THE BENEFITS AND ANCILLARY COSTS OF CONSTRUCTED DUNES: EVIDENCE FROM THE NEW JERSEY COAST

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In the aftermath of post-tropical cyclone Sandy, the federal government allocated approximately $4.5 billion to the US Army Corps of Engineers to construct dunes and fortify beaches against future storm surge and sea level rise. From a policy perspective, an important question is whether the benefits generated by these projects justify their costs. This paper treats the temporal and spatial variation in dune construction along Long Beach Island, NJ in the 12 years *prior* to Sandy as a quasi-experiment that can be used to estimate the benefits to property owners of these large-scale geoengineering projects. Using several identification strategies including a doubly robust Oaxaca-Blinder estimator, my results suggest that housing prices increased by 2.4 to 6.4% as a result of dune construction, with my preferred estimate implying a 3.6% capitalization effect. I then decompose this average effect into three components: 1) storm protection, 2) ocean view effects, and 3) recreational access effects. The latter two components are empirically found to be negative in my study area, implying that the storm protection benefits of constructed dunes are partially offset by ancillary costs associated with lost ocean views and increased visitor access.

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1   Introduction

In the United States, approximately 123 million people, or 39 percent of the population, live in coastal counties (NOAA 2013). Natural hazards, such as tidal flooding and storm surge, place private property and public infrastructure in these areas at an elevated risk for damages. Dense coastal development has led to degradation of ecosystem services that naturally mitigate these risks, with up to 90 percent of the Eastern seaboard experiencing net erosion in recent years (Galgano and Douglas 2000). Climate change further increases this vulnerability given the potential for future sea level rise (Thieler 2000) and a higher frequency of stronger hurricanes (Saunders and Lea 2008). Despite these risks, migration into coastal areas is projected to increase by 8 percent by 2020 (NOAA 2013).

The stabilization and fortification of beaches is thus an increasingly vital component of coastal policy in the United States. This relevance has amplified markedly in the last decade with recognition of the potential for increased damages from climate change and especially in the wake of post-tropical cyclone Sandy. To that end, this paper aims to evaluate a component of the US Army Corps of Engineers (USACE) coastline geoengineering policies related to the construction of dunes. These engineered dunes are costly to build, with expenditures ranging from $1 million to $10 million per mile of coastline. Moving forward post-Sandy, the USACE is now authorized to spend in excess of $4.5 billion in the Mid-Atlantic region alone. Given these expenditures, it is important to assess the economic benefits of constructed dunes. This paper achieves that objective by providing the first estimate of the value of coastal dunes as revealed through housing market transactions.

The stated goal of these constructed dunes is to provide benefits in the form of asset protection during storm events. However, credible identification of the magnitude of storm

protection benefits in practice is challenging for at least two reasons. First, there are many unobserved confounders correlated with storm protection in coastal environments. For example, Bin and Kruse (2006) estimate that homes in flood zones subject to wave action have 27% higher sales prices as compared to homes not located in a federally designated floodplain, demonstrating the conflation of amenities and risk. Second, dune construction impacts ancillary service flows separate from storm protection, such as ocean view and recreational access.[2] The interplay of these impacts determines the overall effect of a policy intervention as the behavior of economic agents can either enhance or offset a policy's goal of providing storm protection services.

This study overcomes the first concern by taking advantage of spatial and temporal discontinuities in dune systems on Long Beach Island, New Jersey. The sequence of events and available information *prior* to post-tropical cyclone Sandy (2000-2012) allow the potential confounds of correlated unobservables, sample selection, and multi-scale capitalization to be accommodated within a quasi-experimental research design. The dune system was only completed in three sections of the island – Surf City, Harvey Cedars, and Brant Beach – due to conflict over partial property easements required for construction to begin. These construction events were largely unanticipated as no community self-selected into the policy by providing all of the necessary signed easements. Implementation in the three treated communities was due to court filings, eminent domain, and re-engineering the dune around easement holdouts. In other words, property rights conflicts generated a state of affairs on the island where there were similar beach homes protected by a new constructed dune system and those that were not.

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This research design is supported by key pieces of evidence. First, erosion in both types of communities was relatively uniform, with treated and control neighborhoods having only 6.4 and 6.6 percent of the necessary protection from natural dunes to withstand a major storm event as recommended by the Federal Emergency Management Agency (FEMA). Second, income levels in the communities did not appear to play a role in selection, with the first two dunes being built in the communities with the lowest (Surf City - $64,375) and the highest (Harvey Cedars - $96,250) median household income levels on the island. Additionally, communities directly adjacent to these two with similar income levels did not receive the dunes. Third, statistical tests suggest that the dune did not induce sorting away from or toward communities with the constructed dunes.

Furthermore, my research design utilizes the logic of the *doubly robust* Oaxaca-Blinder estimator (Oaxaca 1973; Blinder 1973; Kline 2011) to identify the net effect of treatment.[3] This estimation strategy is robust to either exogeneity or conditional independence assumptions regarding treatment. I find housing prices increased by 2.4 to 6.4% as a result of dune construction, with my preferred Oaxaca-Blinder estimate implying a 3.6% capitalization effect. This market response is precisely estimated and economically important, suggesting that federal dune construction effectively transfers an average of $3,229 per year to owners of protected beachfront properties.[4] Results from a falsification test assigning treatment to adjacent control communities support the internal validity of the identification assumptions in my preferred model specification.

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[3] Banzhaf and Walsh (2013) and Kuminoff and Pope (2014) hinted at the usefulness of this logic in a hedonic framework in sorting models and in the interpretation of coefficient estimates as marginal willingness to pay, respectively.

[4] The annualization factor used in all calculations in this manuscript is: $AF = r \, / \, (1 - (1 + r)^{-n})$. For benefits calculations, the discount rate (r) is assumed to be 5% and the average tenure of single family homes *(n)* based on data from the 2011 American Housing Survey is assumed to be 15 years. Costs are calculated with the same discount rate and *n* being equal to the 50 year scope of the dune project.

The magnitude and significance of my results are supported by a number of robustness checks, including alternative estimators, alternative functional forms for the hedonic price function, and spatial boundary restrictions on the data. With current engineering costs approaching $250 million, or an annualized cost per household of $742, these benefit estimates indicate that the dunes are an effective policy. This policy passes a benefit-cost test as long as the present value discounted costs over the 50-year lifespan of the project do not exceed $1.13 billion (2012 dollars). Whether or not this cost threshold will be exceeded is an open question given the uncertainty of future maintenance costs and potential damages from storm events and sea level rise.

To address the concern about ancillary impacts, I utilize high resolution spatial data on dune quality and location, viewshed potential, and beach width to quantify the service flows affected by the dune to decompose the average effect. Results from a difference-in-differences estimation approach implies an average annualized capitalization of $16,122 for the large increase in protection experienced by each home behind the constructed dunes. This benefit outweighs losses associated with average changes in ocean view (-$2,607) and beach width (-$10,677) as a result of the policy intervention.[5] The negative effect from increased beach width captures congestion costs in my empirical setting, which is contrary to previous results in other locations that show positive effects to property owners related to additional beach width (i.e. Landry and Hindsley 2011; Gopalakrishnan et al. 2011).

As stated at the outset, constructed dunes are likely to become commonplace on the Eastern seaboard given the recently authorized federal expenditures. In the context of benefit

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[5] The total annualized capitalization estimated from the decomposition is $2,838, approximately 12 percent less than the capitalized value of the policy. This difference is likely attributable to the different estimations strategies used in the policy estimation (Oaxaca-Blinder) and the decomposition (Difference-in-Differences).

transfer, my estimated hedonic model and methods provide a framework to predict the effect on housing prices of different mixes of storm protection benefits and ancillary impacts in different locales. While my research design identifies the ancillary effects after they occur, future research should aim to integrate them into *ex ante* analyses of proposed policies.

More broadly, my research design demonstrates the importance of disentangling the direct and ancillary effects of climate adaptation polices to identify who wins, who loses, and by how much. Prior research on climate adaptation has largely focused on *ex post* changes in private behavior in the context of agriculture (e.g. Kelly et al. 2005), forestry (e.g. Guo and Costello 2013) and fuel choice (e.g. Mansur et al. 2008). In contrast, public policies will inevitably involve coordinated national strategies that target vulnerable regions and sectors of the economy. My results illustrate that such adaptation may generate economically significant ancillary benefits and costs, resulting in the potential for significant error in measurement of benefits from adaptation services without the decomposition of the policy effect.

The remainder of the paper is organized as follows. In section 2, I detail the coastal policy context and empirical setting. Section 3 discusses the hedonic method, the challenges associated with identification and interpretation of model estimates, and the ability of the model to decompose the policy effect. Section 4 describes the data while the fifth section provides a discussion of the assignment of treatment. The empirical modeling strategies are described in Section 6. Section 7 presents results for the policy effect and the decomposition. Section 8 discusses policy implications and the final section concludes.

2   Coastal Policy Setting

Since 1956, the USACE has engineered 56 percent of New Jersey's 97 miles of developed coastline. Historically, the engineering took the form of groins and jetties for stabilization and localized beach replenishment to support coastal recreation.[6] More recently, the USACE began to advocate for the coupling of beach renourishment with dune construction for storm protection instead of groin installation. As noted in the introduction, building dunes and nourishing beaches are costly, with average construction costs ranging from $1 - $10 million per mile of coastline. Additionally, $4.5 billion in future expenditures in the Mid-Atlantic is already authorized by Congress to the USACE (Disaster Relief Appropriations Act of 2013, P.L. 113-2). This is an unprecedented amount of planned expenditures, signaling that geoengineering of the coastlines is the primary federal strategy for dealing with erosion and the potential impacts of climate change.

The empirical analysis to identify the impacts of constructed dunes focuses on Long Beach Island (LBI), an 18-mile long barrier island in eastern Ocean County, NJ (Figure 1). LBI is bordered by the Atlantic Ocean to the east, Manahawkin Bay to the west, and the only vehicular access is via the State Route 72 bridge over the bay. Approximately 20,000 people reside on LBI year round, but with the island's close proximity to Atlantic City (25 miles), Philadelphia (55 miles), and New York City (75 miles), the summer population often swells to over 100,000 people.[7]

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[6] These stabilization efforts did not appropriately account for coastal dynamics, such as alongshore transport, that move sand in a non-uniform manner. Sand is trapped on one side of the groin at the expense of an adjacent section of beach, creating winners and losers in terms of net erosion at the local level. The renourishment of beaches (i.e. making beaches wider) has been utilized to support local tourism with the USACE spending approximately $5.7 billion (2012 dollars) on the eastern seaboard since 1956, with 21% of that total allocated to NJ.

[7] This arises from people using their homes as summer residences only or renting their homes to vacationers. While the rental market is substantial on the island, it is highly decentralized and records on rental transactions are not maintained by any realty agencies that operate on the island. Email correspondence with Dr. Joseph Seneca of Rutgers University confirmed this: "Data on rentals, rental prices, and supply are notoriously difficult since the industry is so fragmented and many rentals are not even done through agencies (e.g., owners letting rooms in their own homes, or the home itself, for a few peak weeks). This is especially the case in Ocean and Monmouth Counties

In the early 2000s prior to the USACE dune projects, the natural dunes along the island's six municipalities were virtually nonexistent (Barone et al. 2009) with their growth impeded by dense residential development. The island is built-out to near capacity with homes constructed directly on the natural dunes in close proximity to the mean high tide line. Severe erosion in recent decades had left beaches relatively narrow, reaching a width of only 73 feet at low tide in some locations. Thus, private property and island infrastructure are increasingly vulnerable to coastal hazards and in need of intervention to prevent substantial damage from future storm events and sea level rise.

In light of these large planned geoengineering expenditures, it is important to assess the benefits related to constructed dunes. These benefits lie in the buffer of protection the dunes offer to private property from storm surges and tidal flooding. The USACE typically estimates these benefits as avoided damages with either frequency-based or event-driven engineering models. For example, the USACE estimated the annual benefits for a completed 17-mile LBI dune system at approximately $7.7 million, or $440 per household (USACE 1999). This figure measures potential avoided damages from simulated storm events and does not account for behavioral responses to the dunes. From an economic perspective, these benefits can be estimated by modeling individual behavior in response to the policy as revealed through local housing prices.

Although the storm protection benefits of dunes would appear to be a welcome addition to vulnerable coastal communities, the policy opened a veritable Pandora's Box of legal conflicts over property rights with oceanfront homeowners.[8] Issues arise because the boundaries of private property extend to the mean high-tide line and include areas needed for proper dune

where most of Sandy's damage to shore properties occurred." Therefore, this analysis focuses on sales transactions only.

[8] The USACE dune policy is perpetual although a 50-year time horizon is used for benefit-cost analyses of projects.

construction. This necessitates obtaining voluntary partial property easements for construction to begin. Property owners' primary concern is their perception that dunes diminish property value resulting from ancillary costs such as lost ocean views, loss of use of their property, reduced privacy, and concerns regarding the perpetual easements.[9]

In New Jersey, the conflict centers on two well established doctrines of property rights. First, the public trust doctrine maintains access to waterways and shorelines for the general public and allows eminent domain takings and prescriptive easements on private coastal property if deemed in the public interest. Second, waterfront property owners maintain vested property rights to views, access, and ocean breezes and have a right to challenge any government project that would infringe on those rights. The inherent tension between these property rights creates legal challenges to implementing the dune policy where holdouts refuse to sign the easements.

Construction on the first dune began in 2006 in Surf City despite the NJ Department of Environmental Protection (NJDEP) not obtaining all necessary signed easements from property owners in the town. The NJDEP decided to seek a preliminary injunction against the holdouts, claiming the properties were being maintained in an unsafe manner and inaction on the easements was equivalent to failing to abate a nuisance related to severe erosion (*Milgram v. Ginaldi* 2008).[10] However, the outcome of this case ultimately supported the property owners, enforcing the notion that these takings must follow eminent domain procedures when property owners decline to voluntarily sign the easements.

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[9] Opposition is not limited to Long Beach Island. In 2001, the State of New York withheld permits for the USACE, effectively terminating the Fire Island dune project citing property owner opposition, among other concerns (Rather 2001). On Absecon Island, NJ, home of Atlantic City, the anti-dune group D.U.N.E (Do not Upset our Natural Environment) managed to get a referendum on the dune project in front of voters, ultimately delaying the process for a number of years.

[10] The federal government threatened to pull all federal money from the LBI project in 2006 unless at least one project commenced before September 30th. The NJDEP then decided to pursue this course of action in Surf City.

The second dune in Harvey Cedars was constructed in 2009 after the mayor decided to use eminent domain against six holdouts. One resident sued the town seeking more than the $300 compensation offered for the taking. The NJ Superior Court originally ruled that the dunes were a public good that provided *general* benefits to all Harvey Cedars residents and awarded the resident $375,000 as compensation for loss of ocean views (*Harvey Cedars v. Karan*, 2012). On appeal, the New Jersey Supreme Court set the precedent that if private markets shift as a result of the dune construction, then the dune has potential to produce *specific* benefits to homeowners closest to the dune (*Harvey Cedars v. Karan*, 2013). In September 2013, Karan settled out of court for $1.

Lastly, the third dune was constructed in Brant Beach in 2012 after the USACE and township officials agreed on an engineering solution to the holdout problem. The USACE simply altered the engineering plans to avoid construction activities on the property of the remaining holdouts, thus eliminating the barriers to starting construction.

