically built along oceanfront property (NRC 2007).

[8] It is quite difficult to obtain information on the origin of the structures and who paid for them. Although there are some publicly funded adaptation structures, local County contacts indicated that most of them were built by either property developers or added later by private parties.

designated areas or through a waiver process. Where allowed, structural approaches must be considered in the following order of preference: beach nourishment; breakwater; groin or jetty; revetment; and bulkhead. New bulkheads are only permissible when all other non-structural and structural approaches are infeasible.

Unfortunately, the dataset developed by NOAA and VIMS only contains structural adaptation approaches, and so we are only able to evaluate the impact of bulkheads, riprap, and groinfields on property values. The effect of non-structural protection approaches remains an area for further research.[9] It is worth noting that our data on adaptation structures were collected prior to the 2013 regulations that sharply restricted the use of structural approaches to shoreline protection. Also, while the 2013 regulations limit the construction of new structural projects, the existing stock will continue to influence home prices for some time.

The SLR zone data were produced in a joint project between NOAA, the MD Commission on Climate Change, and Towson University. High resolution LIDAR data and data from NOAA tidal stations (for mean sea level determinations) were used to produce GIS maps of the inundation zones of a vertical 2 or 5 foot rise in sea level. Figure 2 contains a map of these zones and illustrates the magnitude of the problem in Anne Arundel County, and Figure 1 illustrates a close-up of these zones in Severna Park. Additionally, FEMA flood zone maps, provided by MD PropertyView, are used to create dummy variables indicating homes facing a 1% annual flood risk (at current sea levels).

Based on location, homes were matched to SLR zones, flood zones, and adaptation structures,[10] as well as land use, census, and other location-based data (such as distance to Baltimore) in ArcGIS. These location-based characteristics supplement the numerous housing structure attributes used to define a housing bundle. Table 1 contains descriptive statistics of the final property sales dataset, which entails 2,841 transactions of single-family homes and townhomes located on the waterfront. Since focus is drawn to waterfront homes, the average price is relatively high at $694,963. The majority of homes are in medium-density areas and border waters with an average depth of 1.7 m. Also, the average home age is 35 years, 11% of the sample is townhomes, 4% have a pool, and 24% have a dock (or similar structure). After 2005–2006, home sales start to decline in the area, illustrating the impact of the recession (a topic we investigate in detail later).

With respect to the SLR variables, only 4% (116 homes) and 9% (268 homes) of transactions are in the 0–2 foot and 2–5 foot SLR zones, respectively. Fifty-five percent of all homes are located in front of at least one adaptation structure, predominantly bulkheads (37%) and ripraps (20%). Among our sample of waterfront home sales, 19% are bulkhead neighbors (meaning that the property is adjacent to a residential property with a bulkhead, but the home itself does not have its own bulkhead). Similarly, 27% are riprap neighbors (but do not have their own riprap). Table 2 illustrates the distribution of structures across homes by SLR zone. It shows that a relatively small sub-sample of the full dataset provides the

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[9] Although they are unable to isolate erosion protection from other ecosystem services provided by submerged aquatic vegetation (SAV), Guignet et al find a 6% premium among properties located along the Chesapeake Bay shoreline when SAV are present.

[10] Thiessen polygons were used to determine adjacency to adaptation structures in ArcGIS.

identification for the impacts of interest in this study. Seventy-nine homes in the 0–2 foot SLR zone and 178 homes in the 2–5 foot SLR zone have an adaptation structure. Bulkheads are the most common structure across all SLR zones, whereas groinfields are quite rare.

IV. METHODS

The hedonic property value model is based on the idea that the price of a home is a function of its characteristics. The model used in this paper sorts characteristics into home structural characteristics (**H**), location-based and neighborhood characteristics (**N**), and the environmental variables of interest (**S** and **Z**). The central model appears in equation (1), where the dependent variable is the natural log of price, as is common in the hedonic literature.[11], [12]

$$\ln(P) = \beta_0 + \beta_H\mathbf{H} + \beta_N\mathbf{N} + \beta_S\mathbf{S} + \beta_Z\mathbf{Z} + \sum_{A=1}^{An}\sum_{R=1}^{Rn}\beta_{AR}S_AZ_R + \gamma\mathbf{T} + \delta\mathbf{F} + \varepsilon \qquad (1)$$

The vectors **T** and **F** represent annual and quarterly time dummies and spatial fixed effects, respectively. **S** denotes the presence of the different adaptation structures, while **Z** represents location in an SLR zone. The coefficients of particular interest are $\boldsymbol{\beta}_S$, which captures the impact of an adaptation structure, and $\boldsymbol{\beta}_Z$, which is the impact of being located in an SLR zone.

