The Economic Effects of Shoreline Change on Housing Prices in Coastal Massachusetts

A thesis submitted by

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Abstract:

Using data on housing characteristics for homes sold between 2000 and 2010 in the towns of Duxbury, Marshfield, and Plymouth, as well as environmental data extracted from MassGIS, this study uses a hedonic pricing model to capture and value the risk of living near the coast in dollar terms. Distance between home and beach, elevation difference between home and beach, and the shoreline erosion rate of the nearest beach from each home were all deemed measurable indicators of shoreline change. This study suggests that the value homeowners place on easy access to the beach and beach amenities more than offset the erosion risks of living near the shoreline. However, as policy makers struggle to find erosion reducing solutions, they must perform thorough analyses on all aspects of the costs and benefits of shoreline erosion reduction methods before taking appropriate action.

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Section 1.

Introduction

Coastlines around the world are under threats of erosion resulting from the constant bashing of storms, wind, waves, and changes in ocean currents. Exacerbated by climate change, rising sea levels also result in the permanent inundation of homes and business, and increased risks of flooding during storms. While storms, wind, and waves can chip away at the shoreline, changes in ocean currents may have the opposite effect. Shoreline can expand or contract depending on the movement of ocean currents that carry sediment from one location to another.

The economic effects of shoreline change, of particular interest to those owning property near the waterfront, is gaining momentum as one of the favorite topics of research. More importantly, it carries significance from a policy perspective. As discussed in Kriesel, Landry, and Keeler (2000), communities can weigh the harmful and beneficial effects of the following policy decisions before deciding the next steps in dealing with shoreline erosion: leave the shoreline alone, nourish the beach, or create a hard stabilization of the shoreline (i.e. seawalls). In the Heinz Center study, *The Evaluation of Erosion Hazard* (2000), it was estimated that 25% of homes within 500 feet of the shoreline will be affected by erosion-related property loss in the next 60 years. To support the Heinz Center's policy recommendations of how to reduce erosion-related property loss, Kriesel et al. (2000) create a hedonic pricing model in an attempt to capture how erosion risks negatively affect coastal property values. More specifically, they used the variable *geotime* to value risk, which they defined as "the number of years until erosion reduces the distance between the building and the water's edge to zero." The Heinz Center and Kriesel et al. (2000) did not include Cape Cod or the New England coastal areas in their study.

This thesis develops a hedonic pricing model to aid in evaluating the net benefits of shoreline change. When presented with erosion-created hazards, people who live on or near the shoreline can choose either to protect their properties (via seawalls, beach nourishment, etc) or relocate farther away from the coast. Behavioral economic theory states that people tend to choose the option that results in the lowest cost. While the benefits of living near the coast are evident through the premium one pays in real estate price, this project seeks to capture and value the risk of living near the coast in dollar terms.

As such, this thesis will expand on the studies done by the Heinz center and Kriesel et al. (2000) by focusing on the Cape Cod communities of Duxbury, Marshfield, and Plymouth, Massachusetts. In addition, this thesis also builds on the Geographical Information System (GIS) methods used by Eberbach (2007) to create the environmental variables that are used to capture erosion risk in Sandwich, Massachusetts. Similar to Kriesel et al. (2000)'s *geotime* variable, this study will use the variable *erosionrate* in meters per year to capture risk of living near the shoreline. In addition, an original variable that incorporates the elevation of each individual shoreline property from the mean high water line will be used.

Section 2.

Literature Review

2.1 How to Value Shoreline

In "Economic Valuation of Shoreline," Brown and Pollakowski (1977) attempt to calculate the implicit price of living near bodies of water by analyzing the straight-line measurements they created in determining the distance between each home and body of water. As such, they sample neighborhoods in Seattle, a city known for being close to many bodies of water, for homes sold between 1969-1974, deflated to 1969 dollars. To ensure homogeneity between various bodies of water and neighborhoods, Brown and Pollakowski (1977) focus on single-family homes in neighborhoods with similar topography. In addition, they attempt to reduce differences in neighborhood characteristics by eliminating homes that are near large commercial areas, or homes near obstacles that would prevent access to the water's setback area. A setback area is an area along the coast where development is restricted or prohibited, and where people can make use of the public space.

After regressing the sale price of homes on housing characteristics, including the log of distance to the beach, Brown and Pollakowski (1977) find positive but diminishing marginal returns of setback width to house value. In addition, they pool a sample taken from areas without setback. In comparing the regressions for samples with the presence of setbacks and with the absence of setbacks, Brown and Pollakowski (1977) find that the premium that one pays for living near the waterfront declines at a much faster rate for homes without setbacks. They find that 3/4th of the marginal increase in home value due to living near the waterfront is lost at a proximity of 300 feet. This makes sense because if a beach is not suitable for recreational purposes, while the waterfront view is still valued, its marginal implicit contribution to property value will not be as large compared to properties with setback. However, an important idea to keep in mind for future studies is that the setback is viewed as a public good. If the setback becomes too congested, then perhaps the marginal increase to property value of a setback will not be as significant.

2.2 Shoreline Width is Dynamic

In "The Value of Disappearing Beaches: A Hedonic Pricing Model with Endogenous Beach Width," Gopalakrishnan et al. (2010) investigate the impact of an often overlooked flaw in hedonic pricing model studies dealing with shoreline change. While past studies have often found positive correlations between beach width and home value, they have not taken into account the dynamic nature of shoreline acretion and erosion. In addition, the act of selecting which beach to nourish is bias in itself. As such, communities must complete a thorough cost-benefit analysis before relying solely on beach nourishment to increase beach width and property values. To look more into this issue, Gopalakrishnan et al. (2010) focus on the variable *beach width*, where the estimator of the impact of beach width on housing prices suffers from attenuation and endogeneity bias. To see where this bias argument comes from, one must understand the inner workings of beach nourishment and how that interacts with the variable *beach width*.

Beach nourishment is the act of dredging sediment from one location, such as a beach or inlet, and depositing it onto another beach that is suffering from erosion problems. When beach nourishment is used in the hedonic pricing model, it also introduces bias because whether or not a beach receives nourishment is not a random event. For example, when erosion causes beach width to diminish around a heavily populated residential coastal area, members of the community will be motivated to nourish the beach. As a result, the now wider beach will influence property prices in the area. This results in an endogeneity bias in the estimator of the *beach width* variable. This is because there is a lack of randomization in determining which beaches to nourish. For example, beaches with more expensive homes in the vicinity tend to have a higher probability of receiving nourishment. In addition, *beach width* is a dynamic variable. Shoreline can expand or shrink at a given point in time depending on such factors as wind and ocean current patterns. Beach width can also differ depending on when the most recent beach nourishment event occurred and how often beach nourishment will take place; both factors are influenced by the current erosion rate of a particular area. While it is possible to measure beach width at a point in time to use in a hedonic pricing model, it is really the beach width measured over a period of time, and the future trajectory of erosion rate, that affects the sale price of property. As such, the use of a point-in-time measurement beach width results in a measurement error that results in attenuation bias.