The legal and political economy described above led to a situation where three communities received the dunes and neighboring communities on the *same* barrier island did not. The communities receiving the policy did not self-select into treatment as the required set of easements from oceanfront property owners was not finalized. The political and legal factors described above determined the course of policy implementation in the years prior to Sandy. This particular set of circumstances and available information allows causal estimation of the value of coastal dunes, as revealed through housing transactions, due to the discontinuous policy implementation.

A potential argument that the mayors of the towns with the lowest levels of protection from the natural dunes had more incentive to seek these political and legal solutions is quickly

countered by an examination of average cross sectional areas of the frontal dune in each town. Treated communities had an average cross-sectional sand area of 34.5 and control communities an average of 35.6. These values represent 6.4 and 6.6 percent of the necessary protection dictated by the FEMA-540 rule and demonstrate that the entire island was highly susceptible to dune failure during a major storm event. The evidence is also inadequate for an argument that income levels in each community may drive selection. The median household income for the island is $76,212 and the first two dunes went to the communities with the lowest ($64,375 in Surf City) and the highest ($96,250 in Harvey Cedars) income levels. Both communities have adjacent neighbors with similar income levels that did not receive the constructed dunes (see Table 1).

3   Recovering Policy Effects with Hedonic Models

To recover the impacts of constructed dunes on housing markets, I utilize a hedonic modeling framework. The maintained assumption underlying this model is that consumers derive utility from the attributes of goods instead of goods directly (Lancaster 1966). Rosen (1974) formalized this idea by theoretically deriving the link between the hedonic price function and preferences of individuals. A common empirical specification takes the general form:

$$P_i = \delta n_i + \beta \boldsymbol{h}_i + \epsilon_i \tag{1}$$

where P_i is the sales price of a house i, n_i is the non-market good of interest, $\boldsymbol{h_i}$ is all other observable characteristics of the house, such as number of bedrooms, square footage and lot size, and ϵ_i is an error term. The importance of Rosen's work lies in the interpretation of the gradient

of the hedonic price function (δ) as an implicit price, or marginal willingness to pay (MWTP),

for a small change in a non-market attribute of a house.[11]

The equilibrium outcome from a hedonic model is illustrated in Figure 2. Two

indifference curves (U^X, U^Y) representing buyers X and Y and two offer curves (O^W, O^Z)

representing sellers W and Z illustrate a market equilibrium defining the expected hedonic price

function for a given amenity. A household maximizes their utility by choosing a single home

with some level of amenity A, *certeris paribus*, subject to their budget constraint. Utility is

maximized at the equilibrium points X_A^* and Y_A^* for each buyer respectively. At these points, the

tangency of the indifference curves and the offer curves forms the hedonic price function. Each

point along the price function equalizes a household's willingness to forgo consumption of the

numéraire for a marginal increase in the amenity A.

3.1 Interpretation of Hedonic Estimates of MWTP

There are a number of challenges associated with interpreting hedonic estimates of MWTP.

While the challenges discussed below do not constitute an exhaustive list, they highlight primary

concerns with using a hedonic framework to value coastal dunes. The first set involves

judgments made by the researcher that are dependent on the empirical context. The decision on

the spatial and temporal extent of the market is critical as estimates with a too narrowly defined

market may be imprecise and bias may be introduced if a market is defined too broadly

(Michaels and Smith 1990). Next, incorrect delineation of the spatial scale of the impacted

amenity with misspecified spatial fixed effects may also introduce bias into model estimates

(Abbott and Klaiber 2011). The extent of potential bias resulting from these choices is explored

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[11] The interpretation rests upon simplifying assumptions commonly used in the empirical literature of a linear hedonic price function and homogenous preferences.

with various robustness checks on my preferred model specification and is discussed in detail in Section 7.

The second set relates to econometric concerns of endogeneity, selection, and functional form choice. Endogeneity caused by unobserved, spatially delineated variables correlated with the non-market good of interest has the potential to confound estimates. Sorting (e.g. Tiebout 1956) may also bias estimates due to the implied selection of desirable locations over undesirable based on unobservables.[12] Lastly, proper specification of the hedonic price function is needed to ensure slope coefficients represent MWTP (Kuminoff and Pope 2014) and may play a role in diminishing the effects of omitted variables (Cropper et al. 1988; Kuminoff et al. 2010).[13]

Development of quasi-experimental research designs exploiting an exogenous shock that varies the public good of interest (n) helps to alleviate some of these concerns.[14] The shock may take the form of an unexpected or unanticipated change in public policy. These types of analyses generally use a panel model, observing p, n, and h after the change in n:

$$\Delta p = \Delta n \chi + \Delta h \beta + \Delta \epsilon_i \tag{2}$$

This differencing strategy utilizes changes over time to remove the effect of time-invariant omitted variables. Note that the implicit price on a *change* in n is now denoted by χ, instead of δ as in equation (1). Careful development of this modeling framework allows identification of χ as an average treatment effect, purged of biases associated with endogeneity and omitted variables that plague traditional hedonic approaches. Next, concern about sorting generating selection

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[12] The assumption needed here to interpret results as an unbiased estimate of MWTP is that the shape of the price function does not change as a result of the change in the amenity of interest.

[13] Cropper et al. (1988) showed simpler functional forms performed best if omitted variables were present and the semi-log form became standard practice in hedonic modeling for many years. More recently, Kuminoff et al. (2010) showed that because omitted variables are now dealt with directly (i.e. quasi-experimental research designs and spatial fixed effects), a more flexible functional form may be the better choice when faced with an omitted variable problem.

[14] See Parmeter and Pope (2012) for a comprehensive review. Examples include studies looking at the housing market impacts of student test scores as a measure of school quality (Black 1999), childhood cancer clusters (Davis 2004), crime (Pope 2008), and proximity to Superfund sites (Greenstone and Gallagher 2008).

concerns induced by the dune policy is alleviated using a simple check to determine if the policy had an effect on the likelihood of a transaction (e.g. Muehlenbachs et al. 2014). I regress log annual transactions in each of the 12 neighborhoods on LBI on a policy indicator variable along with neighborhood and year fixed effects. The effect of the policy is small and statistically insignificant, lessening sample selection concerns.[15]

One final concern of particular importance for interpreting the average treatment effect as MWTP involves the assumption that the price function does not shift over time. The issue centers on whether or not the policy being evaluated generates a change in the variable of interest that alters the structure of the hedonic equilibrium. For relatively small changes, it is plausible that the gradient does not change (i.e. Palmquist 1992). If the change is large however, the hedonic price function may shift to clear the market and the slope coefficients may represent a capitalization effect, not MWTP. Kuminoff and Pope (2014) demonstrate that preferences must remain unchanged over time and the supply and demand curves cannot be altered by the change in the non-market good in order for capitalization effects to be interpreted as a welfare measure. In my simple exposition of the hedonic model above (equations 1 and 2), their insights are equivalent to noting that $\delta \neq \chi$. The research here identifies a capitalization effect and I provide a discussion of the potential direction and magnitude of the bias in the MWTP interpretation with the presentation of the results in Section 7.

Careful consideration is given to the above concerns during construction of the research design for the empirical work in this paper. Incorporation of these insights helps to identify the impact of an unanticipated policy change and modeling choices are made to minimize the potential biases that are prevalent in hedonic estimation. Further discussion related to the

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[15] The coefficient estimate on the policy variable is -0.026 with a standard error of 0.127 and a t-stat of -0.2.

empirical setting is now needed to address the potential for policy to impact multiple housing amenities.

3.2 Ancillary Policy Effects

Temporal and spatial variation in the public good of interest (constructed dunes) is utilized to identify the housing market impacts. However, this effect is influenced by multiple service flows. The policy leads to construction of 22' tall dunes in close proximity to oceanfront homes while also extending the beach berm seaward in the range of 100-200'. The dunes provide storm protection to the community but the height of the dune also compromises ocean views in homes in close proximity. The additional beach width increases recreation opportunities but also may induce congestion in the surrounding areas. Therefore, I view the effect of the construction of the dunes (*D*) on property values (*p*) as arising through three channels – storm protection (*s*), ocean views (*v*), and beach width (*b*) – with **H** and **L** representing vectors of housing and locational attributes influencing housing prices that are unaffected by the dune:

$$p = f[\boldsymbol{H}, \boldsymbol{L}, s(D), v(D), b(D)] \tag{3}$$

$$\frac{dp}{dD} = \frac{\partial f}{\partial s}\frac{ds}{dD} + \frac{\partial f}{\partial v}\frac{dv}{dD} + \frac{\partial f}{\partial b}\frac{db}{dD} \tag{4}$$

Estimation of the effect of constructed dunes (i.e. χ from equation 2) captures the summation of these three impacts, but does not offer insight into the composition. Measuring these components and including these variables in a quasi-experimental framework allows estimation of the decomposed effects to determine the mix of service flows present in the average policy effect.

An additional contribution related to this decomposition of the policy effect warrants discussion here. It relies on the interpretation of storm protection benefits from the dune as a value of climate adaptation. In the adaptation literature, Mendelsohn (2000) makes the distinction between types of adaptation: private versus joint (i.e. public) and anticipatory (*ex*

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ante) versus reactive (*ex post*). Guo and Costello (2013) provide the additional distinction between small adaptive changes in continuous choices (intensive margin) versus large, discrete changes with investment in new capital stock (extensive margin). To that end, federal dune policy anticipates storm events and sea level rise related to climate change and protects coastlines with large geoengineering projects to minimize future damages. In other words, the constructed dunes can be considered an *ex ante* public adaptation to climate change along the extensive margin.

Valuation of the benefits of this type of adaptation is lacking in the literature as the empirical applications to agriculture (i.e. Mendelsohn et al. 1994, Kelly et al. 2005), forestry (i.e. Guo and Costello 2013) and fuel choice (i.e. Mansur et al. 2008) relate to *ex post* private adaptation.[16] Here, I make a slight modification to the stylized model of adaptation valuation in Guo and Costello (2013) to demonstrate a key difference related to public adaptation. The first step is to define the value of adaptation in terms of a public policy outcome with ancillary impacts:

$$\text{Value of Policy = Value of Adaptation +/- Value of Ancillary Impacts} \tag{5}$$

The last term in (5) is a potential consequence of a large, discrete change that has the potential to cause bias if ancillary impacts are overlooked.

To illustrate this concern, assume a social planner seeks to maximize the net benefits of a function of housing values *H* in response to a policy change:[17]

$$H(\theta) = \max_{d} f(z, \mathrm{g}, \theta) = f(z^*(\theta), g[z^*(\theta)], \theta) \tag{6}$$

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[16] Other related *ex post* studies have focused on estimating the value of risk information provided by storm events, such as Hurricane Andrew in Florida (Hallstrom and Smith 2005), and Hurricane Floyd in North Carolina (Bin and Polasky 2004).

[17] I follow Guo and Costello (2013) by assuming the function *f* is strictly concave in θ and *g*, differentiable in θ and *g* and the envelope function *H* is continuous and differentiable.

where θ is an exogenous environmental parameter (e.g. erosion), z is a discrete choice policy variable with two outcomes, $z = \{z_0, z_1\}$, g is a private good (e.g. ocean views) impacted by the change in z, and $z^*(\theta)$ represents the optimal policy given θ. A small change in θ impacts the value of adaptation directly through the optimal choice of z and indirectly through the impacts on g resulting from that optimal choice.

$$\frac{dH(\theta)}{d\theta} = \frac{\partial f}{\partial z}\frac{dz}{d\theta} + f'[g(z^*(\theta))] \cdot \frac{\partial g}{\partial z}\frac{\partial z}{\partial \theta} \cdot \frac{dz}{d\theta} + \frac{\partial f}{\partial \theta} \tag{7}$$

If some threshold level of erosion is not reached, the policy is not implemented and housing values are only affected by the change in erosion ($\frac{\partial f}{\partial \theta}$). If the change in erosion crosses a threshold and results in constructed dunes, the value associated with the policy is now impacted by the value of adaptation ($\frac{\partial f}{\partial z}\frac{dz}{d\theta}$) in the form of storm protection benefits and the ancillary benefits or costs ($f'[g(z^*(\theta))] \cdot \frac{\partial g}{\partial z}\frac{\partial z}{\partial \theta} \cdot \frac{dz}{d\theta}$). This simple extension highlights the potential for bias resulting from interpreting the value of adaptation policy as the value of adaptation if the ancillary impacts are unaccounted for. The empirical analysis demonstrates that both of the post-policy impacts are economically and statistically significant and provides a clear connection to the simple analytical model presented here.

4   Data

4.1 Defining the Market

Housing sales for Long Beach Island were compiled utilizing deed records from the Ocean County Tax Administrator for all recordable transactions from January 1, 2000 until October 28,

2012. LBI is considered by many realtors as its own market due to the island's physical location and character.[18] The spatial extent of the market is restricted slightly by the USACE project scope. The northernmost municipality, Barnegat Light, is not part of the USACE project due to an existing natural dune system. The timing of the market brackets the initial release of information about the USACE's intention to build dunes and the landfall of post-tropical cyclone Sandy. The storm made landfall October 29th, 2012 and I assume that transactions with a closing date on or before October 28th, 2012 are not confounded by information related to the storm.

The universe of residential transactions during this time period contains 9,588 sales records with data on sales price, specific address with block and lot, age of the structure, and an arms-length transaction determination made by local officials. Initially, 610 transactions in Barnegat Light on the northern extent of the island are removed from the analysis. Additional transactions not deemed arms-length are also removed from the data set, reducing the number of potentially viable transactions to 6,744.

Additional data on housing characteristics were obtained from the offices of both county and municipal tax assessors. These data included variables such as the number of bedrooms, number of bathrooms, square footage, lot size, and indicators for the presence of a garage, hot tub and fireplace.[19] The deed records and tax assessor reports were merged using street addresses and by temporally matching date sold with the date on the relevant assessor reports. This merge eliminated an additional 1,167 transactions due to a lack of necessary housing characteristics. 314 observations with unrealistic values for certain variables (e.g. bedrooms = 0) were also removed. Lastly, the coastal location of the study area and the fundamentals of the real estate

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[18] The barrier islands to the north and south of LBI are state and federally protected land, leaving the densely developed island a center for real estate along the central coast of New Jersey. The island is self-contained with only a single access point by causeway. Anecdotally, the island contains very close-knit communities of relatively affluent households.
[19] The hot tub data allow control for the "Jacuzzi effect" discussed in Kahn and Walsh (2014).

market during this time frame led to a small number of knockdowns, where developers were razing older beach cottages and replacing them with larger, more luxurious homes. 351 suspect transactions were identified by observing the same property being sold multiple times in a single year or with quick re-sale (i.e. within 12 months of previous sale) at a substantial higher price. The resulting data set contains 4,912 residential, arms-length sales that are suitable for the empirical analysis.

Table 2 provides summary statistics for key transaction and housing characteristic variables. The mean sales price is $942,344 in 2012 dollars. This high sales mean is a function of the NJ real estate market, the desirable coastal location, and the prevailing market conditions during the study time frame. The average home in the study area has approximately 4 bedrooms and 3 bathrooms with interior living space totaling 1746 square feet and is about 36 years old. The average lot size is relatively small (~ 0.13 acres), indicative of the high density of development on the island. Additional covariates, such as distance to commercial property and public access points, are calculated using publicly available GIS data from multiple sources, including the NJDEP, the NJ Geographic Information Network, and the US Census Bureau. The second panel of Table 1 shows some key distance and location variables. For instance, the average home sold in the sample is 1,145 feet from the Atlantic Ocean, 935 feet from the nearest oceanfront public access point, and 808 feet from Manahawkin Bay.