The interaction term β_{AR} captures the additional premium associated with the presence of an adaptation structure among homes most at risk of SLR (i.e., being located in an SLR zone). Under the assumption that the unobserved neighborhood and house quality characteristics that are correlated with the presence of an adaptation structure are constant across waterfront homes in versus out of a sea level rise zone, this interaction term provides an estimate of the additional premium associated with adaptation structures *among homes most at risk* of SLR. However, placement of adaptation structures is not random; they are more likely to be present at homes that are more desirable and/or located in higher quality neighborhoods. If our numerous observed characteristics and neighborhood fixed effects do not fully control for such factors, then this price differential may not necessarily be interpreted as the causal impact of the adaptation structure. Note that we only include SLR interactions terms for the bulkhead and riprap structures due to insufficient home transactions with groinfields in the 0–2 and 2–5 foot SLR zones.

We also pursue a second specification that includes “neighbors” of adaptation structures. As mentioned above, there may be some externality effects associated with the structures. Living next door to a house that has an adaptation structure could have an impact on a waterfront home’s shoreline, even if the home itself is not directly adjacent to a structure. The impact may be positive or negative, depending on the construction of the structure, the

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[11] Double log specifications, where the non-dummy independent variables appear in natural log form, were also explored and had the same qualitative results with respect to the variables of interest.

[12] The price variable has been adjusted by the Federal Housing Finance Agency’s (FHFA) seasonally adjusted house price index to control for general trends in the real estate market.

shape of the coastline, strength and direction of the current (which may vary with the tide), and several other factors. As it is not possible to accurately capture all of these local directional effects, we include a dummy variable indicating whether a home is a neighbor to either a bulkhead or riprap.[13] (We do not investigate groinfield neighbors in the regression due to the small number of observations for this category.) Equation 2 illustrates the inclusion of the neighbor variables (NE):

$$\ln(P) = \beta_0 + \beta_H \mathbf{H} + \beta_N \mathbf{N} + \beta_S \mathbf{S} + \beta_Z \mathbf{Z} + \sum_{A=1}^{An} \sum_{R=1}^{Rn} \beta_{AR} S_A Z_R + \beta_{NE} \mathbf{NE} + \gamma \mathbf{T} + \delta \mathbf{F} + \varepsilon \quad (2)$$

We also present two specifications that vary according to the assumed spatial fixed effects, including Census tract (51 different tracts) and Census block group (131 different block groups) fixed effects.[14] Census tracts are designed to be relatively homogenous in terms of populations characteristics, economic status, and living conditions,[15] and therefore should help to absorb any time-invariant omitted variables that could bias the estimates of the coefficients of interest. Because Census block groups are even smaller geographic units, they may further reduce potential bias. We are able to include such spatially refined fixed effects in our analysis because most home sales in the dataset occur in Census tracts and block groups in which there is variation in both adaptation structures and SLR zones. However, estimates generated using block group fixed effects are less efficient than those using tract fixed effects because there are fewer block groups containing variation in adaptation structures and in SLR zones, reducing the number of observations used to identify the coefficients of interest.[16]

There have been concerns with the impact of the recent financial crisis on hedonic studies (Boyle et al. 2012), and there is no general consensus on how to treat hedonic estimates in the rise of a real estate bubble. Since our data occur during that time, we pursue several analyses recommended by Boyle et al. (2012). First, Appendix Figure A3 contains a graph of average annual sales price for our sample (Anne Arundel County waterfront sales), waterfront sales across Maryland, all of Anne Arundel county, all of Maryland, and the US average. Our sample mirrors the average MD waterfront sales pretty closely, and exhibits the same general trend as the other averages. The main difference apparent in the figure is the price premium between waterfront and non-waterfront sales. Boyle et al. also suggest looking for increases in the number of vacant homes. Appendix Figure A4 contains a graph of the percent of all home sales in the county that were vacant (waterfront and non-waterfront). The graph shows a relatively flat trend after 2005, which does not solicit any red flags. So overall, we do not see any warning signs for disequilibrium behavior, although the

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[13] Homes can have a riprap and be a bulkhead neighbor, but a home with a bulkhead cannot be a bulkhead neighbor. Different "neighbor" specifications did not have an appreciable impact on results.

[14] We also explored specifications with legislative groups as fixed effects (described here http://www.aacounty.org/elections/councilmaps.cfm). There were only 6 legislative groups, and results were similar to the other FE groups.