To correct for attenuation and endogeneity bias, Gopalakrishnan et al. (2010) introduce instrumental variables in order to measure the marginal implicit price of beach width. The two instruments for *beach width* are "distance to continental shelf" and "beach quality attributes." The first instrument is correlated with the shoreface slope, making it an appropriate instrument because the shoreface slope affects the erosion rate of the beach, which in turn affects beach width. The presence of scarps was used to compile the "beach quality attributes" instrument because they signal the presence of erosion.

Gopalakrishnan et al. (2010) create four hedonic models in an attempt to value beach width. Using the two-stage least squares estimator, they find the coefficient on *beach width* to be five times larger than the coefficient on *beach width* using the ordinary least squares method. Interpreted, this means that beach width has a much larger impact on real estate price than stated in previous literature; property values along the Carolina shoreline decreased by up to 52% when erosion rate and cost of high quality sand, used for beach nourishment purposes, tripled. Gopalakrishnan et al. (2010)'s results carry significant policy implications as they suggest that communities should re-think using beach nourishment as a long-term option to maintain shoreline suffering from erosion. At a time when demand and costs for dredged sand continues to increase among shoreline communities, communities should research other options for maintaining the shoreline as the costs from beach nourishment may outweigh the benefits.

2.3 Capturing the Dollar Value of Risk Aids in Policy Making Decisions

Placing a dollar value on the risks of living near the shoreline proves to be of no use if one cannot incorporate that new information into policy making decisions to bring about economic value. In "Estimating the Value of Beach Recreation from Property Values: An Exploration with Comparisons to Nourishment Costs," Edwards and Gable (1991) provide insight to aid government agencies in their assessments of whether the demand for recreational beach activities outweigh costly beach nourishment projects as a method of erosion control. This study assumes that the implicit demand for beach recreation can be implied by the property values on the beach. Assuming a town average household income of $25,000 and the average distance to the nearest public beach being 5 miles, Edwards and Gable find a per household consumer surplus estimate of $20,100, which can then be used to compare the value of beach recreation to beach nourishment costs. Results suggest that anticipating the beach erosion rate one year into the future, and nourishing beaches according to that rate (in order to maintain beach size) is more cost effective than anticipating erosion rate ten years into the future.

This study showcases how model simulations can help policy makers put a numerical value on the consumer surplus of recreational beach activities experienced by households, which can be incorporated into beach nourishment decisions. However, one must remember not to rely solely on the property values on or near the beach in determining the implicit demands for beach recreation. Other factors that determine beach demand include users who travel from more distant places and businesses that sell products/services on or near the beach. On the other hand, Edwards and Gable explain that property owners pay a premium for waterfront homes because they have "stronger preferences for beach recreation than more distant users." As such, caution should still be used when equating beach property values to beach implicit demand.

Section 3.

Data Description

3.1 Compiling Structural Variables

Data used in this paper were purchased from The Warren Group, a real estate and financial information service data company. Data with property characteristics were purchased for all residential homes sold in the last 10 years for the coastal Massachusetts towns of Duxbury, Marshfield, and Plymouth. Originally, there were 5,925 homes included in the dataset. Figure 1 gives a visual representation of the homes used in this data set:

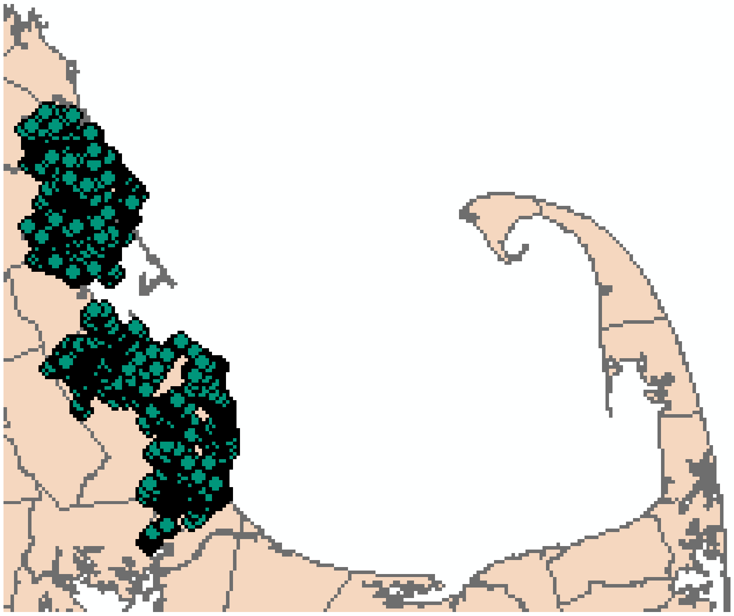

Figure 1: The focus of this thesis. 5,925 homes sold in Duxbury, Marshfield, and Plymouth between the years 2000-2010.

In order to focus on single-family homes, properties designated as condominiums (1,111 observations), 9+ Unit Apartment (1 observation), 4-8 Unit Apartment (23 observations), 3-Family Residence (10 observations), or 2-Family Residence (98 observations) were dropped from the data set. In addition, properties without a designation were also dropped from the data set (365 observations).

The following describes the restrictions that were imposed on the data. First, all homes with a last sale price of less than $10,000 were dropped (342 observations) in order to eliminate all sales within "arms-length." In addition, properties with latitude (41 observations), total rooms (20 observations), and/or bedrooms (1 observation) number of 0 were eliminated since these values were incorrectly reported. Next, properties with fewer than 1 bathroom (5 observations) or greater than 6 bathrooms (2 observations) were dropped. Finally, properties of age less than 0 (21 observations) when they were sold were dropped. After imposing the restrictions stated above, there were 3,945 observations left in the dataset. 545 of these homes are in Duxbury, 925 in Marshfield, and 2,475 in Plymouth.

For a list of variable definitions, please refer to Table 1 in the Appendix. Tables 2 to 5 in the Appendix present the summary statistics by town and also pooled across all towns. Table 6 in the Appendix presents the summary statistics across all towns, but limits the scope to homes in the first three rows from the beach. Table 7 in the Appendix presents the summary statistics across all towns, but excludes the homes in the first three rows from the beach.

3.2 Constructing Environmental Variables

Environmental variables were obtained using Geographic Information System (GIS) and the 2008/2009 Ortho Imagery from MassGIS. In order to obtain the *beachdistance* variable, I had to first plot the 3,945 homes in the three towns using latitude and longitude coordinates provided by The Warren Group (Figure 2). Next, I manually inserted points along the mean high-water line, which is the average high tide level usually indicated by areas of seaweed/sediment aggregation (Figure 3). Finally, I programmed ARCMap (GIS) to measure the shortest distance between each plotted home and any one of the points along the mean high water line, giving me the *beachdistance* variable.