The impact of insurance is controlled for using a flood zone fixed effect as determined by the National Flood Insurance Program maps.[20] All homes on the island lie in one of five potential flood zones, with 3 (VE, AO, and AE) located in the Special Flood Hazard Area.[21]

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[20] The flood maps are currently undergoing a revision so the existing maps have an effective date of September 29, 2006 - before any dunes were constructed. The three municipalities receiving dunes did not file a collective letter of map revision with FEMA to alter the 2006 flood maps to include the flood protection benefits of the dunes. Therefore, dune construction did not result in a change in NFIP insurance premiums.

4.2 Spatial Scale of Capitalization

Housing data are linked to a geo-coded parcel map obtained from the Ocean County Department of Planning in order to help define the spatial extent of the capitalization from the dunes. Identification of the exact spatial location of each transaction allows for the inclusion of spatial fixed effects that define the scale of capitalization and aid in reducing the potential confounds of omitted variables (i.e. Abbott and Klaiber 2011). Proximity to the beach is utilized as a *spatial bin* fixed effect. Each parcel is classified into one of 6 bins: oceanfront, oceanfront block, second, third, and fourth block from the ocean, and bayfront (see Figure 3). The blocks are determined by north-south roadways on the island. For example, oceanfront block homes are in the ocean block and residents do not have to cross a major roadway to access the beach. For the *neighborhood* fixed effect, four of the five towns (Surf City, Harvey Cedars, Ship Bottom, and Beach Haven) constitute individual neighborhoods while the large, discontinuous municipality, Long Beach Township, is divided into eight distinct neighborhoods.

The scale of the capitalization can be characterized in two dimensions based on the geographic orientation of the island. The neighborhood fixed effect captures the *north-south* dimension representing the scale at which the policy intervention occurs. The spatial bin fixed effect captures the *east-west* dimension under the assumption that homes in each spatial bin relative to the dune are impacted in a similar manner by the policy.

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[21] Flood zone designation is the primary driver of cost of premiums in the NFIP program with the median premiums in Ocean County, NJ for single-family homes are $3,144 for V zones, $806 for A zones, and $376 for X zones (Kousky and Kunreuther 2013).

4.3 Quantifying Amenity Variables

The level of storm protection is directly related to the size and positioning of the dune. [22] This

barrier provides both *frontal* and *lateral* protection. In terms of *frontal* protection, the Federal

Emergency Management Agency (FEMA) classifies a dune as an effective barrier to the wave

action associated with a 100-year storm event if the cross-sectional area of the frontal dune is

greater than 540 square feet. This frontal dune area is triangular with the base being determined

by the 100 year flood elevation and the height defined with a vertical line from the peak of the

dune as illustrated in Figure 4. Barone et al. (2009) measured this area at 250' intervals on Long

Beach Island in 2005 prior to any USACE replenishment project and I utilize this data set to

proxy for protection level in the control communities. This variable is calculated for all

transacted parcels in the control group by averaging the area values of the five bins in closest

proximity to the property. For the control group transactions, the mean (max) value for the cross-

sectional area of the frontal dune is 41.2 (159.9), or about 7 percent of the level required for

adequate protection. For treated parcels, a value of 540 is assigned as the dunes were constructed

by the USACE to satisfy the FEMA-540 rule.

Fortunately, there is a second aspect of the empirical setting that provides some variation

in the *lateral* protection level for treated transactions. The discontinuous nature on the dune

system generates a spatial externality, leaving protected homes on the boundaries more

susceptible to storm surge and thus less protected than homes in the interior of the dune. This

observation, motivated by Smith et al. (2014), is incorporated into the categorization of the

protection variable by measuring the distance of each treated parcel to the nearest lateral edges of

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[22] Simply using an indicator variable for protection is inadequate as it implies each home receives either no
protection or full protection from storm surges and flooding.

the three dune systems on the island. In other words, a property is assigned a higher protection level the further it is away from the boundary discontinuity in the dune system.

Using a combination of the measures for *frontal* and *lateral* protection, the protection variable is assigned a value on a scale of 0 (no protection) to 10 (protected by USACE dune and at least 3500' from the dune boundary). Values 0 to 5 correspond to *frontal* protection levels on the natural dune system for control group parcels. Values 6 to 10 are assigned to treated parcels and are differentiated by the level of *lateral* protection. Homes within 500 feet of the dune boundary are assigned a value of 6 while homes at least 3,500 feet from the boundary are assigned a value of 10. A value of 10 does not imply full protection but represents the highest level of protection possible on the island. Table 3 provides a breakdown of how the transacted parcels are assigned this value.

Ocean view is defined in terms of the degrees of Atlantic Ocean visible from an observer on each floor of each home, with a marginal change as a result of the policy expressed as a one degree decrease. Quantifying this presents a challenge since I cannot directly observe these views for each property in the sample. However, availability of rich spatial data for the study area combined with sophisticated geo-processing techniques allow for the estimation of an approximate viewshed for each observation. A viewshed tool was developed following a similar methodology outlined in both Bin et al. (2008b) and Crawford et al. (2014).[23] Details on the development of the viewshed tool are provided in Appendix A.3.

The USACE project also results in the addition of sand to increase the size of the beach berm seaward of the dune in the treated communities. A wider beach has the potential to increase

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[23] Crawford et al. (2014) find that using yearly viewshed measures in a coastal housing market did not produce significantly different effects on sales prices compared to a single viewshed for multiple years. Considering this result and the near build-out density of development on LBI, this analysis focuses on producing two viewshed measures (pre-dune and post-dune) to capture the policy impact on ocean views.

recreation opportunities and tourist visitation making beach width a common proxy variable in the coastal hedonic literature (e.g. Pompe and Reinhardt 1995, Gopalkrishnan et al. 2011). In this research, beach width is interpreted as a proxy for recreational access. Homeowners receive improved recreation opportunities but also endure increased visitation that reduces the semi-private nature of the beaches.

The variable for beach width corresponding to each parcel is a measure, in feet, of the distance from the nearest public access point to the Atlantic Ocean shoreline, including both beach berm and dunes. Due to the dynamic nature of erosion, GIS shoreline features at different points in time during the study time frame (2002, 2007, and 2012) are used to provide some variation in the beach width measure. Transactions are grouped into three periods, 2000-2004, 2005-2009, and 2010-2012 and assigned a width value based on the 2002, 2007, and 2012 shoreline, respectively. A marginal change is defined as a one-foot increase in width.

5   Defining Treatment

In 1999, the USACE first publicly announced plans for the construction dunes and beach renourishment along the oceanfront of a majority of the Long Beach Island (USACE 1999). All neighborhoods and parcels in the study area are slated to receive dunes and beach replenishment once the voluntary easements are signed by oceanfront homeowners. In every municipality, some of these property owners vehemently opposed the perpetual easements, citing loss of view, loss of privacy from increased public access, and a general distrust of the government agencies involved.[24] This resistance led to the overwhelming public opinion that the USACE projects

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[24] This point on opposition is strengthened by the fact that holdouts still remain despite the massive destruction caused by PTC Sandy on the island. The latest count (6/17/2014) shows 55 holdouts in Long Beach Township and

would not commence, even after a project cooperation agreement authorizing federal money for the project was signed in 2005 (Smothers 2006; Urgo 2006).[25] For instance, an April 2006 *New York Times* article stated "Work was scheduled to start this month but without all the easement agreements signed, that is unlikely. The delay places the federal money in peril; it will be taken back if none is spent by the end of the federal fiscal year on Sept. 30. The state allocation, which is a matching percentage of the federal money, would disappear as well." (Smothers 2006, pp B2).

However, in the intervening years prior to post-tropical cyclone Sandy, the proposed policy was *unexpectedly* completed by the federal and state governments in three neighborhoods on the island using a variety of political and legal maneuvers, including nuisance lawsuits, eminent domain, and threats of loss of federal funding.[26] In other words, no community self-selected into receiving the policy treatment and the political and legal moves provide a starting point for determining when the policy begins to impact housing prices. Figure 5 provides a comprehensive timeline of events surrounding the implementation of the policy.

Treatment is formally defined across both time and space. An observation is considered treated if the sales transaction occurs in one of the three neighborhoods receiving a constructed dune after a distinct treatment timing date. To operationalize this definition, GIS processes are utilized to identify each transaction in space and I make the following assumption regarding treatment timing:

Timing Assumption 1: Treatment occurs *after* construction is completed (A1)

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10 in Ship Bottom. Holgate (LBT) and Beach Haven have secured all easements and replenishment is sent to begin in the Fall 2014.

[25] Figure A.2 in the Appendix provides graphical evidence supporting this belief, showing that the housing market did not react to the agreement.

[26] A discussion of the political and legal environment during this time period is provided in Section 2 and Appendix A.1 to lend support to this assumption that the change was relatively unexpected.

This definition assumes that the housing market does not respond to the policy until it is fully implemented. This timing is appealing as it removes any potential uncertainty involving the amenity impacts of the projects. To further that end, transactions during the construction phase are removed from the data set. Graphical analyses of the price trends around the timing choice support this assumption. Figure 6 compares housing prices from 2000 – 2012 in first community to receive a dune, Surf City, and all control neighborhoods. The trend lines are estimated non-parametrically with a tri-cube weighting function and a bandwidth of 0.5 both before and after the end of dune construction in Surf City.[27] The graph demonstrates similar trends for both groups with a distinct jump in prices in Surf City and a small decline in the controls around the timing date. Figure 7 shows the same comparison with Surf City and its adjoining control neighbor, Ship Bottom, providing a localized picture of the discontinuity in prices. In this treatment, there are 357 parcels in the treatment group, or 7.2 percent of the remaining sample of 4,827 transactions.

A second treatment timing assumption is explored as a robustness check. Treatment is assigned in this scenario when the public becomes aware that the projects may commence in Surf City on June 16th, 2006, Harvey Cedars on July 15th, 2008, and Brant Beach on September 30th, 2011.[28] Graphical evidence using this second timing option supports the choice of the original timing assumption and is provided in Appendix A.2. Table 4 provides a summary of the treated observations categorized by timing assumption and spatial location on the island.[29]

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[27] This choice follows the work of Greenstone and Gallagher (2005) using Cleveland's (1979) tri-cube weighting function.

[28] The reasons for choosing these dates are discussed in detail in Appendix A.1.

[29] Simple Oaxaca-Blinder regressions using only the treated observations with an indicator variable for timing assumption show that there no statistically significant difference in housing characteristics between the two groups generated by the assumptions on treatment.

6   Empirical Strategy

Data are a pooled cross-section of housing sales on LBI observed over time.[30] All quasi-experimental estimation strategies used in this work utilize a combination of neighborhood, spatial bin, and flood zone fixed effects to control for time-invariant unobservables at a fine spatial scale while year and quarter fixed effects control for time-varying unobservables and adjustments in the housing market.

6.1 Conventional Assumptions and Methods

The policy arena surrounding this complex issue lends credibility to plausibly assuming that there are not any confounding factors that influence housing prices other than the dune and renourishment policy:

Treatment Assumption 1: Treatment is exogenous (A2)

The policy was not expected to be implemented in any community until political and legal interventions paved the way for construction in Surf City, Harvey Cedars, and Brant Beach at different points in time.

Treatment exogeneity motivates using regression-based methods, such as difference-in differences (DID), to identify the policy effect. In general, the treatment effect is written as follows:

$$DID_{TE} = E[Price_i^1 - Price_i^0 | \mathbf{X}, D = 1] \tag{8}$$

where $\mathbf{X}$ is a vector of housing attributes, D indicates treatment status, and the superscript on price indicates assignment in either the treatment (1) or control (0) groups.

Despite the evidence, exogeneity of treatment is still a relatively strong assumption. Alternatively, it is also plausible to assume that the assignment of treatment was determined by

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[30] The lack of a substantial number of repeat sales in this data precludes the use of property-level fixed effects.

observable characteristics of the oceanfront homes where owners were required to sign the easements for the projects to commence. In other words, the communities that received the treatment did so because of some observable differences in characteristics that led to the political and legal interventions:

Treatment Assumption 2: Conditional Independence (i.e. Selection on Observables) (A3)

This assumption states that treatment status is randomly assigned conditional on covariates. Formally,

$$(Price_i^1, Price_i^0) \perp (D_i \mid \mathbf{X}_i) \tag{9}$$

As shown in Table 5, there are observable differences in key variables that may help explain selection into treatment, specifically distance to public access and lot size. Oceanfront homes in the control group are further from public access points (i.e. more private) with an average distance of 184 feet, compared to 78 feet for the treatment group. The concern among oceanfront property owners is that increased public access with federal and state funds being used to construct the dunes will decrease property values and reduce their own enjoyment of the beach. This apprehension was discussed extensively in the local and national media prior to the construction of the first dune (e.g. Smothers 2006; Urgo 2006). Additionally, the control group oceanfront homes sit on larger lots and are likely to experience a larger loss in first floor views than homes on smaller lots. These differences lend credibility to selection on observables and applying the conditional independence assumption, or *unconfoundedness*, first proposed by Rosenbaum and Rubin (1983) in the context of propensity score models.

6.2 Oaxaca-Blinder Estimator

Choosing between the assumptions is problematic due to evidence that supports the plausibility of both assumptions. In order to accommodate this set of circumstances, I utilize the logic of the

Oaxaca-Blinder decomposition (Oaxaca 1973; Blinder 1973) to estimate the impact of the dunes. This technique is ideal for this research because it consistently identifies the parameter of interest under both sets of assumptions (Kline 2011). In other words, the estimator is *doubly robust*. Additionally, Kline (2011) also shows that this estimator has useful small sample properties for unbalanced research designs with small treatment groups relative to the controls. These properties bode well for this research where only 357 observations out of 4,827 are in the treatment group under the preferred treatment timing assumption.

The Oaxaca-Blinder estimator was developed for empirical work in labor markets, being used extensively to identify the wage impacts of racial and gender discrimination. Application of this logic in housing markets is a relatively new development, receiving cursory treatment in two recent papers. Banzhaf and Walsh (2013) use a form of the Oaxaca decomposition to reveal a potential for omitted variable bias in sorting models that ignore changes in reduced form relationships. Kuminoff and Pope (2014) note that allowing the coefficient of interest for a public good to vary across two time periods, while maintaining the assumption that the housing characteristics do not change over the same time frame, is equivalent to Oaxaca's (1973) original decomposition.[31] While these studies adapt Oaxaca decompositions to look at changes over time in housing markets, this study makes direct use of the decomposition to examine differences between groups at a point in time and estimates the net effect of treatment in a policy evaluation setting.