[15] https://factfinder.census.gov/help/en/census_tract.htm

[16] Ninety-three percent of home sales in the dataset are located in a Census tract that has at least two SLR zones and has homes with and without adaptation structures. The remaining 7% of home sales are all located in tracts in which all home sales are in the > 5 foot SLR zone. Seventy percent of home sales occur in a Census block group where there is variation in the SLR zone and the presence of adaptation structures.

literature in this area is still unsettled. Nonetheless, as depicted in equation (1), we include annual and quarterly time indicators to account for overall year-to-year fluctuations and seasonal cycles in property prices.

V. RESULTS

Estimation results of the main hedonic models appear in Table 3. The results for the variables related to SLR and adaptation structures are presented here, while the estimates for other variables appear in an appendix available upon request. Most of the variables not included in Table 3 had the expected signs (all significant variables had expected signs). For example, distance from wastewater treatment plants is positive and significantly related to home price, indicating that people want to live farther from such disamenities. The water depth along the waterfront is significant and positive, perhaps indicating a preference for boatable waters. Also, home square footage, parcel acreage, basements, and having a pier are all significant and positively related to home price.

Our variables of interest – the SLR zone and adaptation structure – are dummy variables, and so, as is common in the literature, the reported coefficient estimates are first transformed so that they can be interpreted as the percentage change in price as a result of the corresponding dummy variable going from zero to one (Halvorsen and Palmquist 1980). For example, in Table 3 the reported percent change in price from an adaptation structure (e.g., *Bulkhead*, *RipRap*, and *Groinfield*) is calculated as $(e^{\beta_S} - 1)$.

Table 3 contains estimates for two broad model specifications, and within each model there are two variations based on the level of spatial fixed effects (Census tract or block group). The first model is a basic specification that includes the SLR zones and adaptation structure variables, but omits the interactions between them. The SLR zone variables are insignificant across both specifications, suggesting (perhaps surprisingly) that living in an area threatened by SLR is not associated with a decrease in home price.

The presence of bulkheads and ripraps are consistently positive and significant across both FE specifications; but groinfields are never significant, either alone or when used in conjunction with defensive structures, as noted by the interaction terms *Bulkhead*GroinField* and *RipRap*Groinfield*. This suggests that the additional protection afforded by the groinfield is crowded out by other offsetting impacts, such as a decrease in the ability to have a dock and boating access. The lack of significance may also be due to the limited number of homes with groinfields in our sample, so caution is warranted in interpreting those estimates.

The second model in Table 3 includes interaction terms between the SLR and adaptation structure variables. These interaction terms allow us to differentiate between protected and unprotected parcels within a SLR zone; in this way we can focus on the value of adaptation structures in areas most threatened by SLR. In these columns, the 0–2 foot and 2–5 foot SLR coefficients represent the impact to homes threatened by SLR that are *not* protected by an adaptation structure. Focusing on the 0–2 foot SLR zone, the effects are negative and are now two to three times larger in magnitude in the tract fixed-effect model, and an order of magnitude larger for the block fixed-effect model. The estimates are statistically significant in the tract specification and suggest a 19% decrease in home price for unprotected homes in the 0–2 foot SLR zone. The 2–5 foot SLR zone coefficients are not statistically different from zero.

Moving on to the estimates for the adaptation structures, the (uninteracted) bulkhead and riprap estimates are positive and significant, with groinfields remaining insignificant. The estimates indicate bulkheads offer a 12–14% increase in price for homes outside of the SLR zone, while ripraps offer a 19–21% increase in price for those homes. Although these effects are quite large, the structures provide homes with several current amenities in addition to protection against future SLR. In addition, as described in Section IV, these premiums could, at least partially, reflect unobserved characteristics corresponding to higher quality homes and neighborhoods.

To better illustrate the magnitude of these effects, Table 4 contains the average implicit prices of the adaptation structures and SLR zones arising from Table 3. Since the dependent variables appears in logs, the implicit price of turning each dummy variable from zero to one is calculated as the percent change in price multiplied by the average price of homes outside of the 0–2 foot SLR zone and without a bulkhead or riprap, which is $540,994 (based on 1,345 observations). The first row in the table contains the implicit price of a bulkhead for homes outside of the 0–2 foot SLR zone, which ranges from $65,799 - $73,856. Lower in the table the riprap implicit price for homes outside of the 0–2 foot SLR zone are even higher at $104,967 - $111,292. This may indicate substantial benefits from these structures beyond SLR protection, such as their ability to minimize current levels of erosion, storm surge damages, and flood protection, as well as providing recreational and ecosystem amenities (in the case of bulkheads and ripraps, respectively). The second row of the table shows that the average disbenefit, or negative benefit, of living in the 0–2 SLR zone (with no adaptation structure) is $60,614 - $102,109.