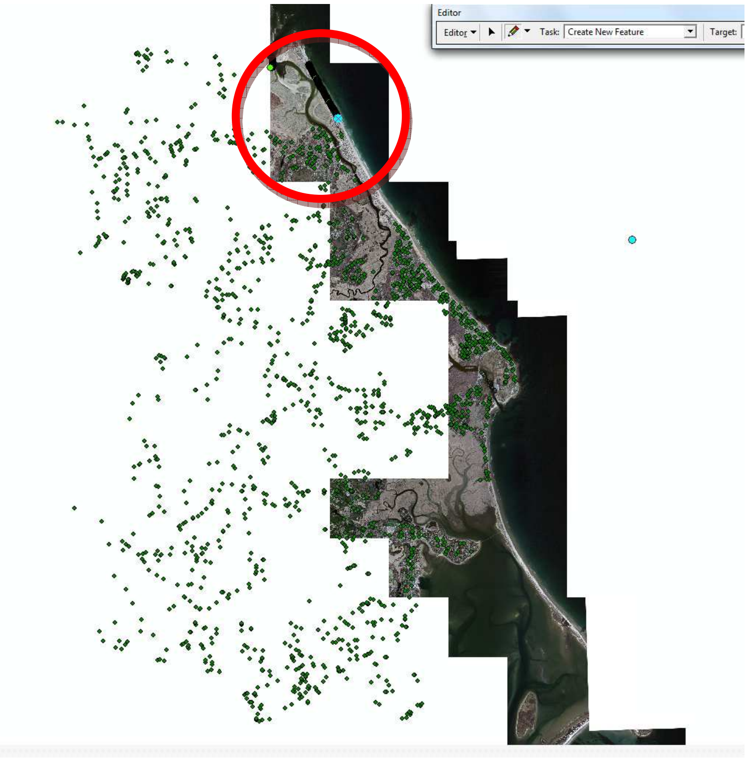

Figure 2: Green dots represent the 3,945 homes sold in Duxbury, Marshfield, and Plymouth between the years 2000-2010. The red circle highlights where I have started to manually insert points along the mean high-water line (dark line along the shore).

Figure 3: Green dots represent points drawn along the mean high-water line (average high tide level). Take note of how the line divides areas of dark colored sand, created by heavy sediment deposits, from areas of light colored sand.

A similar technique was also used to obtain the *elevationdifference*. A 2005 elevation layer downloaded off MassGIS, with each color corresponding to an elevation level, was placed on top of the layer in Figure 2. I then programmed ArcMap (GIS) to give me the difference in elevation between each plotted home and that same point selected as the shortest distance along the mean high water line (for consistency). Refer to Figure 4 below for a visual representation.

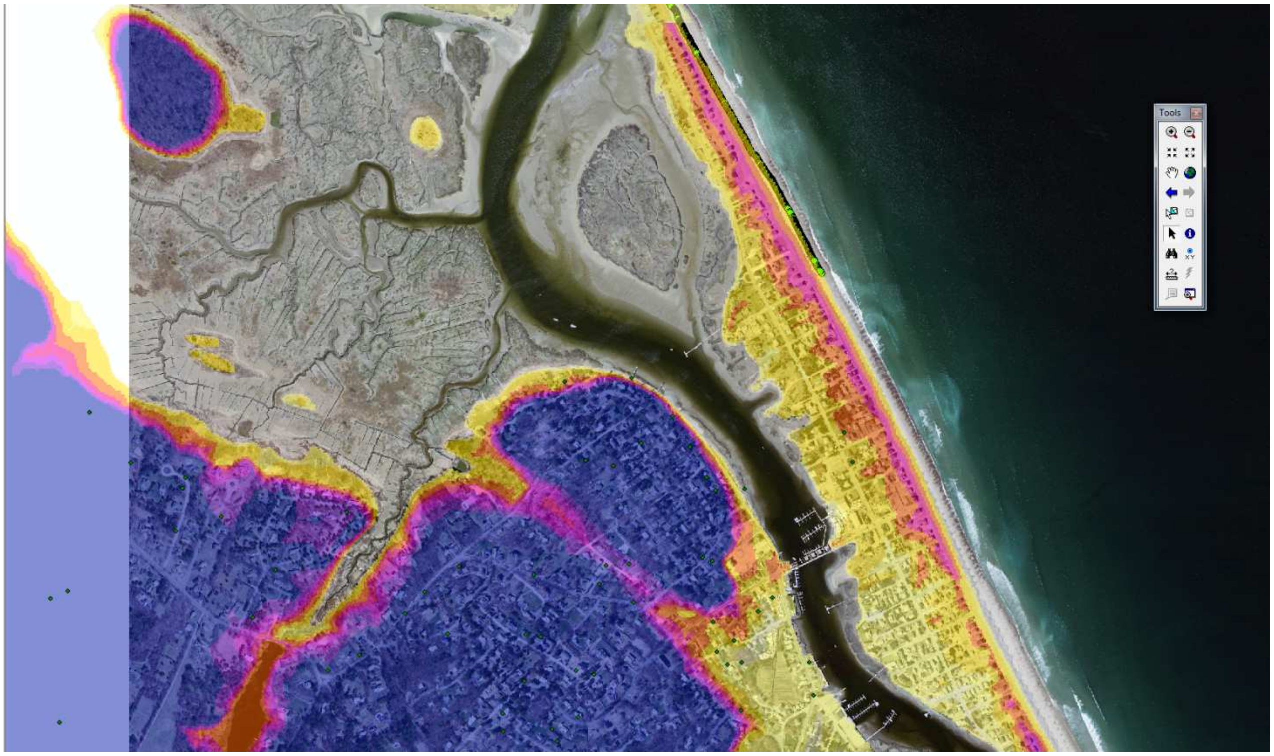

Figure 4: Elevation layer of coastal Massachusetts. Each color corresponds to an elevation level, with the dark purple indicating an elevation of 4+ meters.

Finally, in order to compile the *erosionrate* (erosion rate in meters per year) variable, erosion rates were calculated using transects that were created along the Massachusetts coast over a 150 year time span between 1884 and 1994. At each transect approximately 50 meters apart, a measurement of the mean high-water line was taken. To estimate the rate of erosion from two data points, the following equation was used:

rate = distance between 2 points / number of years (meters/year)

where the distance between 2 points was calculated by:

distance between 2 points = sqrt(
(x coordinate of mean high tide line in 1994 - x coordinate of mean high tide line in year closest to 1994 with data)^2
+
(y coordinate of mean high tide line in 1994 - y coordinate of mean high tide line in year closest to 1994 with data)^2)).

The erosion rates were then plotted along the coastline using their corresponding x and y coordinates (from the Massachusetts State Plane Coordinate System). Similar to the technique used to obtain the *beachdistance* and *elevationdifference* variables, ArcMap (GIS) was programmed to find the closest available erosion rate to each home.

Section 4.

Model Description

4.1 The Hedonic Model

The hedonic model is commonly used to determine how much each housing characteristic factors into property values. Using a hedonic pricing model similar to the one used by Kriesel et al. (2000), the natural log of the last sale price serves as the dependent variable, while individual property characteristics serves as the independent variables. The resulting regression coefficient on each independent variable can be interpreted as, for example in the case of *bathrooms*, the average percentage increase in property value associated with having one additional bathroom in the home.