Specifically, the model of potential outcomes can be specified as follows:

$$\text{Price}_i^d = \mathbf{X}_i' \beta^d + \varepsilon_i^d, \tag{10}$$

$$\mathrm{E}\left[\varepsilon_i^d \mid \mathbf{X}_i, Dune_i \right] = 0 \quad \text{for} \quad d \in \{0,1\} \tag{11}$$

---

[31] A footnote indicates that exploratory tests of their capitalization model with Oaxaca decompositions were inconclusive and they were unable to compare the performance relative to their preferred models.

where $\mathbf{X}_i^{'}$ is a vector of housing attributes, β^d is a vector of coefficients, ε_i^d is the error term, and the superscript ^{d} indicates assignment in either the treatment ($d=1$) or control ($d=0$) groups. The differences in expected outcomes between the two groups can be decomposed in three steps:

$$
\begin{aligned}
E\left[Price_i^1 - Price_i^o \right] &= E\left[\mathbf{X}_i \mid Dune_i = 1 \right]^{'} \cdot \beta^1 - E\left[\mathbf{X}_i \mid Dune_i = 0 \right]^{'} \cdot \beta^0 \\
&= E\left[\mathbf{X}_i \mid Dune_i = 1 \right]^{'} \cdot \beta^1 - E\left[\mathbf{X}_i \mid Dune_i = 0 \right]^{'} \cdot \beta^0 \\
&\quad + E\left[\mathbf{X}_i \mid Dune_i = 1 \right]^{'} \cdot \beta^* - E\left[\mathbf{X}_i \mid Dune_i = 1 \right]^{'} \cdot \beta^* \qquad (12) \\
&= E\left[\mathbf{X}_i \mid Dune_i = 1 \right]^{'} \cdot \left(\beta^1 - \beta^* \right) + \left(E\left[\mathbf{X}_i \mid Dune_i = 1 \right]^{'} - E\left[\mathbf{X}_i \mid Dune_i = 0 \right]^{'} \right) \cdot \left(\beta^* - \beta^0 \right) \\
&= E\left[Price_i^1 - Price_i^* \mid Dune_i = 1 \right] + \left(E\left[Price_i^* \mid Dune_i = 1 \right] - E\left[Price_i^o \mid Dune_i = 0 \right] \right)
\end{aligned}
$$

The second line adds and subtracts the unobserved counterfactual. The reference coefficients β^* estimate the counterfactual price structure and are determined by the weighting matrix ($\mathbf{\Omega}$):

$$
\beta^* = \mathbf{\Omega}\hat{\beta}^1 + (I - \mathbf{\Omega})\hat{\beta}^0 \qquad (13)
$$

 The third line consolidates terms and the fourth line is the resulting decomposition. The first term of the fourth line in (12) is equivalent to the net effect of treatment (i.e. the unexplained component) and the second term captures the difference in price attributable to differences in characteristics between the treatment and control groups (i.e. the explained component).

Operationally, separate regressions are run for both treatment and control groups to recover least squares estimates of β^0 and β^1. The decomposition then requires an estimate of the unobserved counterfactual coefficient vector β^*, which is dependent on the choice of $\mathbf{\Omega}$. In his original work, Oaxaca (1973) estimated the counterfactual wage in absence of gender discrimination separately using the wage structure for each group as reference (i.e. male $\mathbf{\Omega}_O = 1$; female $\mathbf{\Omega}_O = 0$) to show a range of potential values for the discrimination coefficient. Reimers (1983) thought the counterfactual wage structure should lie somewhere in between and choose to

use $\mathbf{\Omega}_R = (0.5)I$ as the weighting matrix. Cotton (1988) argued that the weights should reflect

the composition of the two groups in the sample, $\mathbf{\Omega}_C = sI$, where s captures relative group size.

Oaxaca and Ransom (1994) argue that each of the weights described above are arbitrarily chosen

and theoretically derive a weighting matrix given as:

$$\mathbf{\Omega}_{OR} = (\mathbf{X}'\mathbf{X})^{-1}(\mathbf{X}_0'\mathbf{X}_0) \tag{14}$$

where $\mathbf{X}$ is a matrix of observations for a pooled sample (i.e. both treated and control

observations) and $\mathbf{X}_0$ is the observation matrix for the control group. The weighting matrix in

(14) interprets the regression estimate from a pooled model over both groups as the

counterfactual price structure that would exist in the absence of treatment. In other words, it is

equivalent to using the coefficients from a pooled model as the reference coefficients instead of

using reference coefficients from an arbitrarily assigned weighting matrix.

For this empirical work, it is difficult to determine whether the treated or control

properties are more representative of the housing market in absence of treatment, eliminating

Oaxaca (1973) as a potential weighting strategy. The unbalanced nature of the data set

eliminates Reimer (1983) as a feasible option. Cotton (1988) is intuitively appealing but as

Oaxaca and Ransom (1994) note, it is an arbitrary choice. Therefore, I utilize Oaxaca and

Ransom's (1994) theoretically derived weighting matrix for this analysis.[32] The reference

coefficients for (13) can then be expressed as follows:

$$\beta^* = \mathbf{\Omega}_{OR}\hat{\beta}^1 + (I - \mathbf{\Omega}_{OR})\hat{\beta}^0 \tag{15}$$

where (14) defines $\mathbf{\Omega}_{OR}$, and $\hat{\beta}^1$ and $\hat{\beta}^0$ are the estimates for the treatment and control groups,

respectively.

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[32] Results for the parameter of interest using the alternative weighting schemes are presented in Appendix A.4 for comparison purposes.

6.3. Decomposition of Amenity Effects

The decomposition of the policy impact is needed to separate the economic value associated with providing storm protection from the ancillary impacts associated with the dune. Since the Oaxaca-Blinder estimator identifies only average differences between two groups, decomposition of the impact of the dune into the heterogeneous amenity effects requires a different modeling strategy. A difference-in-differences framework is adopted here and the dune effect is decomposed by adding interaction terms with the treatment variable for each affected amenity as follows:

$$\ln \text{Price}_{ijt} = \alpha + Protect_{it}\left[\delta_1 + \delta_2 Dune_{it}\right] + View_{it}\left[\chi_1 + \chi_2 Dune_{it}\right] +$$
$$BW_{it}\left[\mu_1 + \mu_2 Dune_{it}\right]\mathbf{X}_{it}\sigma + \mathbf{L}_{it}\rho + \tau_t + \eta_j + v_i + \gamma_i + \varepsilon_{ijt} \tag{16}$$

This model takes a semi-log form with the natural log of the *Price* of house i in municipality j at time t as the dependent variable. $Dune_{it}$ is the policy variable of interest equal to one if the transaction is assigned treatment status while $Protect_{it}$, $View_{it}$ and BW_{it} are variables quantifying protection, first-floor ocean views, and beach width, respectively. The vectors $\mathbf{X}$ and $\mathbf{L}$ represent housing and location characteristics of each transacted home. The model also contains fixed effects for time (τ_t), neighborhood (η_t), flood zone (v_i), and spatial bin (γ_i). The coefficients of interest (δ_2, χ_2, μ_2) capture the impact of each respective amenity as a result of dune construction. The model is estimated with robust standard errors clustered by neighborhood, year sold and month sold.

7   Results

7.1   Value of Coastal Dunes

The preferred research design uses the Oaxaca-Blinder estimator with the Oaxaca and Ransom (1994) weighting matrix and bootstrapped standard errors, timing assumption (A1), and a semi-log function form for the hedonic price function. The first row of Table 6 shows the results for the net effect of treatment of the dune on property values. The naïve model in column (1) using only housing characteristics and the spatial amenities as controls shows no significant effect. The model in column (2) estimates a positive significant effect of 10.6 percent resulting from the dune using only spatial and temporal fixed effects as covariates. Column (3) shows the results from the preferred model specification, utilizing all housing characteristics, spatial amenities, distances to important features, and fixed effects. The estimated capitalization as a result of construction of the dune is approximately 3.6 percent and highly significant.[33] This translates to an average capitalization in the range of $27,222 - $33,511, or an annualized benefit of $2,623 - $3,229 per home.[34] For a fully built dune system on LBI, the annual benefit would range from $45.9 to $56.5 million dollars.

With these results, it is important to return to the question of interpretation raised in section 3. At the very minimum, this research design generated estimates of the capitalization of the dunes into the local housing market, reflecting a measure of the economic value of adaptation policy. Given the modeling choices in this empirical work, I return to the sufficient conditions of Kuminoff and Pope (2014) for interpreting capitalization as a welfare measure, or MWTP. First, rewrite the time-differenced hedonic price function from (2) as:

$$\Delta p = (n_2 \chi_2 - n_1 \chi_1) + (h_2 \beta_2 - h_1 \beta_1) + \Delta e \tag{17}$$

---

[33] Percentage effects determined using the method outlined in Halvorsen and Palmquist (1980).
[34] Results based on median ($765,492) and mean ($942,344) sales prices in the sample and assuming a time horizon of 15 years (which is the average tenure of single family homes based on data from the 2011 American Housing Survey).

The welfare interpretation of the estimated effect is valid if $\chi_2 = \chi_1$, $\beta_2 = \beta_1$ and the error terms

are orthogonal. In order to compare my results to estimates where these conditions hold, I

estimate six single-year hedonic price functions for 2007 – 2012, with 2007 being the year the

first dune was completed. I utilize the exact model specification as the full sample for each year.

Results show a range of significant policy effects from 2.9 percent to 5.7 percent.[35] These results

suggest the wedge between the two is likely to be small in this setting, allowing cautious

interpretation of capitalization as ex-post MWTP.

In terms of the spatial scale of the capitalization, it is naïve to assume that the impact is

homogenous for all homes on the island. Additional models are run for each spatial bin. The

point estimates indicate a spatial limit to the effects and non-monotonic pattern to the

capitalization of benefits from the dune. Oceanfront block homes receive the largest benefit of

6.6 percent, with oceanfront homes increasing by approximately 4.3 percent.[36] Homes in the

second block from the ocean have an insignificant 1 percent impact. This lack of an impact may

be explained by the fact that the second block tends to be a narrow band between two main

north-south thoroughfares with numerous commercial properties, indicating other factors have

more influence on prices than construction of the dune.[37] The positive and significant impact

extends to homes in the third block (3.1 percent) and turns negative and insignificant after that

point. The non-monotonic nature of these results is displayed in Figure 8 with 95 percent

confidence intervals around the point estimates.

7.2   Robustness Checks

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[35] See Table A.2 in the Appendix for a table of these results.

[36] Although the point estimates show a non-monotonic result, a T-test cannot reject the null hypothesis that the coefficients for oceanfront and oceanfront block are the same.

[37] Alternatively, the sample sizes are much smaller for these spatial bin models creating difficulty in estimating the effects precisely.

The preferred model specification is subject to assumptions on treatment assignment, treatment timing, functional form, and the specific spatial-temporal landscape for the housing market. To first test the identification assumptions of the preferred model, I conduct a falsification test. I would expect that the control outcomes should not be affected by the treatment intervention. Therefore, I eliminate all treated observations so the data contain only control group observations. Next, I falsely assign treatment to control communities that are directly adjacent to treated communities under the same timing assumptions as my preferred full sample model. The results suggest a net effect of treatment that is not significantly different from zero, lending support to the internal validity of the preferred model estimates. To further demonstrate the robustness of the main result, this remainder of this section describes alternative specifications of the preferred model.

7.2.1   Alternative Estimators

In the previous section, arguments were presented on the plausibility of the assumptions of both treatment exogeneity and selection on observables. The first check on the doubly robust Oaxaca-Blinder estimate is to use the alternative estimators implied by those assumptions. Panel A of Table 7 displays these results. The first alternative uses the treatment exogeneity assumption and estimates the treatment effect with a difference-in-differences (DID) estimator:

$$\ln \text{Price}_{ijt} = \alpha + \psi(Dune_{it}) + \mathbf{X}_{it}\sigma + \mathbf{L}_{it}\rho + \tau_t + \eta_j + v_i + \gamma_i + \varepsilon_{ijt} \tag{18}$$

where ψ is the coefficient of interest and the remaining parts of the model are defined in the same manner as (16) in Section 6.3. Results from the model estimated with robust standard errors clustered by neighborhood, year sold and month sold show a significant impact of 5.2 percent on housing prices from the dunes.

The second alternative uses a bias-corrected nearest neighbor matching estimator (Abadie and Imbens 2002). This model relies on the assumption that treatment is random conditional on covariates and model restrictions reduce the potential confounds of unobservables. The sample average treatment effect is written as:

$$\tau_{MATCH} = \frac{1}{N}\sum_{i=1}^{N}\{\widehat{Price}_i(1) - \widehat{Price}_i(0)\} \tag{19}$$

with the missing outcomes predicted as follows:

$$\widehat{Price}_i(0) = \begin{cases} Price_i & if\ Dune_i = 0 \\ \frac{1}{\#\Gamma_M(i)}\sum_{\omega\in\Gamma_M(i)}\{Price_\omega + \widehat{\mu_0}(X_i) - \widehat{\mu_0}(X_\omega)\} & if\ Dune_i = 1 \end{cases} \tag{20}$$

$$\widehat{Price}_i(1) = \begin{cases} \frac{1}{\#\Gamma_M(i)}\sum_{\omega\in\Gamma_M(i)}\{Price_\omega + \widehat{\mu_1}(X_i) - \widehat{\mu_1}(X_\omega)\} & if\ Dune_i = 0 \\ Price_i & if\ Dune_i = 1 \end{cases} \tag{21}$$

$\Gamma_M(i)$ is the set of indices for the matches for observation i, # indicates the number of elements used from that set, X represents the set of observable characteristics for each observation, and the subscript ω designates observations from the opposite group used as a match. Lastly, $\hat{\mu}$ is an estimated regression function with data from the matched sample with the subscript indicating from which group the data is drawn.

Operationally, exact matches are required for spatial bin, year sold, and age of the home to control for neighborhood unobservables, time-varying unobservables, and unobservables at the house level[38], respectively. Additional matching variables are chosen to correspond to characteristics that are plausibly driving selection into treatment as seen in Table 5 (i.e. distances to public access, bayfront and commercial properties, lot size, square footage). The model is specified to require four matches per observation with bias-adjusted robust standard errors. Results from this estimator yield a 4.8 percent treatment effect.

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[38] The idea here is that homes of the same age are likely to be built of similar construction materials and design features that may be unobservable to the econometrician.

The three estimators provide a range of 3.6 – 5.2 percent for the average treatment effect with the preferred Oaxaca Blinder estimate providing a lower bound. It is interesting to note that Oaxaca-Blinder estimate results in tighter confidence intervals than the more traditional DID and matching estimator approaches. Yet, results with Oaxaca's (1973) original weighting scheme or the sample size method of Cotton (1998) are closer in magnitude with similarly wide confidence intervals to results of the other estimators.[39] This demonstrates that the choice of the weighting matrix for the counterfactual coefficients may have a measurable effect on the magnitude and precision of the estimate for the outcome of interest.

7.2.2 Functional Form, Spatial Boundary, and Temporal Robustness

The preferred model specification utilizes a semi-log form for the hedonic price function. Panel C of Table 7 provides results from using a more flexible form – linear Box-Cox. Maximum likelihood estimation rejects the linear, multiplicative inverse, and log specifications of the model and yields a positive and significant transformation parameter on sales price of approximately 0.09. This transformed dependent variable is then used in the Oaxaca-Blinder estimation and yields a very similar percentage effect of treatment (3.3 percent) as the model using the semi-log price function. [40]

Next, I check for any spatial boundary constructs that may influence the main result. Since the dune construction is discontinuous during the time frame of analysis, I test the impact of proximity to the boundaries of the dune. Five models are examined, each with a different subset of the original data. The Oaxaca-Blinder estimator is run with data that includes only transactions within 1 mile, ½ mile, and ¼ mile of the dune boundaries and data that excludes all

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[39] See Table A.1 in the appendix for results of the alternative weighting schemes for estimating the Oaxaca-Blinder decomposition.

[40] The percentage effect for the dune is calculated by dividing the marginal price by the average sales price in the sample as follows: $\frac{\widehat{\beta_t} \cdot Dune_i \cdot SalesPrice_i^{1-\theta}}{\overline{SalesPrice}}$, where the transformation parameter is $\theta = 0.09$.

transactions within ¼ mile and 500 foot boundary of the dune edge. The range of effects found in the inclusion models is small (3 – 3.5 percent) and similar to the full sample estimate of 3.6 percent. The exclusion models have a range of 3 – 4.3 percent, with the large impact occurring when homes very close (less than 500') to the dune edge are excluded. This result lends support to the protection categorization scheme outlined in Section 4. That is, protection benefits are likely less on the dune boundaries due to the discontinuities and get larger as the distance from the edge increases. Panel B of Table 8 displays results from these spatial checks.