We next turn to the estimates corresponding to the interactions between the SLR and the adaptation structure variables. Returning to Table 3, the interaction term between the 0–2 foot SLR zone and bulkhead is significant and positive in the census tract and block FE variations, implying an additional 22% increase in home price from a bulkhead in this SLR zone. The implicit price for this additional effect appears in the third row of Table 4, representing an average price premium of $117,294 to $119,560 associated with bulkheads among these homes most at risk to SLR. This represents the average price impact of a bulkhead among homes most at risk of SLR. Notice that this offsets the loss in value associated with being in the higher risk 0–2 foot SLR zone.

For illustrative purposes, we calculate the combined impact of all three coefficients just discussed in the fourth row of Table 4 for bulkheads (similarly for ripraps in the final row). Since the calculation of these implicit prices involves a nonlinear combination of the coefficients, it is not simply equal to the sum of the previous three rows.[17] This effect is approximately $68,043 to $114,554, suggesting that even when a home is in a SLR zone, the

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[17] For example, the (Halvorsen and Palmquist (1980) corrected) calculation is $\bar{P} * (\exp(\beta_s + \beta_Z + \beta_{AR}) - 1)$

existence of a structure is a net benefit. As stressed before, this combined estimate does not necessarily reflect the causal effect of adaptation structures on home values net of being located in a 0–2 foot SLR zone because the placement of these structures could be correlated with unobserved neighborhood and house characteristics that also influence home values. Nonetheless, under our model assumptions, the premium from getting a bulkhead or riprap (un-interacted) will absorb many of these confounding effects.

The interaction between bulkheads and the 2–5 foot SLR zone is only significant in the tract fixed effects regressions, suggesting an increase of 9 percent. The corresponding estimate in the block group fixed effects regression is smaller in magnitude and insignificant. In general, it is unsurprising that any price differentials corresponding to the adaptation structures are smaller in the 2–5 foot SLR zone, given that SLR will likely only affect these properties in the more distant future.

The effect is similar for ripraps: the interaction term with the 0–2 foot SLR zone is positive (though not always statistically significant), and the magnitude offsets much of the disamenity value of living in the 0–2 foot SLR zone. There is also a substantial premium for homes with ripraps regardless of SLR zone. For homes located in the 0–2 foot SLR zone, the total effect of having either a bulkhead or a riprap is similar in magnitude.

Lastly, we estimate an additional model in order to fully explore the impacts associated with adaptation structures. Anecdotal evidence suggests that the structures may produce negative externalities to neighboring homes, in the form of additional erosion. For this third model, with estimates appearing in Table 5, we include “neighbor” variables. When these are added, there are only minor differences with the coefficients corresponding to the variables we just discussed, indicating that the overall story about adaptation structures and SLR zones is not largely affected by controlling for neighbors. While properties that neighbor an adaptation structure are located in both the SLR zones and outside of these zones, we do not interact the neighbor variables with the SLR zone variables given the relatively small number of observations that are neighbors within the 0–2 and 2–5 foot SLR zones (52 and 136 observations, respectively). Therefore, the coefficient on the neighbor variable represents the average effect across all homes neighboring an adaptation structure in the dataset regardless of SLR zone.

In this model specification, the SLR 0–2 zone is significant in both fixed effects specifications. The estimated effect of being a neighbor to either a bulkhead or a riprap is also large – an 8–14% increase in price – and statistically significant. This may suggest some positive externality effect due to proximity to these adaptation structures, so that neighbors perceive some spillover benefits from these structures.[18] It is also possible that the coefficients on the neighbor indicators are reflecting some unobserved spatially correlated desirable attributes of the homes and neighborhoods where adaptation structures tend to be located.

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[18] This effect may represent an upper bound due to concerns with data. Although the data are fairly spatially explicit, there may have been errors in identifying homes with structures. Some homes identified as neighbors may also have structures themselves. Although we do not have any reason to suspect this, it is fairly difficult to verify the exact location of structures using satellite images, particularly with so many observations.

Although our data did not allow a comparison to other approaches beyond bulkheads and ripraps, the strong positive impact of both of these structures is somewhat surprising, given that the other types of structures are environmentally preferred and may have longer expected lifetimes (Barnard 1993). However, Anne Arundel County has a long history of boating and fishing recreation, with the 11th highest number of recreational vessels among US counties.[19] Since bulkheads are better suited for docks and boating, these results may reflect a preference for boating friendly structures. Also, when properly built, both of these structures can be quite effective at deflecting wave energy and rising tides. “Softer” approaches like groinfields and breakwaters may not be as effective due to their lower average height.