Kriesel et al (2000) set up their hedonic pricing model using the structure first used by Freeman (1993) in "The Measurement of Environmental and Resource Values: Theory and Methods" where:

$$\text{Property Value} = f(S,N,Q)$$

S = Structural Variables
N = Neighborhood Characteristics
Q = Environmental Quality Characteristics

Freeman (1993) states that most of the characteristics that explain the hedonic price model fall into the categories of structural characteristics, neighborhood characteristics, or environmental characteristics. This study focuses on how environmental characteristics related to the proximity to the shoreline affects property values. More importantly, I am especially interested in how environmental variables affect property values as the coefficients on these variables are the marginal implicit prices that land owners are willing to pay to reduce the risk exposure of their properties (Smith, 1985). As such, the model analyzed in this study is as follows:

$$lnsaleprice_{it} = \beta_0 + \beta_1 S_{it} + \beta_2 N_{it} + \beta_3 beachdistance_{it} + \beta_4 elevationdifference_{it} + \beta_5 erosionrate_{it} + u_{it}$$

For clarification purposes, the *lnsaleprice* dependent variable is the natural log of the last sale price. This reflects the fact that the distribution of home sale prices is skewed to the right. As such, taking logs results in a distribution that is closer to a normal distribution, which generally results in a model that fits the data better.

4.2 Structural Variables

The structural variables used in this study to assess property values are: lot size (square acres), living area (square meters), total rooms, number of bathrooms, number of bedrooms, and the age of the house when it was sold. It is expected that lot size, living area, and number of bathrooms will have a positive effect on property values. This makes sense because larger homes tend to be more expensive. On the contrary, after a certain point, increasing the number of bedrooms in a home is expected to have a negative effect on property values. This is because *ceteris paribus*, increasing the number of bedrooms in a home while keeping, for example, living area constant produces an undesirable effect as the size of all other rooms in the house must now decrease. The age of the house when it was sold is also expected to have a negative effect on property values as it can be viewed, in some sense, as an annual depreciation rate (Kriesel et al, 2000). The amount of money needed to maintain or fix up a home is expected to be greater the older the property, thus decreasing property values.

4.3 Environmental Variables

The environmental independent variables used in this study to determine the effect of coastal erosion on property value are: *beachdistance* (distance to beach in kilometers), *elevationdifference* (elevation between home and mean high-water line in meters), and *erosionrate* (erosion rate in meters per year). Each of these variables are measurable indicators of shoreline change.

The coefficient on the *beachdistance* variable is expected to have a negative influence on property values. Properties closer to the shoreline are associated with such amenities as easier and faster access to recreational beach activities and a perhaps a better ocean view. This is the motivation behind the inclusion of the *rows1to3* dummy variable. The coefficient on the *rows1to3* dummy variable will indicate the premium one pays for real estate within the first three rows from the beach. While this may be the case, one must also consider the opposing positive influence to the regression. Properties located farther from the shoreline are more protected from erosion risk.

It is uncertain whether the coefficient on the *elevationdifference* variable is to have a positive or negative influence on property values. On the one hand, properties that are well elevated above the shoreline are more protected against floods and storm surges (reduced erosion risk is implicit here). The higher elevation may also provide a better ocean view. However, a higher elevation also means that one is more removed from recreational beach activities. As such, one would have to take more time traveling over longer distances to use the beach.

The coefficient on the *erosionrate* variable is expected to have a negative influence on property values. Properties near a shoreline with high erosion rates are expected to be worth less. This makes sense because properties farther away from a coastline with high erosion rates are more protected from erosion risk. Also, shorelines with lower erosion rates tend to have wider beaches and higher perceived beach quality. However, the opposing force here is that as properties become more removed from the coastline, they also become more removed from beach amenities.

Section 5.

Results

This section will showcase the regression results for the towns of Duxbury (regression 1), Marshfield (regression 2), Plymouth (regression 3), and the data pooled across all towns (regression 4) as seen in Table 8 in the Appendix. Regression 5 is the same as regression 4, except that 70 outlier observations were dropped across the three towns using the dfits (threshold = 2*sqrt((e(df_m)+1)/(e(N)) in Stata) threshold of 0.201. Unless otherwise stated, regression 4 is referred to when “pooled data” is mentioned. The natural log of home sale price was regressed on various property structural and environmental variables. In addition, the regressions in Table 8 include non-linear (squared) terms lot size and living area.

5.1 Structural Characteristics Results

Focusing on the structural characteristics, Table 8 shows a positive coefficient on property *lotsize* and *livingarea* at the 1% significance level across all towns (regression 4) as well as in each individual town. The only exception is the coefficient on *lotsize* in Duxbury, which was found to be statistically insignificant. However, the coefficient on *lotsize2* is negative and statistically significant at the 1% level in regression 4. This suggests that an additional square acre in lot size adds value to the property but at a diminishing rate.

As expected, the coefficients on the dummies indicating the number of bathrooms were positive at the 1% significance level for the regression across all towns. For the most part, the coefficients on the bathroom dummies for Duxbury and Plymouth were statistically significant at a 1%, 5%, or 10% significant level. A sample interpretation of the 0.102 coefficient on the *bathrooms2half* dummy in regression 4 indicates that having one additional bathroom in a home, holding all other independent variables constant, results in the sale price of a home being on average 10.7% higher. While regression results show that an additional bathroom contributes significantly to the sale price of a home, an additional bedroom does not have the same effect. None of the coefficients on the dummy variables indicating the number of bedrooms were statistically significant in regression 4. This suggests that keeping all else (including living area) equal, homeowners place more value on having an additional bathroom in the home rather than having an additional bedroom.

For the most part, the coefficients on the dummies for each sale year of a home were all positive and significant at the 1%, 5% or 10% significant levels across all towns. This means that relative to the base year of 2000, the value of properties have gone up. The exception here is that the coefficient on the *sale01* dummy variable was found to be statistically insignificant in

Duxbury and Marshfield. It is interesting to note that the coefficients on the dummies for sale years 2007 and onwards are not as large as the coefficients on the dummies for the previous years. This makes sense because the economy and housing market started to take a downturn in late 2007 with the recession beginning in 2008.

Furthermore, the age of the house when it was sold did have a statistically significant effect on the sale price of the homes across all towns. The town of Plymouth also had a statistically significant (1% level) negative coefficient on the *age* variable and a statistically significant (1% level) positive coefficient on the *age2_1000s* variable. Interpreted, this means that *age* has a negative impact on the sale prices of homes but at a decreasing rate. For example, the sale price difference between a 5 and 6 year old house would be greater than the sale price difference between a 20 and 21 year old house. Similarly, the town of Duxbury had a statistically significant (5% level) negative coefficient on *age*. This agrees with the intuition that an older home should result in a significantly lower sale price.