Lastly, two models are run with data restricted to observations around the construction of the first dune intervention in Surf City, from 2004-2009 and from 2005-2008, respectively.[41] The results imply that the dune effect increases marginally compared to the preferred estimate and the effect become largest when the time frame is narrowed to three years (4.6 percent). Panel C of Table 8 displays the temporal results.

Figure 9 displays the preferred estimate along with alternative estimators, treatment timing, functional form, spatial boundary, and narrowed temporal window robustness checks with 95% confidence intervals. The light grey shaded area represents the range of the confidence interval for the preferred estimate which includes *all point estimates* of the robustness checks.

7.3   Decomposition of the Treatment Effect

The jointness of the amenity impacts from the dune policy is decomposed using treatment-amenity interaction terms as specified in equation (16). Relating this back to equation (5), the value of adaptation is linked to the storm protection results while the ancillary impacts of the policy are connected to the viewshed and beach width variables. Table 9 displays the results.

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[41] The focus here is on the Surf City dune due to data limitations for performing the same checks around the Harvey Cedars and Brant Beach dunes. The number of observations for the treated group is much smaller for these interventions due to the temporal constraints of the market definition.

Column (1) includes spatial bin fixed effects only, column (2) spatial bin, neighborhood, and time fixed effects, and the preferred estimation in column (3) utilizes spatial bin, neighborhood, and time fixed effects with selected home characteristics and distance variables.[42] The preferred specification in column (3a) yields significant results for the each interaction of treatment and the amenity of interest.

The capitalization effect of a one unit increase in protection level yields a 2.6 percent increase in housing value. This marginal change translates to an annualized benefit of $2,360 per household. The total average annualized benefit is $16,122 per home as a result of an average increase of 6.83 in the level of storm protection. These estimates represent the first empirical estimate of storm protection benefits in the valuation literature.

The first ancillary effect of the policy is viewshed loss from the first floor of homes. A degree loss of ocean view translates to a 0.4 percent decline in price, or an annualized change of -$363 per degree lost. This result is similar to two previous studies measuring ocean views that find a 0.3 and 0.34 percent increase for additional degree of view, respectively (Bin et al 2008; Crawford et al. 2014). The 0.4 percent decline translates to an annualized loss of $2,607 per home, given an average first floor view difference of -7.2 degrees between treated and control homes.

Next, the model in (3a) estimates a 0.10 percent decline in housing prices per foot increase in beach width. Annualized, this represents a loss of $91 per foot per home. Given the average increase of nearly 118', this translates to an annual loss of $10,677 per home. The negative coefficient on the interaction of the policy variable and beach width warrants discussion. There are two plausible explanations that may support this somewhat counter-

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[42] House characteristics include indicator variables for condo, garage, fireplace, and hot tub and the distance variables include distances to commercial properties and public access points with quadratic terms included.

intuitive result. First, this decomposition is the first to separate the effect of storm protection from beach width. Previous hedonic studies (i.e. Landry and Hinsley 2011; Gopalakrishnan et al. 2011) find large increases in housing prices associated with wider beaches without this separation.[43] In this case, the negative coefficient on beach width arises after netting out the storm protection benefits with another variable. Second, the decomposition characterizes the location-specific mix of service flows that are likely to vary with the policy setting, pointing to an external validity issue. In this study, concerns of congestion costs stemming from a wider beach outweigh recreation benefits for property owners in close proximity to the sand. Due to the access concerns and privacy fears on Long Beach Island, the significant and negative coefficient on the interaction between dune and beach width is unsurprising and points to decomposition as a means to determine location-specific service flows.

To facilitate the discussion relating the decomposition to the value of adaptation, equation (5) is restated here:

$$\textit{Value of Policy = Value of Adaptation +/- Value of Ancillary Impacts} \qquad (5)$$

The LHS of (5) is estimated with the Oaxaca-Blinder model, resulting in mean-based annualized capitalization of $3,229 per home. Summation of the total annualized value of adaptation from storm protection ($16,122) and the indirect effects of beach width and view (-$10,677 and -$2,607) yield a total value for the RHS of $2,838, approximately 12 percent less than the capitalized value of the policy. This demonstrates that the decomposition connects to the policy effect quite well, with the difference likely attributable to alternative estimation strategies used. The Oaxaca-Blinder estimator is limited to distinguishing differences between two groups and

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[43] These results also run counter to the travel cost literature that typically find a positive impact of increasing the width of the beach (i.e. Parsons et al. 1999, Whitehead, et al. 2008, Parsons et al. 2013). However, these studies measure the value of beach width to visitors, not owners of oceanfront property.

therefore the decomposition needed a more flexible DID estimator to recover the ancillary impacts.

The storm protection estimates are most likely a lower bound on these values as they are measured using revealed preferences *before* Sandy. Long Beach Island had not experienced a major storm event prior to Sandy since the Ash Wednesday storm of 1962. The information provided by the storm highlighted the effectiveness of the dunes to minimize damage and the risks associated with being located in an unprotected town (see Table 10). Intuitively, post-Sandy individuals are likely to value the benefits of storm protection more so then their pre-Sandy counterparts.

8   Discussion

This paper provides empirical estimates of the value of dunes and places decomposed service flow values in the context of benefit transfer issues and public adaptation to climate change. Annualized estimates on the capitalization of the policy ($3,229 per home) were calculated in the previous section.[44] Initial USACE estimates of construction costs were approximately $157 million dollars for the life of the project.[45] Annualizing this estimate assuming a discount rate of 5% and the stated 50-year span of the project, yields an annual cost of $8.6 million or $491 per household. However, actual costs to date, including emergency expenditure to repair damage from Sandy, top $250 million, or $742 per household. Additionally, this represents costs for

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[44] An *ex post* look at damages from post-tropical cyclone Sandy demonstrates the realization of the storm protection benefits. Post-Sandy expenditures clearly show a significant cost savings in the protected communities compared to their unprotected counterparts (NFIP 2014).[44] For example, compare Surf City (treated) and neighboring Ship Bottom (untreated) on Table 9. Both towns are very similar in terms of population, demographics, and housing stock but the federal government had $46 million less in post-Sandy liabilities in Surf City.

[45] External costs of surfing site loss (Harvey Cedars was a world class surf break before the policy intervention), injuries caused by dangerous surf conditions resulting from the renourishment, and damage to benthic habitat and marine life loss are not accounted for in this cost estimates described here.

construction for only 4.3 miles of coastline, or 25 percent of the original project scope, and maintenance and repairs for only 7 years of the 50 year commitment. Based on the annualization assumptions, the aggregate capitalization effect of the full project would outweigh the costs as long as the total engineering costs do not exceed $1.13 billion over the life of the project.

For more clarity on costs in this analysis, consider the community of Surf City that received the first dune in 2007. The USACE has spent $71 million to date on initial construction and repairs from Sandy on the Surf City dune. Assuming $20 million for additional repairs and maintenance for the remaining 43 years of the project scope, the annualized cost per household is $1,916, well below the annual capitalization. In terms of the decomposition results, the dunes are on net beneficial but there is potential to increase these capitalization benefits if consideration is given to the viewshed and recreational access concerns of the local property owners.

It is important to note a distributional, or equity, concern related to the USACE policy intervention. According to the Project Cooperation Agreement signed in 2005 between NJDEP and USACE, replenishment geared toward storm protection has the following cost share: 65% federal & 35 % non-federal. 75% of non-federal expenditures are covered by NJDEP, leaving approximately 8.75 % of total costs the responsibility of the communities receiving the dune and beach replenishment (USACE 2005). Using the annualized cost figures for Surf City from above, this cost-sharing arrangement changes the annualized household cost of the dune to approximately $168 per year. The remaining cost of $1748 is spread among federal and state taxpayers. In essence, federal and state taxpayers are subsidizing the protection of assets for a very small number of individuals who have chosen to reside in a high-cost, high-risk location. My results here point to the need for re-evaluation of how these projects are funded. The annualized capitalization per home ($3,229) could form the basis for a property tax surcharge

after dune construction, forcing property owners to internalize the costs of their housing decisions.

Lastly, it is important to note some practical implications of my results. State and local authorities are currently determining their course of action to obtain easements needed for dune projects to commence. The immediate and direct implication from this research's results is that it lends support to the recent eminent domain legal precedent from *Harvey Cedars v. Karan* (2013) on the inclusion of specific benefits in partial-taking valuation. My results suggest that private markets *are* moving as a result of the dune policy and that specific benefits are accruing to property owners in close proximity to the dune. The results here also provide economic evidence to support NJ Governor Chris Christie's Executive Order 140 (Christie 2013) and his bid to use partial takings (with minimal compensation) to allow large scale dune construction to proceed on the remainder of the New Jersey coastline.

9   Conclusion

The federal policy response to vulnerable coastal communities has recently shifted to include the construction of dunes to protect property and infrastructure. Little is known about the benefits and ancillary costs generated by these dunes. This research represents the first effort on valuation of dunes and demonstrates the need for more empirical work related to coastline stabilization and public policies aimed at providing adaptation services.

This paper evaluates a policy of building dunes designed to mitigate risk associated with hurricanes and sea level rise using residential housing data from a barrier island in New Jersey. Using the logic of the Oaxaca-Blinder estimator, I find the value of the dunes to be strictly positive (3.6 percent) and variable in a non-monotonic manner across space. The policy effect is

decomposed into impacts associated with storm protection, ocean views, and recreational access. The value of storm protection is then connected to the value of adaptation, where dunes provide annualized benefits to homeowners of $16,122. This gain outweighs the ancillary costs associated with viewshed impairment and recreational access issues. Based on the estimates here, the dune policy passes a benefit-cost test assuming the total expenditures for the life of the project do not exceed $1.13 billion. These results counter the common perception on the ground of dunes as diminishing property values and inform the legal and political debate on coastline stabilization moving forward.

The efficacy of the storm protection benefits of the dunes was demonstrated *ex post* when the dunes withstood the storm surges from post-tropical cyclone Sandy. Practically speaking, the dune valuation and storm protection estimates from this research are likely to transfer to similar coastal areas on the Eastern seaboard. However, the decomposition revealed the ancillary impacts in NJ were negative, reducing the effectiveness of the intervention. These ancillary effects are likely to be location specific, as demonstrated by the negative coefficient on the interaction of the policy and beach width. This particular results runs counter to results from both the hedonic and travel cost literature and highlights the need for identifying the ancillary services flows impacted by dunes in each location. Fortunately, the estimation method and data generation techniques used in this work are straightforward to replicate in other coastal areas where dunes are planned.

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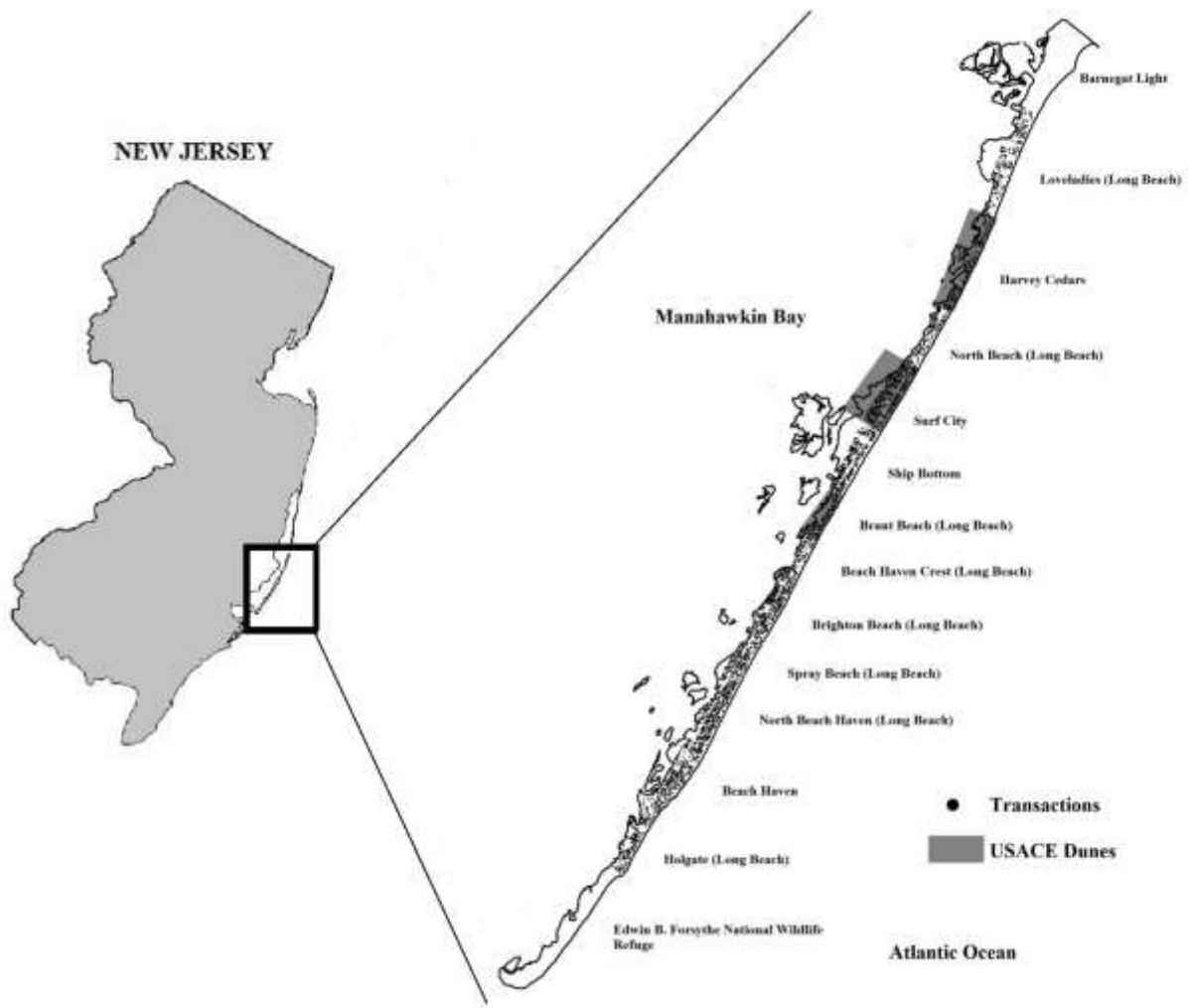Figure 1: Study Area and Location of USACE-constructed dunes