While these results show important interactions between SLR zones and adaptation structures, there may also be other confounding factors involved. As discussed earlier, adaptation structures may also protect against related disamenities like storm surge and other storm related activity. We attempted to estimate additional models to test the robustness of the effects, while incorporating the threat of storm surge from hurricanes.[20] Unfortunately only 10 homes in the SLR 0–2 zone are outside of the most threatened storm surge category. We therefore do not have enough variation to estimate additional interactions between the SLR zone, adaptation structure, and storm surge variables. Nonetheless, it is worth noting that the effects estimated in Table 3 and Table 5 are robust to the inclusion of storm surge variables.[21]

VI. Conclusion

This is the first hedonic study to examine the impacts of both sea level rise and mitigating responses on property values. We utilize a novel, spatially explicit dataset on adaptation structures. Combining this with GIS data of sea level rise zones, we compare the prices of protected and unprotected waterfront homes. In this framework we find evidence of a negative impact for homes located in the 0–2 foot sea level rise (SLR) zone. Since the sea level in the study area is projected to rise at least one foot by 2100 (MD DNR 2011), the 0–2 foot zone faces the most salient risk.

To differentiate between homes protected and unprotected from SLR, we identified homes with protective adaptation structures. Results indicate a large positive effect for both bulkhead and ripraps. In fact, having a bulkhead protecting the property can compensate for the negative impact of being located in the 0–2 foot SLR zone. Bulkheads were found to increase a home’s value even more when the home was in that SLR zone. There is similar evidence for ripraps in SLR zones, although the effect is not as robust across models.

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[19] As seen on http://www.boatinfoworld.com/

[20] This was done using data from a computerized model run by the National Weather Service (the SLOSH Model) to estimate storm surge heights resulting from historical, hypothetical, and predicted hurricanes. The resulting variable takes a value of 0–4, corresponding to the category of hurricane that would impact the parcel, so being located in a level 2 hazard zone means that a category 2 hurricane would threaten that parcel. The GIS data used for this variable were obtained from VIMS.

[21] There are also concerns about the behavior of the property market at the time, as the sample period encompasses the large rise and fall of property sale prices. We tested several models that included interaction effects with our SLR and adaptation variables with dummies representing an increasing or decreasing property market. These interaction terms were never statistically different from zero, suggesting that the original time dummies and housing price index-based corrections were sufficient to account for these market abnormalities.

The results also suggest that bulkheads and ripraps may yield a substantial premium for homes regardless of sea level rise risks, indicating that they provide other amenities, possibly related to storm protection or recreation. We propose several explanations for these results; in particular, bulkheads are the most compatible with boating, and can visually appear to be the most protective. Anne Arundel County has a long history of boating, and bulkheads are the most conducive to docks. We note, however, that under our model interpretation the premium associated with adaptation structures outside of the SLR zones may also reflect unobserved desirable characteristics of the home or neighborhood.