5.2 Environmental Characteristics Results

Turning our attention to the effect of environmental variables on home sale prices: This study produced nebulous results of the impact of shoreline change on home sale prices in each of the individual towns. Unless otherwise stated, regression 4 is referred to when "pooled data" is mentioned. The coefficients on *beachdistance*, *elevationdifference*, and *erosionrate*, were all found to be statistically significant (1 to 10% level) when the data are pooled. The same could not be said for the town-level regressions. Marshfield did not produce any statistically significant coefficients on the three environmental variables mentioned above. On the other hand, the negative coefficients on *beachdistance* and *elevationdifference* were statistically significant

(1% level) for Duxbury, while the negative coefficients on *beachdistance* and *erosionrate* were statistically significant (1% and 5%, respectively) for Plymouth. One explanation for the statistically insignificant coefficient on *erosionrate* in Duxbury is that the waterfront properties are enclosed in a bay area. As such, the perceived risk of living near the water is reduced due to the natural protection the bay offers from violent waves chipping away at the shoreline.

A negative coefficient on *beachdistance* makes sense because an increase in the distance one would have to travel to the beach would naturally have a negative effect on the sale price of a home. Likewise, an increase in the erosion rate of the nearest shoreline would also have a negative effect on the sale price of a home because 1) A higher shoreline erosion rate may be correlated with a more narrow/rocky beach thus affecting perceived beach quality and 2) A higher shoreline erosion rate may increase the probability of homes, particularly front row beach homes, of being washed away in future decades. Despite a statistically significant coefficient on the *erosionrate* variable, the negative coefficient on the interaction of the erosion rate variable with the dummy on the first three rows of homes, *erosionrate_rows1to3*, was found to be statistically insignificant in regression 4. In addition, the negative coefficient on the interaction of the elevation difference variable with the dummy on the first three rows of homes, *elevationdifference_rows1to3,* was found to be statistically significant at the 10% level when the data are pooled. The insignificance of the coefficient on *erosionrate_rows1to3* coupled with the significance of the coefficient on *elevationdifference_rows1to3* suggests that the value homeowners place on easy access to the beach and beach amenities more than offset the erosion risks of living near the shoreline. However, if one focuses on regression 5 where 70 outlier observations are dropped, the negative significant (10% level) coefficient on the *erosionrate_rows1to3* suggests that people do care about the erosion risks of living near the shoreline.

Another aspect to consider is the elasticities of the *beachdistance*, *elevationdifference*, and *erosionrate* variables. Despite the statistical significance of the coefficients, the elasticity for *beachdistance* is -.047%, while the elasticity for *elevationdifference* is .013%. Also, the elasticity for *erosionrate* is -.021%. In calculating these elasticities, the means when the data are pooled (regression 4) for *beachdistance* and *erosionrate* were used. However, the mean elevation difference for front row homes across all towns was used to calculate the elasticity of *elevationdifference.* This is because the *elevationdifference* variable is mainly applicable for homes close to the beach in determining the risk of living near the shoreline. The mean across all towns was used to calculate the elasticity of *erosionrate* because shoreline erosion affects beach quality, which in turn is thought to impact the value of beach amenity for both those living near and farther away from the beach.

It appears that the size of the coefficients on the three variables above is not large enough to have practical significance. If one evaluates the elasticity at the mean, a one percent increase in, for example, elevation difference between the home and mean high water line results in only a .013% increase in home value. Also, a 30 meter increase in elevation (based on a 0.001 coefficient) is going to cause a \$19,406 (3% of \$646,882) increase in sale price for the average home in the first three rows from the beach. Even so, \$19,406 is not a particularly large figure for a mean home sale price of \$646,882. This suggests that people will pay slightly more for homes that are higher up from the mean high water line (in order to reduce flooding risk), but not that much more to the extent that it removes them from the beach. One explanation of why a larger *elevationdifference* does not have a larger impact on sale price is that a home higher up from the beach can offer better ocean views. Regardless, while there are a wide range of sale prices and elevation differences in the dataset, the small magnitude of the *elevationdifference* elasticity figure means that *elevationdifference* does not have quite a significant real-life impact on the sale prices of homes.

It is difficult to analyze the environmental variables in each specific town as research into the data indicate statistically insignificant results due to, in most cases, low observation numbers. For example, separate dummy variables were initially created for each of the first, second, and third row homes as well as in each of the individual towns. However, it was found that $n<30$ in some towns and/or rows. As such, the decision was made to combine the first, second, and third row homes into one dummy variable and run a regression for these homes pooled across all towns.

Section 6.

Application: A Cost-Benefit Analysis of Beach Nourishment

According to the National Research Council's Committee on Beach Nourishment and Protection (1995), one must conduct a thorough cost-benefit analysis on a beach nourishment project before going ahead with such a costly project. Some of the benefits of beach nourishment to consider are the resulting property value change; changes in what beachgoers are willing to pay, amenity value, and commercial profits resulting from better perceived beach quality; spillover effects, and ecological benefits. Some of the costs to consider are the opportunity costs, negative externalities (such as environmental), negative changes in the amenities and quality of life, and the burden of having increased infrastructure.

This analysis will focus purely on the benefit to property prices versus the costs to nourish the beach in front of these properties. As seen in the regression results (4), homes within the first three rows from the beach sold for, on average, 60.0% more than homes that are not. The mean sale price of a home pooled across all towns, excluding the homes in the first three rows from the beach, was found to be approximately $395,000. As such, if the mean home was placed on the first three rows of homes from the beach, it would sell for approximately $636,000. Assuming that the all benefits to living on the beach are effectively captured in home value, the premium one pays to live on the beach is $241,000.

According to a study by Hoagland et al. (2011) the cost of beach replenishment in Massachusetts was found to be approximately \$14.43/yd^3 in 2008 dollars, or \$14.61/yd^3 in 2010 dollars using the Consumer Price Index released by the U.S. Bureau of Labor Statistics. Using the regression results found in the thesis, one is able to perform a cost-benefit analysis on the hypothetical situation of widening the public shorelines in Duxbury, Marshfield, and Plymouth by 1 cubic meter. To determine the benefits of the proposed beach nourishment, one must determine how much households are willing to pay for this additional cubic meter increase by backing out this figure from the coefficient on the *erosionrate* variable. The coefficient on *erosionrate* when the data are pooled (regression 4) was found to be -0.026, which means that a decrease in beach width of 1 meter will result in a 2.6% decrease in home sale price. The average home sale price in the dataset (in 2010 dollars) is $421,362.00. Because a 1 meter increase in erosion rate results in a $10,955.41 decrease in home sale price, we can also assume that each household is willing to pay this amount to increase beach width by 1 meter. With 3,945 households in the dataset, the total benefit to beach nourishment in Duxbury, Marshfield, and

Plymouth was found to be \$43,219,100.34. This figure holds under the assumption that on average, households in the three towns place some amount of value to having the beach near by.