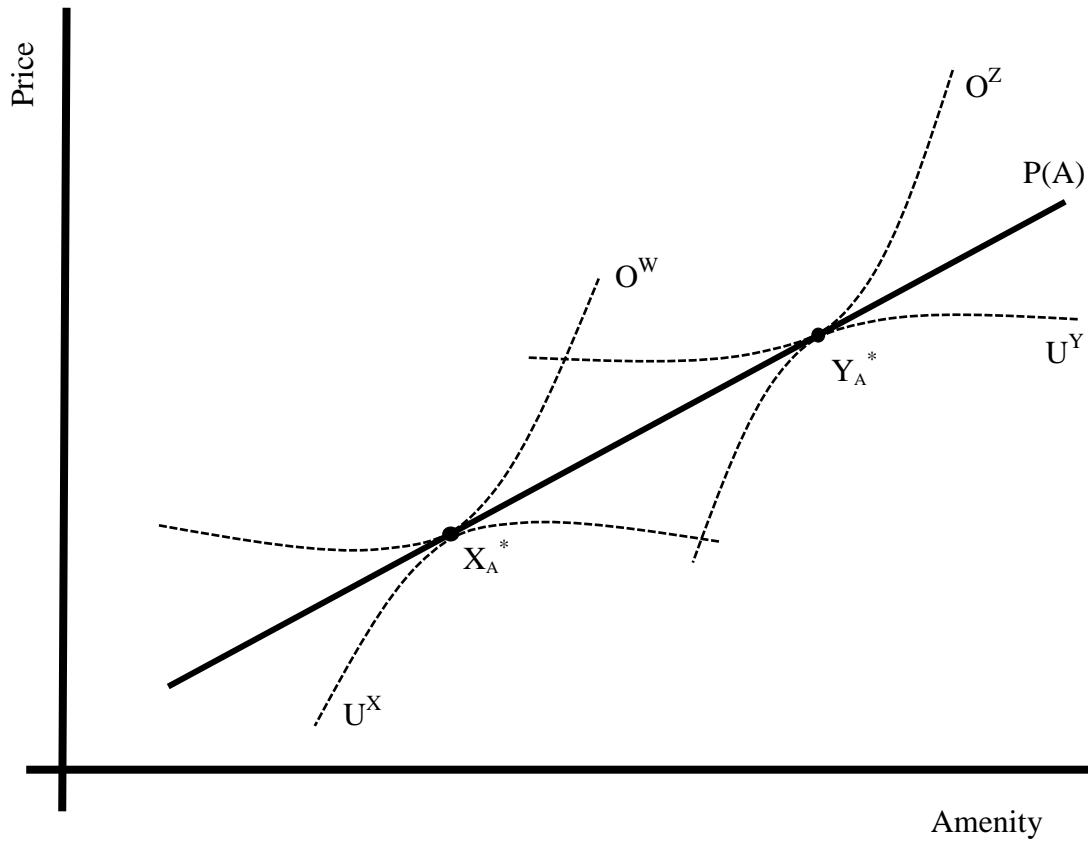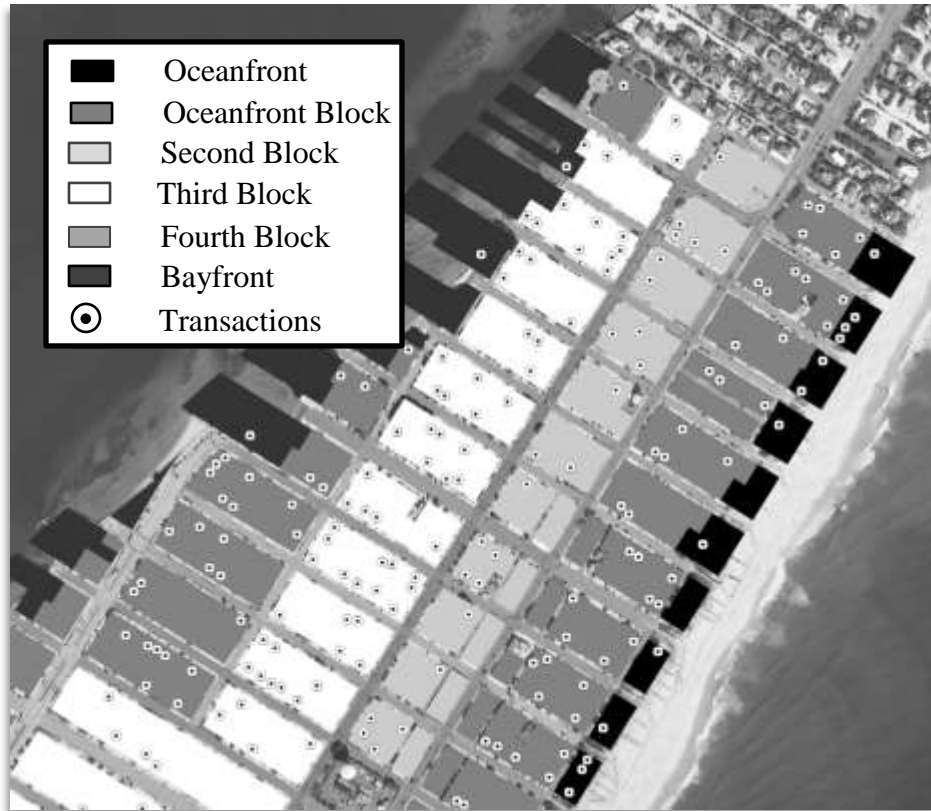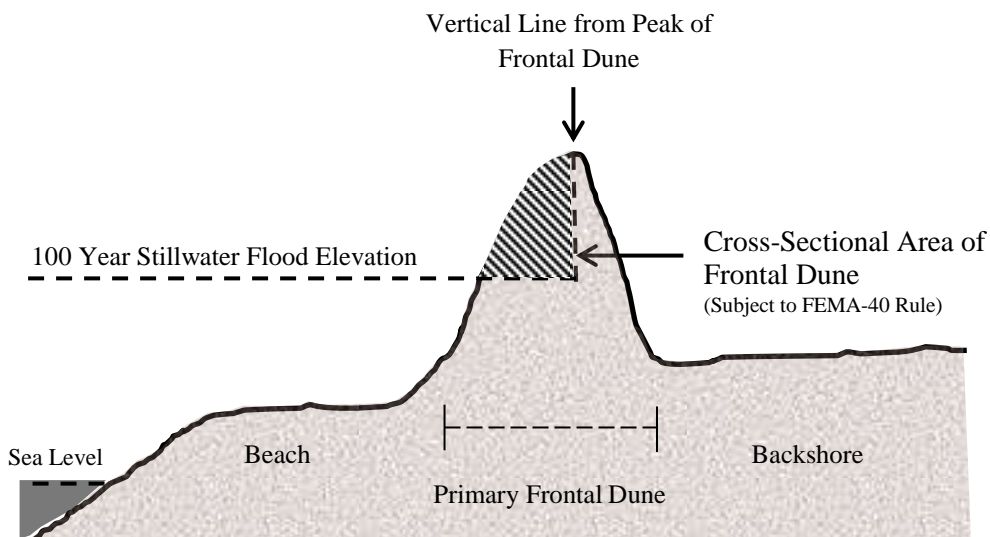Figure 2: Example of a Hedonic Equilibrium

Figure 3: Delineation of Spatial Bin Fixed Effect in northern Surf City

Notes: Map shows the north end of Surf City with spatial bins and the exact location of transactions.

Figure 4: Schematic of a Dune System Highlighting the FEMA-540 Rule

Notes: Figure adapted from Barone et al. (2009).

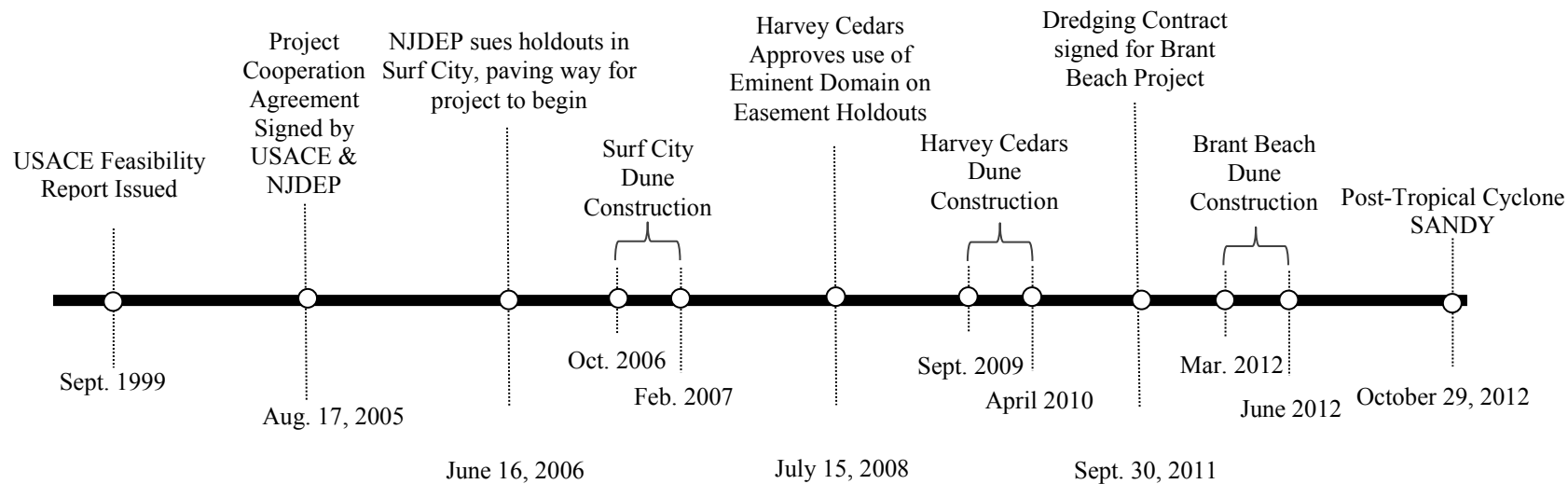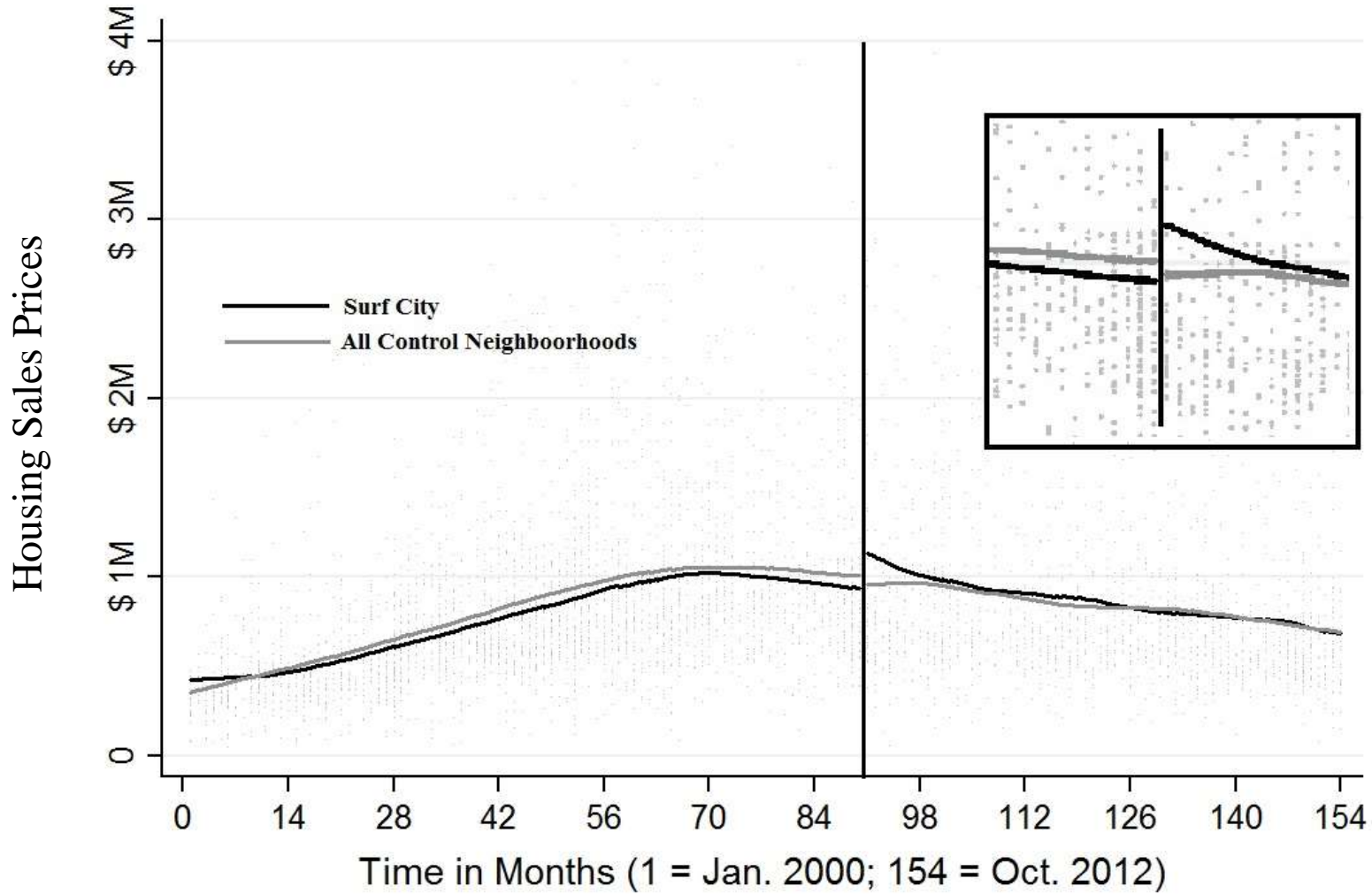Figure 5: Timeline of Important Events Related to Dune Construction on LBI
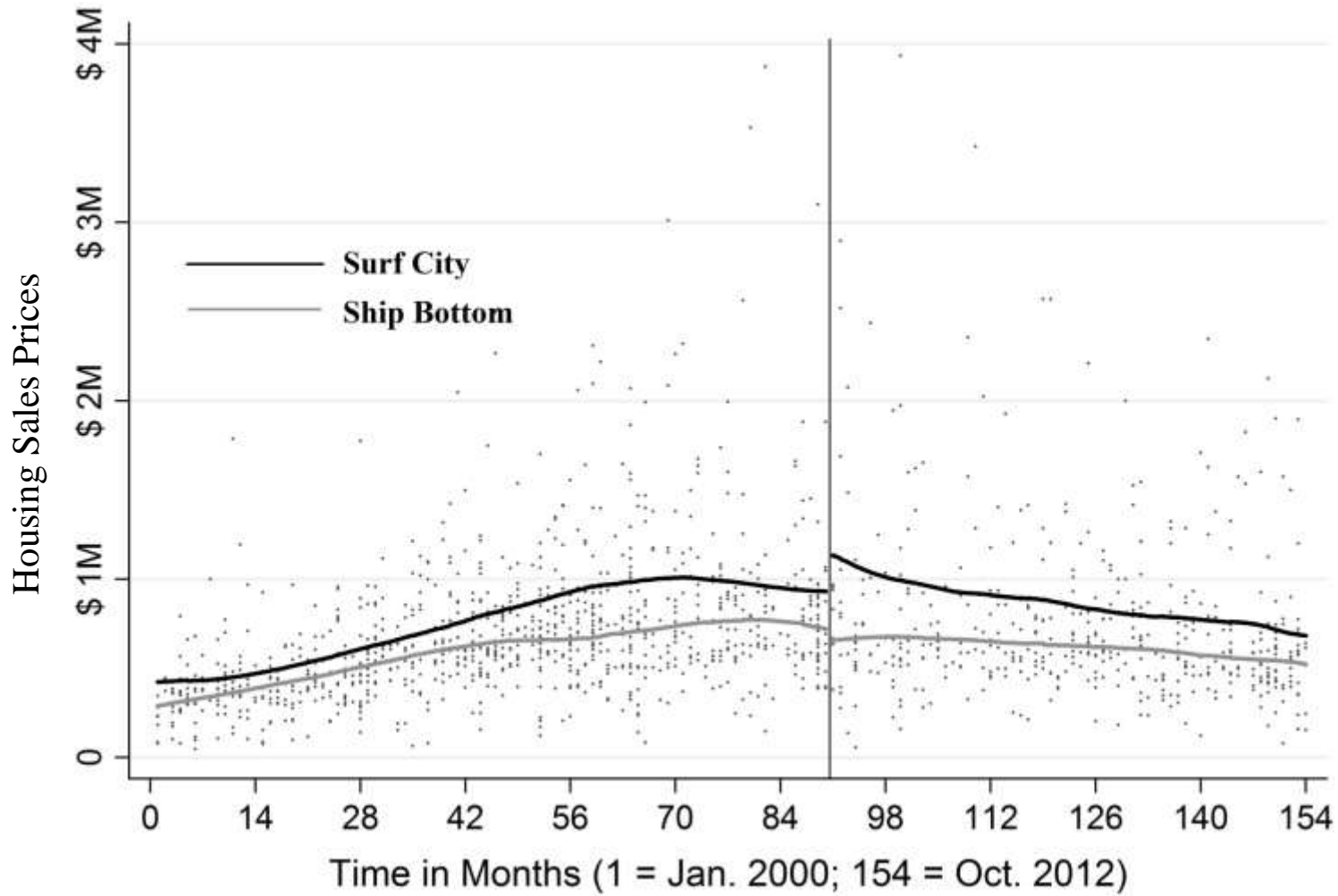
Figure 6: Transaction Prices in Surf City and All Control Communities 2000-2012

Notes: The trend lines are estimated separately for the time periods before and after the completion of dune construction in Surf City using nonparametric regressions with Cleveland's (1979) tri-cube weighting function and a bandwidth of 0.5. The inset on the upper right is a close-up of the discontinuity.