Given recent changes in local policy, these results have several important implications. Maryland recently banned the construction of new bulkheads, instead favoring vegetative and other non-structural approaches to shoreline protection. Since this policy effectively fixes the supply of homes with bulkheads, it may drive up their price premium in the short term. If current coastal policies and development trends continue in the face of a rising sea level, current research indicates that additional shoreline protection will be deployed (MD DNR 2011). It is therefore important to study the local economic impacts of SLR and shoreline protection.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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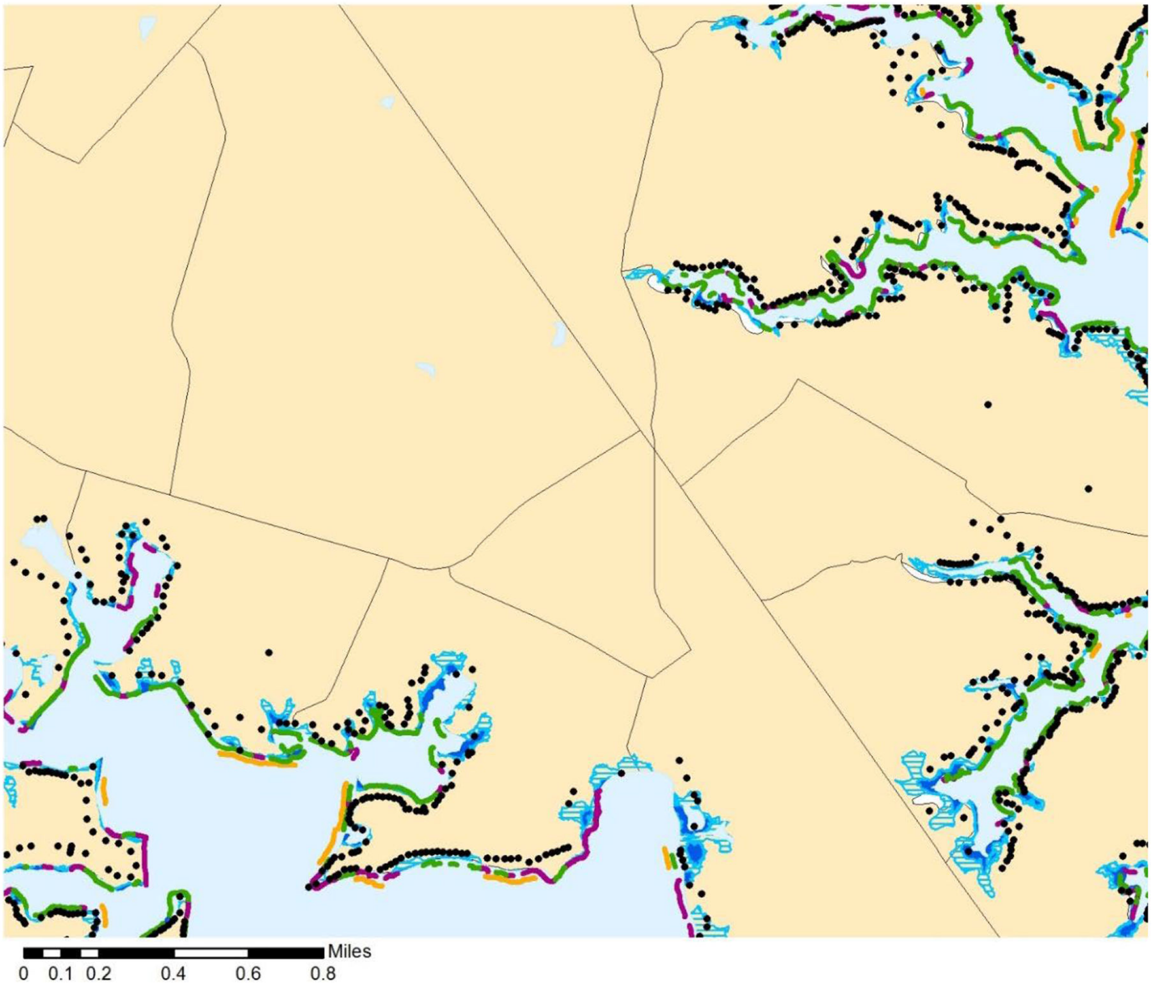

Figure 1:

Adaptation Structures, SLR Zones, and Census Block Group Boundaries

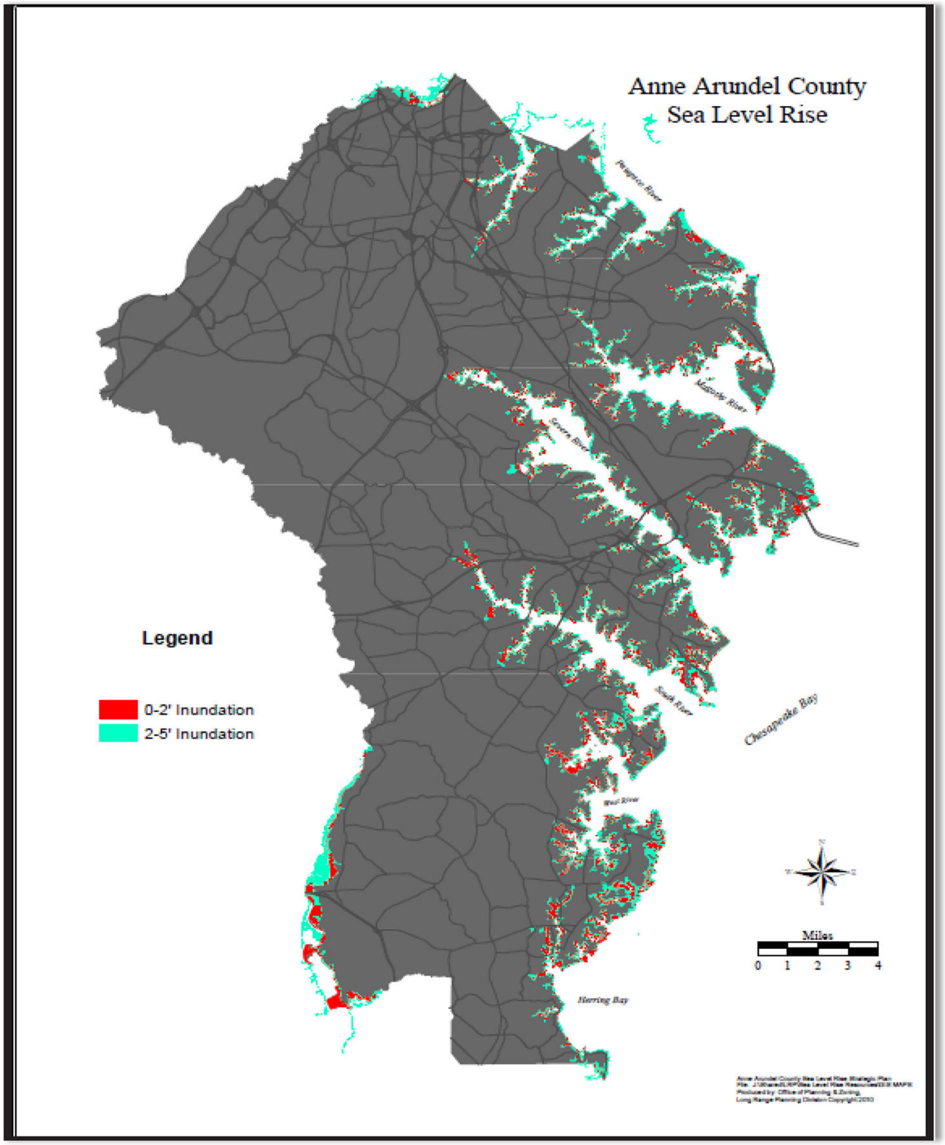

Figure 2:
Sea Level Rise Zones in Anne Arundel County

Table 1:

Descriptive Statistics (2,841 observations)

Variable	Mean	Std. Dev.	Min	Max
price	$694,963	$551,707	$32,318	$3,683,234
SLR Zone 0–2	0.041	0.198	0	1
SLR Zone 2–5	0.094	0.292	0	1
Bulkhead	0.374	0.484	0	1
RipRap	0.200	0.400	0	1
GroinField	0.052	0.223	0	1
Bulkhead Neighbor	0.191	0.393	0	1
Riprap Neighbor	0.274	0.446	0	1
High Density Res	0.086	0.281	0	1
Med Density Res	0.624	0.484	0	1
Forest	0.054	0.226	0	1
Water Depth	1.682	1.227	0.5	6.5
Distance to WWTP	5,288.36	3,448.32	340.86	13,458.69
Distance to DC (m)	48,899.61	4,287.37	31,186.80	57,624.15
Value of Improvements	$147,083	$148,680	$0	$2,396,310
Missing variables on Improvements	0.063	0.244	0	1
Age	34.75	27.52	0	207
Age squared	1,964.80	2,623.24	0	42849
Square feet of Structure	1,786.52	1,097.55	0	8566
Missing variables on Square feet	0.030	0.171	0	1
Lot Size (Acres)	0.593	1.804	0.018	64.99
Townhouse	0.106	0.308	0	1
Basement	0.483	0.500	0	1
Number of Bathrooms	1.860	1.068	0	10.5
Attached Garage	0.279	0.449	0	1
Pool	0.036	0.187	0	1
Pier	0.244	0.429	0	1
AC	0.673	0.469	0	1
Flood Zone	0.221	0.415	0	1
y03	0.194	0.396	0	1
y04	0.209	0.407	0	1
y05	0.196	0.397	0	1
y06	0.168	0.374	0	1
y07	0.133	0.340	0	1
y08	0.099	0.299	0	1

Table 2:

Property Sales by SLR Zones and Adaptation Structures in Sample

	0–2	**2–5**	**>5**	**Total**
Adaptation structure[*]	79	178	1,291	1,548
Bulkhead	*58*	*120*	*885*	*1,063*
Riprap	*27*	*81*	*459*	*567*
Groinfield	3	5	141	149
No structure	37	90	1,166	1,293
Total	116	268	2,457	2,841

[*] Properties may have more than one type of adaptation structure present.

Table 3:

Percent change in housing prices due to SLR zones and adaptive structures

	Basic Model		**Interaction Model**	
	Tract	**Block**	**Tract**	**Block**
SLR Zone 0–2	−0.0582	0.0121	-0.1887^{***}	−0.1120
	(0.0440)	(0.0488)	(0.0698)	(0.0749)
SLR Zone 2–5	0.0021	0.0306	−0.0228	0.0046
	(0.0298)	(0.0316)	(0.0423)	(0.0457)
Bulkhead	0.1580^{***}	0.1411^{***}	0.1365^{***}	0.1216^{***}
	(0.0205)	(0.0198)	(0.0218)	(0.0210)
RipRap	0.2048^{***}	0.1925^{***}	0.2057^{***}	0.1940^{***}
	(0.0243)	(0.0238)	(0.0266)	(0.0263)
GroinField	−0.0623	0.0288	−0.0667	0.0267
	(0.0538)	(0.0695)	(0.0536)	(0.0694)
Bulkhead*GroinField	0.1072	0.0192	0.1159	0.0252
	(0.0858)	(0.0829)	(0.0863)	(0.0834)
RipRap*GroinField	0.2368	0.0538	0.2273	0.0481
	(0.1763)	(0.1401)	(0.1743)	(0.1390)
SLR Zone 0–2* Bulkhead			0.2210^{**}	0.2166^{**}
			(0.1110)	(0.1067)
SLR Zone 2–5* Bulkhead			0.0912^{*}	0.0750
			(0.0537)	(0.0546)
SLR Zone 0–2*RipRap			0.2292^{*}	0.1429
			(0.1191)	(0.1057)
SLR Zone 2–5*RipRap			−0.0580	−0.0348
			(0.0513)	(0.0532)
Flood Zone	0.0029	0.0128	0.0071	0.0137
	(0.0232)	(0.0238)	(0.0234)	(0.0240)
Observations	2,841	2,841	2,841	2,841
Number of FEs	49	126	49	126
R-squared	0.778	0.802	0.779	0.803

Standard errors appear in parentheses.

Percentage change in price estimates in the table are transformed using the Halvorsen and Palmquist (1981) correction $(e^{\beta s}-1)$.

***p<0.01,

**p<0.05,

*p<0.1

Table 4:

Implicit Prices (Interaction Model)

	Tract	Block
Implicit price impact compared to a house outside of the 0–5 foot SLR zone and without a bulkhead or riprap (Average price of $540,994 based on 1,345 observations)		
Having a bulkhead	$73,856 ***	$65,799 ***
	(11,797)	(11,352)
Being located in 0–2 foot SLR zone (with no structure)	−$102,109 ***	−$60,614
	(37,784)	(40,533)
Additional effect of having a bulkhead in the 0–2 foot SLR zone	$119,560 **	$117,204 **
	(60,061)	(57,722)
Combined effect of a bulkhead and the 0–2 foot SLR zone	$68,043 *	$114,544 ***
	(34,891)	(38,394)
Having a riprap	$111,292 ***	$104,967 ***
	(14,377)	(14,242)
Being located in 0–2 foot SLR zone (with no structure)	−$102,109 ***	−$60,614
	(37,784)	(40,533)
Additional effect of having a riprap in the 0–2 foot SLR zone	$124,004 *	$77,302
	(64,422)	(57,192)
Combined effect of a riprap and the 0–2 foot SLR zone	$109,473 **	$114,552 **
	(50,168)	(50,517)

Standard errors appear in parentheses.

Implicit price estimates are based on the Halvorsen and Palmquist (1981) adjusted estimates in Table 3.

*** p<0.01,

** p<0.05,

* p<0.1

Table 5:

Neighbor Interactions

	Tract	Block
SLR Zone 0–2	-0.1923^{***}	-0.1227^{*}
	(0.0663)	(0.0711)
SLR Zone 2–5	−0.0335	−0.0101
	(0.0412)	(0.0444)
Bulkhead	0.2000^{***}	0.1699^{***}
	(0.0284)	(0.0277)
RipRap	0.2121^{***}	0.2123^{***}
	(0.0290)	(0.0294)
GroinField	0.0112	0.0781
	(0.0570)	(0.0695)
Bulkhead*GroinField	0.0392	−0.0150
	(0.0777)	(0.0766)
RipRap*GroinField	0.1394	0.0043
	(0.1562)	(0.1299)
Bulkhead*Neighbor	0.1446^{***}	0.1116^{***}
	(0.0291)	(0.0282)
RipRap*Neighbor	0.0754^{***}	0.0830^{***}
	(0.0207)	(0.0205)
SLR Zone 0–2* Bulkhead	0.2322^{**}	0.2424^{**}
	(0.1088)	(0.1064)
SLR Zone 2–5* Bulkhead	0.0918^{*}	0.0770
	(0.0522)	(0.0534)
SLR Zone 0–2*RipRap	0.2509^{**}	0.1575
	(0.1190)	(0.1049)
SLR Zone 2–5*RipRap	−0.0296	−0.0077
	(0.0519)	(0.0539)
Flood Zone	−0.0027	0.0059
	(0.0231)	(0.0236)
Observations	2,841	2,841
Number of FEs	49	126
R-squared	0.785	0.806

Standard errors appear in parentheses.

Coefficients in the table are transformed using the Halvorsen and Palmquist (1981) correction ($e^{\beta s}$-1).

***p<0.01,

**p<0.05,

*p<0.1