To determine the cost of beach nourishment, one must first convert the \$14.61/yd^3 cost into cubic meters, which was found to be \$15.98/m^3. In addition, it was found that Duxbury has 37 miles of coastline, and Plymouth has 30 miles of coastline. While a figure could not be found for Marshfield, I will assume that Marshfield has 30 miles of coastline in this analysis. As such, the total miles of shoreline across the three towns are about 97 miles. This equates to 156,105.398 meters of public beaches. To determine the total cost of beach nourishment, simply multiple the total meters of public beaches by \$15.98/m^3. As such, the total cost of beach nourishment was found to be \$2,494,564.26. Finally, the hypothetical net benefit of beach nourishment in the three towns was found to be \$40,724,536.08. This shows that the households in the three towns should be willing to pay for 1 cubic meter of beach nourishment as the benefits to this are quite extreme.

However, policy makers must be cautious about moving forward with beach nourishment projects by first considering all the costs related to this in the foreseeable future. In addition, the magnitude of the net benefit (or cost) to beach nourishment differs from town to down depending on such factors as erosion rate and homeowners' willingness to pay. Now I will consider a cost-benefit analysis of periodic beach nourishment. The maximum erosion rate across the three towns was found to be about 2.50 meters per year. As such, the fastest eroding beach will have a 15 meter narrower beach width after 6 years. I assume that the average homeowner owns their home for 24 years, which means that the average homeowner pays for 4 beach nourishment projects. Based on these assumptions, the total cost of widening the coastline by 15 meters every

6 years for 24 years is $149,673,855.60 ($2,494,564.26 x 15 meters x 4 beach nourishment projects). As such, the upper-bound net (negative) benefit to beach nourishment is -$106,454,755.30. This is an example of a scenario where an initial beach nourishment project can bring a positive net benefit, but also result in a negative net benefit over time.

A cost-benefit analysis of the mean erosion rate across the three towns of 0.8 meter per year can also be considered. For a better comparison, the same assumptions from above will be used. The beach will be nourished every 6 years. After 6 years, the average rate eroding beach will have a 4.8 meter narrower beach. This will be rounded up to 5 meters for simplicity in calculations. As such, the total cost of widening the coastline by 5 meters every 6 years for 24 years is $49,891,285.20 ($2,494,564.26 x 5 meters x 4 beach nourishment projects). As such, the net (negative) benefit to nourishing a coastline that is eroding at the average erosion rate is only -$6,672,184.86.

If the total net benefit to beach nourishment can be shown to be positive (or close to positive), then one must question why towns are not sponsoring more beach nourishment projects in order to reduce the negative impacts from climate change. The problem boils down to who should take on a larger burden of the financial costs related to beach nourishment. While some believe that the states or towns should finance these projects, others believe that waterfront property owners who will see their home values rise as a result of beach nourishment projects should take on some of the costs.

Section 7.

Conclusion

Hedonic regressions were used to determine how housing and associated environmental characteristics contribute to property values in the towns of Duxbury, Marshfield, and Plymouth. Due to the small sample size of homes sold in each of the individual towns between the years 2000 and 2010, this study focused on the significant coefficients that were mainly found in the regression when the data are pooled (regression 4). As expected, regression results showed statistically significant (1 to 10% level) negative coefficients on the three measurable indicators of shoreline change: *beachdistance*, *elevationdifference*, and *erosionrate*. The negative coefficient on *beachdistance* is intuitive because making one more removed from the beach increases the distance one would have to travel to the beach. Naturally, this would result in the reduced sale price of a home.

While the negative coefficient on the *erosionrate* variable was statistically significant, the negative coefficient on the interaction of the *erosionrate* variable and dummy on the first three rows of homes (*erosionrate_rows1to3*) was not. One explanation of the case mentioned above is that a higher erosion rate affects perceived beach quality, and thus reduces home sale price. However, households in the first three rows from the beach seem to value their close proximity to a beach, rather than view it as a risky location that increases the probability of their homes being washed away in the future. To further support this conclusion, the negative coefficient on the interaction of the elevation difference variable with the dummy on the first three rows of homes (*elevationdifference_rows1to3*) was found to be statistically significant at the 10% level when the data are pooled across all towns (regression 4). While a higher elevation would provide more protection from floods for homes in the first three rows from the beach, regression results show that homeowners do not place much value on this elevation gain. Again, this suggests that the value households place on the ease of beach access offsets the erosion risks of living near the shoreline.

The value homeowners place on living near the beach explains why homes in the front three rows from the beach sold on average 60.0% more than homes not in the front three rows. It is also not surprising that the net benefit to households in the three towns of expanding their public shoreline by 1 cubic meter was found to be $43,219,100.34. In addition, the net cost to widening the coastline by 5 meters every 6 years for 24 years is only -$6,672,184.86.

While towns may use the techniques used in this study to make informed decisions about the costs and benefits of beach nourishment, beach nourishment may not always be the most cost effective and/or beneficial to both households and the environment. For example, beach nourishment can potentially be a danger to areas with fragile ecosystems as sand dredging may introduce non-native species that pose a threat. In addition, beach nourishment is not a permanent solution to expanding or maintaining beach width. An alternative to beach nourishment is the construction of seawalls. Seawalls are structures that are built in front of individual homes or group of homes so as to reduce the impact of waves crashing into the shoreline. However, even the presence of seawalls may prove to be environmentally costly as they can change/redirect shoreline currents to neighboring homes unprotected by seawalls, thus promoting floods. In addition, while seawalls are more costly to build, they also offer protection that lasts longer than a single beach nourishment project. Ultimately, policy makers must perform thorough analyses on all aspects of the costs and benefits of shoreline erosion reduction methods before taking appropriate action. But policy makers must act quickly, as the impacts of exacerbating climate change are becoming more and more devastating.

Section 8.

Appendix

Table 1 in the Appendix describes the different variables used in this study. Tables 2, 3, 4, and 5 provide summary statistics for the towns of Duxbury, Marshfield, Plymouth, and when the data are pooled across all towns, respectively. Table 6 provides summary statistics across all towns, but is limited to the homes located in the first three rows from the beach. Similarly, Table 7 provides summary statistics across all towns, but excludes the homes located in the first three rows from the beach. Table 8 displays four regression results for the towns of Duxbury (1), Marshfield (2), Plymouth (3), and across all towns (4).