Figure 7: Transaction Prices in Surf City and Ship Bottom 2000-2012

Notes: The trend lines are estimated separately for the time periods before and after completion of dune construction in Surf City using nonparametric regressions with Cleveland's (1979) tri-cube weighting function and a bandwidth of 0.5.

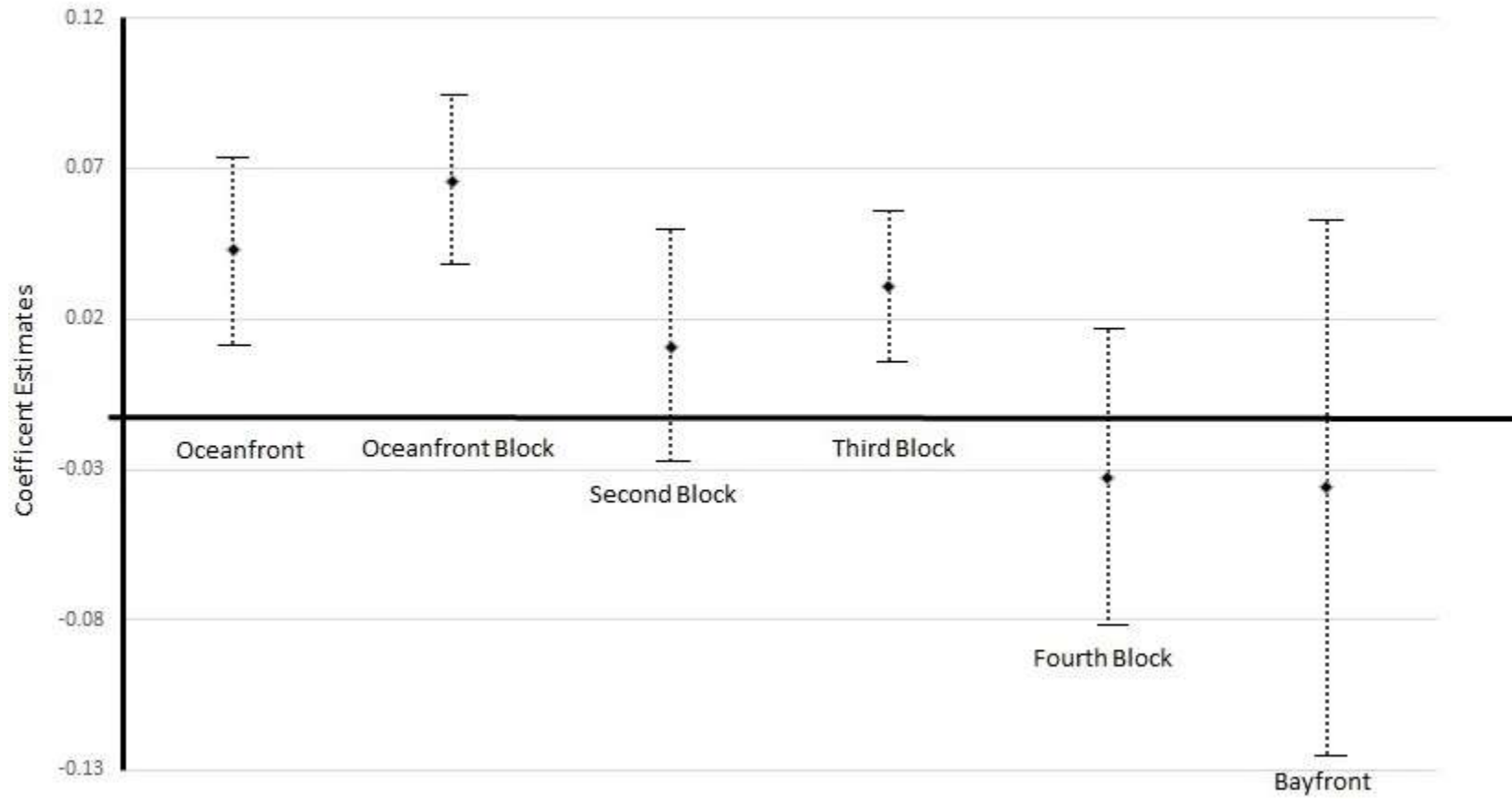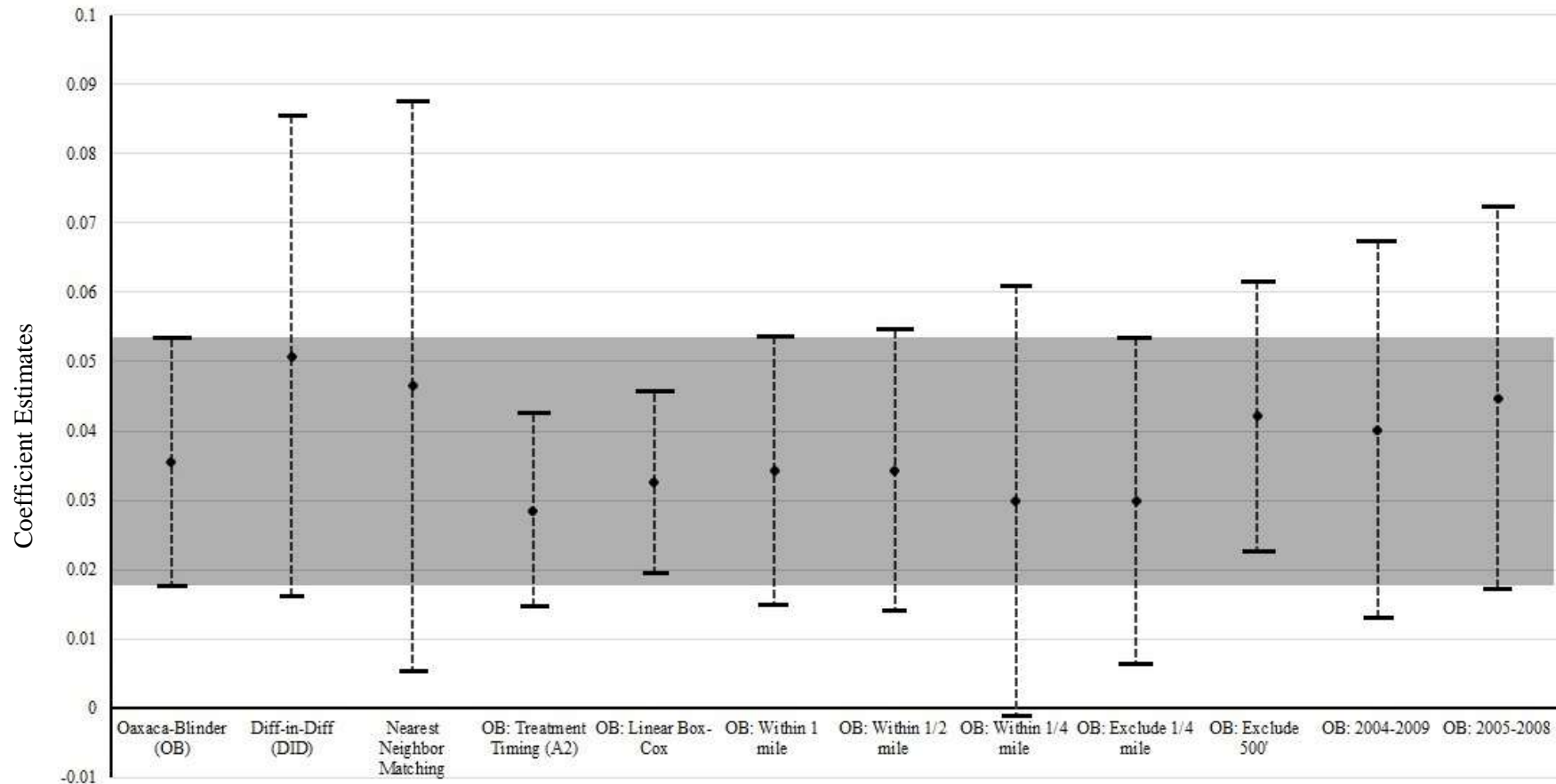Figure 8: Spatially Explicit Treatment Effects from Oaxaca-Blinder Estimator

Figure 9: Robustness Checks on Average Treatment Effects from Oaxaca-Blinder Estimator

Notes: *The grey box corresponds to the confidence interval for the preferred model estimate. Notice the point estimates for all robustness checks fall within this range (approximately 2-5 %).*

Table 1: Evidence Supporting Research Design

A. Cross-Sectional Area of Natural Dunes (Pre-Intervention) [a]

	Cross-Sectional Area	Percentage of Protection for 100-year Storm Event
Treated Communities	34.53	6.4 %
Control Communities	35.61	6.6 %

B. Median Household Income [b]

Long Beach Island	$76,212
Treated	
Surf City	$64,375
Harvey Cedars	$96,250
Control	
Ship Bottom	$65,167
Beach Haven	$75,500
Long Beach Township	$89,077

C. Log Number of Transactions on Dune Treatment [c]

Dune	-0.026
	(0.127)
Neighborhood FE	Yes
Year FE	Yes

D. Falsification Test [d]

Dune	-0.018
	(0.011)

Notes: [a] Data from Barone et al. (2009)

[b] Income data from US Census American Community Survey (2008-2012)

[c] Dependent variable is the log annual number of properties sold in a neighborhood on LBI. Regressor is the policy indicator variable for dune construction. Standard errors are clustered by neighborhood and year.

[d] Only control observations are used and treatment is falsely assigned to communities adjacent to treatment groups where the sales price is unaffected by the treatment. Model is specified in same manner as preferred model.

Table 2: Summary Statistics for Residential Home Sales on LBI: 2000-2012

(N=4,827)	Housing Characteristics			
	Mean	Std. Dev.	Min	Max
Sales Price (in 2012 dollars)	$942,344	$698,399	$46,667	$9,101,058
Bedrooms	3.79	1.18	1	10
Bathrooms	2.71	1.09	1	11
Square Footage	1746	796	195	18,000
Lot Size (feet^2)	5700	4915	0	86,249
Age	35.7	23	0	137
			Mean	# parcels = 1
Oceanfront			0.058	281
Oceanfront Block			0.167	804
Second Block			0.262	1266
Third Block			0.259	1251
Fourth Block			0.131	632
Bayfront			0.123	593
Condo			0.059	284
Garage			0.422	2039
Hot Tub			0.093	448
Fireplace			0.422	2036

Location/Amenity Characteristics (all distance values in feet)				
	Mean	Std. Dev.	Min	Max
Distance to Ocean	1145	740	0	4256
Distance to Bay	808	590	0	2928
Distance to Public Access	935	704	0	3927
Distance to Commercial Property	507	515	0	3790
Beach/Dune Width	285	69	73.7	544
Protection (Cross-Sectional Dune Area)	78.1	134	0.34	540
View (°): 1st Floor (6.8% of obs.)	44	43.5	0.24	157.2
View (°): 2nd Floor (26.3% of obs.)	27.9	40	0.22	157.5

Neighborhoods		
	Mean	# parcels = 1
Harvey Cedars	0.065	320
Surf City	0.134	662
Ship Bottom	0.153	757
Beach Haven	0.159	786
Long Beach Township		
Loveladies	0.064	316
North Beach	0.035	171
Brant Beach	0.057	282
Beach Haven Crest	0.032	159
Holgate	0.047	230
Brighton/Beach Haven Park	0.174	859
Spray Beach	0.018	87
North Beach Haven	0.040	198

Table 3: Categorization of Storm Protection Variable

	Protection Level	Frontal Dune Cross-Sectional Area	Distance to Dune Boundary (if *dune*=1)	Number of Parcels
	0	0 – 50	n/a	3,040
	1	51 – 100	n/a	1,249
Control	2	101 – 200	n/a	181
Group	3	201 – 300	n/a	0
	4	301 – 400	n/a	0
	5	401 - 500	n/a	0
	6	540	0 – 500'	62
	7	540	501 – 1500'	107
Treated	8	540	1501 – 2500'	135
Group	9	540	2501 – 3500'	92
	10	540	> 3500'	46

Notes: Protection levels 0 – 5 represent the protection received from the natural dune system prior to the policy intervention (i.e. the control transactions). Protection levels 6 – 10 differentiate protection received based on being behind a USACE dune relative to location near the boundaries of the dune.

Table 4: Treatment Status Breakdown by Timing Assumption and Spatial Bin

TREATMENT	Timing Assumption 1 [a] (*N=4,827*)		Timing Assumption 2 [b] (*N=4,912*)	
	Percent	# parcels = 1	Percent	# of parcels =1
Dune	7.4	357	9.0	442
Oceanfront	0.64	31	0.71	35
Oceanfront Block	1.51	73	1.83	90
Second Block	1.03	50	1.57	77
Third Block	2.63	127	3.03	149
Fourth Block	1.06	51	1.18	58
Bay front	0.52	25	0.67	33

Notes: [a] Treatment status is assigned to all transactions behind a dune after completion construction AND transactions between the date that knowledge of the project was publicly known and the end of construction are removed to reduce potential confounds associated with uncertainty of the timing of dune construction (Surf City: Feb. 2007; Harvey Cedars: April 2010; Brant Beach: July 2012)
[b] Treatment status is assigned to all transactions behind a dune after the date it became apparent to the general public that the municipality was moving forward with the USACE project (Surf City: June 15th, 2006; Harvey Cedars: July 15th, 2008; Brant Beach: Sep. 30th, 2011.