Table 1: Data Description

VARIABLE	VARIABLE DESCRIPTION
beachdistance	Distance from home to mean high water line (in kilometers)
elevationdifference	Elevation difference between home and mean high water line (in meters)
erosionrate	Erosion rate of nearest measured shoreline point (in meters/year)
rows1to3	Dummy variable; 1 if home is within the first three rows of homes from the shoreline
elevationdifference_rows1to3	Interaction term between the following variables: elevationdifference and rows1to3
erosionrate_rows1to3	Interaction term between the following variables: erosionrate and rows1to3
lotsize	Lot size of property (in square acres)
lotsize2	Lot size variable squared
livingarea	Living area of home (in square meters)
livingarea2_1000s	Living area variable squared divided by 1000
age	Age of home when it was sold
age2_1000s	Age variable squared divided by 1000
totalrooms	Total number of rooms
bedrooms2	Dummy variable; 1 if home has 2 bedrooms
bedrooms3	Dummy variable; 1 if home has 3 bedrooms
bedrooms4	Dummy variable; 1 if home has 4 bedrooms
bedrooms5	Dummy variable; 1 if home has 5 bedrooms
bedrooms6	Dummy variable; 1 if home has 6 bedrooms
bedrooms7	Dummy variable; 1 if home has 7 bedrooms
bathrooms2	Dummy variable; 1 if home has 2 bathrooms
bathrooms2half	Dummy variable; 1 if home has 2.5 bathrooms
bathrooms3	Dummy variable; 1 if home has 3 bathrooms
bathrooms3half	Dummy variable; 1 if home has 3.5 bathrooms
bathrooms4	Dummy variable; 1 if home has 4 bathrooms
bathrooms4half	Dummy variable; 1 if home has 4.5 bathrooms
bathrooms5	Dummy variable; 1 if home has 5 bathrooms
bathrooms5half	Dummy variable; 1 if home has 5.5 bathrooms
sale01	Dummy variable; 1 if home sold in 2001
sale02	Dummy variable; 1 if home sold in 2002

sale03	Dummy variable; 1 if home sold in 2003
sale04	Dummy variable; 1 if home sold in 2004
sale05	Dummy variable; 1 if home sold in 2005
sale06	Dummy variable; 1 if home sold in 2006
sale07	Dummy variable; 1 if home sold in 2007
sale08	Dummy variable; 1 if home sold in 2008
sale09	Dummy variable; 1 if home sold in 2009
sale10	Dummy variable; 1 if home sold in 2010

Table 2: Duxbury Summary Statistics

Variable	Obs	Mean	Std.Dev.	Median	Min	Max
saleprice	545	$673,996.00	$420,469.00	$587,000.00	$40,000.00	$4,300,000.00
beachdistance	545	2.079	1.839	1.307	0.00498	7.171
elevationdifference	545	18.45	9.107	19.00	1	37
erosionrate	545	0.806	0.893	0.577	0.0114	2.550
rows1to3	545	0.0312	0.174	0	0	1
lotsize	545	1.122	1.154	0.940	0.0800	14.88
livingarea	545	226.7	91.50	211.9	43.11	560.2
age	545	45.63	49.03	34.00	0	305
totalrooms	545	7.459	1.611	7.00	3	15
bedrooms	545	3.576	0.817	4.000	1	6
bathrooms	545	2.476	0.813	2.500	1	5.500
yearbuilt	545	1961	49.02	1972	1700	2009
yearsold	545	2006	2.582	2007	2000	2010

Table 3: Marshfield Summary Statistics

Variable	Obs	Mean	Std.Dev.	Median	Min	Max
saleprice	925	$414,792.00	$191,929.00	$375,000.00	$11,700.00	$1,525,000.00
beachdistance	925	1.645	1.513	1.258	0.00744	11.44
elevationdifference	925	15.22	15.65	8.00	-7	70
erosionrate	925	0.654	0.415	0.637	0.0146	2.280
rows1to3	925	0.0346	0.183	0	0	1
lotsize	925	0.708	1.100	0.459	0.0321	14.30
livingarea	925	164.4	82.44	148.1	39.02	593.4
age	924	44.57	38.04	40.50	0	309
totalrooms	925	6.710	1.618	7.00	2	13
bedrooms	925	3.197	0.828	3.000	1	6
bathrooms	925	1.909	0.806	2.000	1	5
yearbuilt	924	1962	37.96	1967	1700	2009
yearsold	925	2006	2.603	2007	2000	2010

Table 4: Plymouth Summary Statistics

Variable	Obs	Mean	Std.Dev.	Median	Min	Max
saleprice	2475	$337,351.00	$138,800.00	$315,900.00	$15,000.00	$1,350,000.00
beachdistance	2475	3.093	2.49	2.878	0.0226	9.315
elevationdifference	2475	26.85	16.59	24.00	-7	83
erosionrate	2475	0.854	0.628	0.705	0.0101	2.204
rows1to3	2475	0.0246	0.155	0	0	1
lotsize	2475	0.636	0.683	0.470	0.03	8.04
livingarea	2475	172.1	72.24	161.3	40.88	542
age	2474	32.35	32.58	27.00	0	360
totalrooms	2475	6.709	1.735	7.00	2	16
bedrooms	2475	3.049	0.784	3.000	1	7
bathrooms	2475	1.884	0.747	2.000	1	5.5
yearbuilt	2474	1974	32.41	1978	1650	2009
yearsold	2475	2006	2.549	2006	2000	2010

Table 5: Summary Statistics Across All Towns

Variable	Obs	Mean	Std.Dev.	Median	Min	Max
saleprice	3945	$402,016.00	$240,800.00	$349,000.00	$11,700.00	$4,300,000.00
beachdistance	3945	2.613	2.301	1.852	0.00498	11.44
elevationdifference	3945	22.96	16.37	20.00	-7	83
erosionrate	3945	0.8	0.636	0.634	0.0101	2.55
rows1to3	3945	0.0279	0.165	0	0	1
lotsize	3945	0.72	0.887	0.490	0.03	14.88
livingarea	3945	177.8	80.09	164.8	39.02	593.4
age	3943	37.05	37.07	31.00	0	360
totalrooms	3945	6.813	1.711	7.00	2	16
bedrooms	3945	3.156	0.819	3.000	1	7
bathrooms	3945	1.971	0.796	2.000	1	5.5
yearbuilt	3943	1969	36.93	1975	1650	2009
yearsold	3945	2006	2.568	2006	2000	2010

Table 6: Summary Statistics Across All Towns (Limited to Homes on Rows 1 to 3)

Variable	Obs	Mean	Std.Dev.	Median	Min	Max
saleprice	110	$646,882.90	$588,648.60	$510,000.00	$80,000.00	$4,300,000.00
beachdistance	110	0.077	0.041	0.071	0.007	0.248
elevationdifference	110	13.16	12.39	7.00	0	47
erosionrate	110	0.598	0.510	0.477	0.010	2.182
lotsize	110	0.379	0.442	0.220	0.057	2.730
livingarea	110	177.74	99.78	156.2	41.62	541.44
age	110	52.53	33.24	50.50	0	130
totalrooms	110	6.445	1.850	6.00	2	12
bedrooms	110	3.055	0.917	3.000	1	5
bathrooms	110	2.077	1.003	2.000	1	5.5
yearbuilt	110	1953	32.93	1955	1880	2007
yearsold	110	2006	2.67	2006	2000	2010

Table 7: Summary Statistics Across All Towns (Excluding Homes in Rows 1 to 3)

Variable	Obs	Mean	Std.Dev.	Median	Min	Max
saleprice	3835	$394,992.90	$219,151.50	$345,000.00	$11,700.00	$3,700,000.00
beachdistance	3835	2.686	2.293	2.075	0.005	11.444
elevationdifference	3835	23.24	16.38	20.00	-7	83
erosionrate	3835	0.8061	0.6386	0.637	0.0109	2.5504
lotsize	3835	0.730	0.894	0.498	0.030	14.880
livingarea	3835	177.85	79.47	165.0	39.02	593.37
age	3835	36.60	37.08	31.00	0	360
totalrooms	3835	6.823	1.706	7.00	2	16
bedrooms	3835	3.159	0.815	3.000	1	7
bathrooms	3835	1.968	0.789	2.000	1	5.5
yearbuilt	3835	1970	36.94	1976	1650	2009
yearsold	3835	2006	36.94	2006	2000	2010

Table 8: Regression Results
DEPENDENT VARIABLE: Log of last sale price (*lnlstpr*).
Regression 4 base town is Marshfield. Regression 5 is the same as regression 4, except with 70 dropped outlier observations.

	(1)	(2)	(3)	(4)	(5)
TOWNS	Duxbury	Marshfield	Plymouth	All	All-Dropped
beachdistance	-0.037***	-0.010	-0.015***	-0.018***	-0.018***
	(0.010)	(0.009)	(0.003)	(0.002)	(0.002)
elevationdifference	-0.007***	0.001	0.001	0.001*	0.001***
	(0.002)	(0.001)	(0.000)	(0.000)	(0.000)
erosionrate	-0.005	0.027	-0.026**	-0.026***	-0.024***
	(0.016)	(0.028)	(0.011)	(0.008)	(0.008)
rows1to3	0.317	0.360**	0.549***	0.451***	0.390***
	(0.205)	(0.152)	(0.077)	(0.053)	(0.056)
elevationdifference_rows1to3	0.014	-0.024	-0.008**	-0.005*	-0.004
	(0.034)	(0.031)	(0.003)	(0.002)	(0.003)
erosionrate_rows1to3	0.073	0.072	-0.021	-0.042	-0.129*
	(0.237)	(0.114)	(0.078)	(0.059)	(0.067)
lotsize	0.038	0.074***	0.075***	0.059***	0.064***
	(0.026)	(0.023)	(0.019)	(0.011)	(0.011)
lotsize2	-0.002	-0.002	-0.008**	-0.003***	-0.005***
	(0.002)	(0.002)	(0.004)	(0.001)	(0.001)
livingarea	0.003***	0.005***	0.005***	0.005***	0.005***
	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)
livingarea2_1000s	-0.001	-0.006***	-0.005***	-0.004***	-0.004***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
age	-0.002**	-0.001	-0.002***	-0.001***	-0.002***
	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)
age2_1000s	0.005	0.001	0.007***	0.005***	0.005***
	(0.004)	(0.003)	(0.002)	(0.002)	(0.002)
totalrooms	0.015	0.034***	-0.005	0.001	0.002
	(0.017)	(0.011)	(0.007)	(0.006)	(0.005)
bedrooms2	-0.026	0.202**	-0.358	-0.038	0.076
	(0.148)	(0.088)	(0.310)	(0.311)	(0.091)
bedrooms3	0.139	0.172*	-0.374	-0.049	0.065
	(0.134)	(0.090)	(0.309)	(0.310)	(0.089)
bedrooms4	0.141	0.163*	-0.374	-0.046	0.072
	(0.128)	(0.096)	(0.309)	(0.310)	(0.089)
bedrooms5	0.091	0.155	-0.421	-0.078	0.036
	(0.128)	(0.109)	(0.309)	(0.310)	(0.091)
bedrooms6		0.517**	-0.539	-0.100	
		(0.253)	(0.331)	(0.319)	
bedrooms7	-0.210		-0.472	-0.177	-0.100
	(0.233)		(0.314)	(0.314)	(0.101)
bathrooms2	0.147***	0.015	0.050***	0.056***	0.054***

	(0.046)	(0.030)	(0.018)	(0.015)	(0.014)
bathrooms2half	0.167***	0.076**	0.101***	0.102***	0.094***
	(0.045)	(0.038)	(0.020)	(0.017)	(0.016)
bathrooms3	0.121*	0.053	0.071**	0.071***	0.049*
	(0.065)	(0.058)	(0.034)	(0.027)	(0.026)
bathrooms3half	0.292***	0.110*	0.145***	0.182***	0.161***
	(0.060)	(0.061)	(0.040)	(0.029)	(0.028)
bathrooms4	0.422***	-0.149	0.312***	0.197***	0.109*
	(0.140)	(0.107)	(0.074)	(0.055)	(0.058)
bathrooms4half	0.427***	0.306**	0.435***	0.406***	0.290***
	(0.102)	(0.147)	(0.101)	(0.064)	(0.068)
bathrooms5	0.429**	0.275		0.495***	0.327**
	(0.189)	(0.190)		(0.130)	(0.151)
bathrooms5half	0.627***		0.000	0.590***	0.260
	(0.202)		(0.301)	(0.159)	(0.214)
sale01	0.102	0.019	0.310***	0.163***	0.230***
	(0.125)	(0.115)	(0.071)	(0.054)	(0.055)
sale02	0.255**	0.240**	0.484***	0.353***	0.452***
	(0.114)	(0.103)	(0.066)	(0.050)	(0.051)
sale03	0.312***	0.329***	0.674***	0.507***	0.592***
	(0.100)	(0.100)	(0.063)	(0.048)	(0.049)
sale04	0.369***	0.522***	0.774***	0.618***	0.705***
	(0.099)	(0.098)	(0.063)	(0.047)	(0.049)
sale05	0.367***	0.576***	0.839***	0.665***	0.756***
	(0.095)	(0.098)	(0.062)	(0.047)	(0.048)
sale06	0.365***	0.569***	0.793***	0.642***	0.728***
	(0.098)	(0.097)	(0.063)	(0.047)	(0.048)
sale07	0.402***	0.425***	0.743***	0.578***	0.669***
	(0.096)	(0.097)	(0.062)	(0.047)	(0.048)
sale08	0.314***	0.368***	0.614***	0.470***	0.550***
	(0.096)	(0.098)	(0.063)	(0.047)	(0.048)
sale09	0.234**	0.318***	0.589***	0.431***	0.528***
	(0.094)	(0.096)	(0.062)	(0.046)	(0.047)
sale10	0.191*	0.331***	0.603***	0.439***	0.536***
	(0.097)	(0.097)	(0.063)	(0.047)	(0.048)
plymouth				-0.202***	-0.208***
				(0.013)	(0.013)
duxbury				0.218***	0.203***
				(0.017)	(0.017)
Constant	12.206***	11.302***	11.746***	11.740***	11.516***
	(0.233)	(0.138)	(0.308)	(0.310)	(0.111)
Observations	544	924	2,474	3,943	3,875
R-squared	0.690	0.605	0.519	0.632	0.630

Section 9.

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