Table 5: Summary Statistics for Oceanfront Homes by Treatment Status

Housing Characteristics		
Treatment Timing	Timing Assumption 1 [a]	
	Treated (N=31)	*Control (N= 250)*
	Mean	Mean
Sales Price (in 2012 dollars)	$2,042,123	$2,152,182
Bedrooms	4.32	4.23
Bathrooms	3.68	3.5
Square Footage	2,523	2,124
Lot Size (feet^2)	7,798	10,911
Age	27.3	27.5
Garage	0.48	0.44
Fireplace	0.48	0.38
Location Characteristics (all distance values in feet)		
Distance to Ocean	155	126
Distance to Bay	1,522	1,364
Distance to Public Access	77.7	184

Notes: [a] Treatment status is assigned to all transactions behind a dune after completion construction AND transactions between the date that knowledge of the project was publicly known and the end of construction are removed to reduce potential confounds associated with uncertainty of the timing of dune construction (Surf City: Feb. 2007; Harvey Cedars: April 2010; Brant Beach: July 2012)

Table 6: Impacts of Dune Construction on Housing Prices

Oaxaca-Blinder [a]	Naïve Model	Fixed Effects Only	Preferred Model
Dune	0.0072	0.1058***	0.0356***
	(0.0122)	(0.0157)	(0.010)
Dune*Oceanfront	-0.0406	0.1221**	0.0430***
	(0.0549)	(0.0538)	(0.0159)
Dune*Oceanfront Block	0.0058	0.2205***	0.0659***
	(0.0186)	(0.0371)	(0.0143)
Dune*Second Block	-0.2241***	0.0657	0.0105
	(0.0421)	(0.0427)	(0.020)
Dune*Third Block	0.0003	0.1033***	0.0313**
	(0.0190)	(0.0205)	(0.0129)
Dune*Fourth Block	-0.0217	-0.0011	-0.0327
	(0.0345)	(0.0363)	(0.0253)
Dune*Bayfront	-0.0861	0.0138	-0.0360
	(0.0685)	(0.0977)	(0.0452)
Housing Characteristics	Yes	No	Yes
[# of bedrooms^ & bathrooms^, interior size (ft^2)^, lot size (ft^2)^, age (years)^, dummies for condo, garage, fireplace, & hot tub]			
Spatial Amenities	Yes	No	Yes
[Ocean View from first^ & second^ floor, beach width^]			
Distances (feet)	No	No	Yes
[Ocean^, bay^, public access point ^, & commercial properties^]			
Year & Quarter FE	No	Yes	Yes
Neighborhood FE	No	Yes	Yes
Spatial Bin FE	No	Yes	Yes
Flood Zone FE	No	Yes	Yes

Notes: Point estimates for the treatment effect of the dune obtained from Oaxaca-Blinder regressions of log housing prices on a variety of housing characteristics, distances to important features, spatial amenities, and fixed effects. The interaction of Dune and spatial bins are run as separate models for each spatial bin using the same estimation strategy. Asterisks are based on bootstrapped standard errors with 50 replications, *** denotes p-value < 0.01, ** denotes p-value < 0.05 and * denotes p-value < 0.10.

[a] Models shown utilize the weighing strategy of Oaxaca and Ransom (1994) where coefficients from a pooled model over both groups are used as the reference coefficients. Alternative weights for the preferred model (3) yield similar but slightly higher coefficients on *Dune*: Oaxaca (1973): 0.051*** & Cotton (1988): 0.054***.

^ indicates a quadratic term of the variable was included in the estimation.

Table 7: Average Treatment Effects with Alternative Estimators and Functional Forms for Price

	Coefficient	Standard Errors	95% Confidence Interval		Percentage Effects [a]
Price Function: Semi-log			A. *Timing Assumption 1*		
Oaxaca-Blinder (O-B) [b]	0.036***	0.009	0.018	0.053	3.62 %
Difference-in-Differences (DID) [c]	0.051***	0.018	0.016	0.085	5.19 %
Nearest Neighbor Matching (NNM) [d]	0.047**	0.021	0.006	0.088	4.77 %
			B. *Timing Assumption 2*		
O-B	0.028***	0.007	0.014	0.043	2.88 %
DID	0.040**	0.016	0.008	0.071	4.05 %
NNM	0.038*	0.021	-0.003	0.079	3.85 %
Price Function: Linear Box-Cox [e]			C. *Timing Assumption 1*		
O-B	0.116***	0.004	0.107	0.125	3.31 %
DID	0.184***	0.011	0.162	0.206	5.24 %
NNM	0.083	0.074	-0.061	0.228	2.38 %
			D. *Timing Assumption 2*		
O-B	0.089***	0.004	0.081	0.097	2.44 %
DID	0.134***	0.011	0.113	0.155	3.66 %
NNM	0.236***	0.072	0.095	0.378	6.44%

Notes: *** denotes p-value < 0.01, ** denotes p-value < 0.05, * denotes p-value < 0.1.

[a] Percentage effects for the dune dummy with the semi-log price function are calculated using adjustments from Halvorsen and Palmquist (1980).

[b] Bootstrapped standard errors

[c] Robust standard errors clustered by neighborhood and year and month

[d] Four matches per observation. Exact matches: year sold, age, & spatial bin with robust standard errors.

[e] Percentage effects for the dune dummy with the linear Box-Cox are calculated by dividing the marginal price $\hat{\beta} Dune P^{1-\theta}$ (where θ is the transformation parameter) by the average sales price

Table 8: Spatial and Temporal Robustness Checks on Oaxaca-Blinder Average Treatment Effects

	Coefficient	Standard Errors	95% Confidence Interval		Percentage Effects [a]
A. Alternative Estimators					
Oaxaca-Blinder (O-B) [b]	0.036***	0.011	0.015	0.057	3.62 %
Difference-in-Differences (DID) [c]	0.051***	0.018	0.016	0.085	5.19 %
Nearest Neighbor Matching (NNM) [d]	0.047**	0.021	0.006	0.088	4.77 %
B. Oaxaca-Blinder Spatial Robustness Checks					
Within 1 Mile	0.034***	0.009	0.015	0.054	3.46 %
Within ½ Mile	0.034***	0.010	0.014	0.055	3.45 %
Within ¼ Mile	0.030*	0.016	-0.001	0.061	3.04 %
Exclude ¼ Mile	0.030**	0.012	0.006	0.053	3.04 %
Exclude 500 feet	0.042***	0.010	0.023	0.062	4.28 %
C. Oaxaca-Blinder Temporal Robustness Checks [e]					
2004 – 2009	0.040***	0.014	0.013	0.067	4.09 %
2005 – 2008	0.045***	0.014	0.017	0.072	4.55 %

Notes: *** denotes p-value < 0.01, ** denotes p-value < 0.05, * denotes p-value < 0.1.

[a] Percentage effects for the dune dummy with the semi-log price function are calculated following Halvorsen and Palmquist (1980).

[b] Bootstrapped standard errors

[c] Robust standard errors clustered by neighborhood and year and month

[d] Four matches per observation. Exact matches: year sold, quarter sold, & spatial bin. Robust standard errors.

[e] Temporal restrictions are centered on the dune intervention in Surf City. The dunes in Harvey Cedars and Brant Beach were built toward the latter end of the sample close to PTC Sandy and the lack of observations prevents similar temporal restrictions on those two events. Transactions after 10/2012 are likely confounded by the storm event and therefore not added to expand the scope of this robustness check.

Table 9: Decomposition of the Average Treatment Effect of Dune Construction [a]

	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)
1(Dune)*Protect	0.0828***	-	0.0322**	-	0.0261**	-
1(Dune)*View	-0.0026	-	-0.0025	-	-0.0036**	-
1(Dune)*Beach Width	-0.0008***	-	-0.0004	-	-0.0010***	-
1(Dune)*Protect*OF	-	0.1078**	-	0.0688**	-	0.0666*
1(Dune)*Protect*OFB	-	0.1044***	-	0.0478*	-	0.0252
1(Dune)*Protect*2	-	0.0501	-	0.0122	-	0.0003
1(Dune)*Protect*3	-	0.0480**	-	0.0003	-	0.0065
1(Dune)*Protect*4	-	0.0721***	-	0.0210	-	0.0175
1(Dune)*Protect*BF	-	0.0866	-	0.0247	-	0.0486
1(Dune)*View*OF	-	-0.0026	-	-0.0023	-	-0.0031**
1(Dune)*View*OFB	-	-0.0422***	-	-0.0863***	-	-0.0967***
1(Dune)*BeachWidth*OF	-	-0.0020**	-	-0.0016**	-	-0.0023**
1(Dune)*BeachWidth*OFB	-	-0.0009	-	-0.0003	-	-0.0005
1(Dune)*BeachWidth*2	-	-0.0007	-	-0.0004	-	-0.0006
1(Dune)*BeachWidth*3	-	-0.0001	-	0.0001	-	-0.0006*
1(Dune)*BeachWidth*4	-	-0.0004	-	-0.0003	-	-0.0009*
1(Dune)*BeachWidth*BF	-	-0.0014	-	-0.0003	-	-0.0017
Spatial Bin FE	X	X	X	X	X	X
Neighborhood FE	-	-	X	X	X	X
Time FE	-	-	X	X	X	X
Selected Characteristic FE [b]	-	-	-	-	X	X
Distance Variables [c]	-	-	-	-	X	X
R-Squared	0.3653	0.3685	0.5978	0.6000	0.7025	0.7047

Notes: *** denotes p-value < 0.01, ** denotes p-value < 0.05, * denotes p-value < 0.1. [a] All models: robust standard errors clustered by neighborhood, year sold and month sold. [b] Dummies for condo, fireplace, garage & hot tub. [c] Distances (with quadratic term) for commercial properties and beach public access.

Table 10: Housing Damages and Federal Aid for Sandy Relief in the Six Municipalities on Long Beach Island

	Long Beach Township	Harvey Cedars[a]	Surf City[a]	Ship Bottom	Beach Haven	Barnegat Light[b]
A. Housing Damages related to Sandy						
Total Housing Units	8418	1218	2583	2031	2549	1252
Total Homes Damaged	810	64	608	829	260	17
Rental Units Damaged	198	12	55	110	109	2
% Impacted [c]	12.0%	6.2%	25.7%	46.2%	14.5%	1.5%
% Major Impact [d]	8.5%	5.0%	2.0%	4.0%	10.2%	1.2%
% Severe Impact [e]	2.0%	0.7%	0.6%	2.5%	2.2%	0.2%
B. Non-NFIP Federal Funds Distribution for Sandy Relief						
Total Federal Funds	$11,088,034	$1,269,886	$2,092,094	$7,364,868	$12,972,642	$549,457
per capita	$3,618.81	$2,475.41	$1,689.90	$6,707.53	$10,892.23	$988.23
C. National Flood Insurance Data (1/1/78 to 5/31/14)[f]						
Total Loss Claims	7,519	857	1,381	1,616	2,609	238
Total Payments	$214,831,368	$10,188,404	$20,877,434	$61,387,954	$83,761,839	$2,589,196

Notes: [a] Communities receiving dunes and beach replenishment prior to Sandy.
[b] Barnegat Light has a substantial natural dune system and is not in this study. Column provided for comparison purposes
[c] Damages are considered minor under $8,000
[d] Damages are considered major between $8,000 and $28,800.
[e] Damages are considered severe above $28,800.
[f] NFIP does not break down payments by storm, but discussion with local officials confirms a majority of these payments were related to Sandy.

APPENDIX (For Online Publication)

A.1: Political and Legal Maneuvers Resulting in Treatment

In the summer of 2006, the USACE issued an ultimatum that all easements must be signed by September 30th or they would reallocate the federal funds for the project elsewhere. At that point in time, Long Beach Township only had 40 easements signed of the 600 needed, Harvey Cedars 41 of 82, and Surf City 14 of 25 (Smothers 2006). Despite the 2006 deadline and similar threats in subsequent years, no municipality on the island ever received all of the voluntary easements needed for the project. In other words, hold outs remained in each area and no town self-selected into the policy.

The policy arena surrounding this complex issue lends credibility to plausibly assuming that the assignment of treatment is exogenous. The circumstances in Surf City, Harvey Cedars, and Brant Beach resulting in construction of the dunes were due to political and legal interventions. Under pressure from the threat of the loss of federal funding, then NJ Governor Jon S. Corzine allowed the NJ DEP to commence legal proceedings against the remaining holdouts in Surf City in July 2006. Four holdouts signed the easements under threat of a lawsuit, but five oceanfront homeowners still refused. The case, *Milgram v. Ginaldi*, sought to force these holdouts to comply with the easements. The lawsuit was filed October 13th, 2006 and initial construction began a few weeks later.

On July 15th, 2008, the NJ Superior Court Appellate Division upheld the trial court decision in *Milgram v. Ginaldi* that towns cannot sue the holdouts and must following the legal framework of eminent domain to obtain easements. Later the same evening, the Borough of Harvey Cedars issued ordinance 2008-15 authorizing the use of eminent domain on the remaining holdouts. The condemnation process lasted more than a year and initial construction begin in September 2009.

Lastly, the mayor of Long Beach Township publicly stated his refusal to use eminent domain to procure easements. However, the township and the USACE were able to reach an agreement for a dune in the Long Beach neighborhood of Brant Beach before a funding deadline in September 2011. The USACE was able to engineer the dune around the property boundaries of six holdouts, allowing construction to proceed. Construction on this section of the dune system began in February 2012.

A.2: Alternative Treatment Timing Assumptions

Figure A.1: Transactions Prices in Surf City and Ship Bottom 2000-2012 (*Timing Assumption 2*)
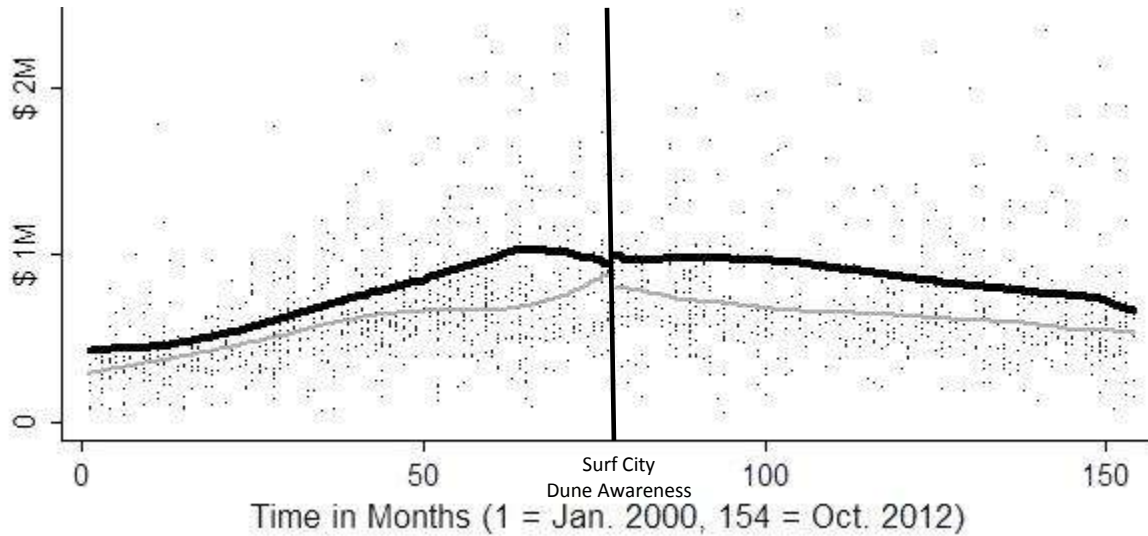
Notes: The trend lines are estimated separately for the time periods before and after awareness of dune construction in Surf City using nonparametric regressions with Cleveland's (1979) tri-cube weighting function and a bandwidth of 0.5. The vertical line represents the date that NJDEP sued the holdouts and the public became aware of the project commencing in the near future (July 2006).

Figure A.2: Transactions Prices in Surf City and Ship Bottom 2000-2012 (*PCA Signing*)
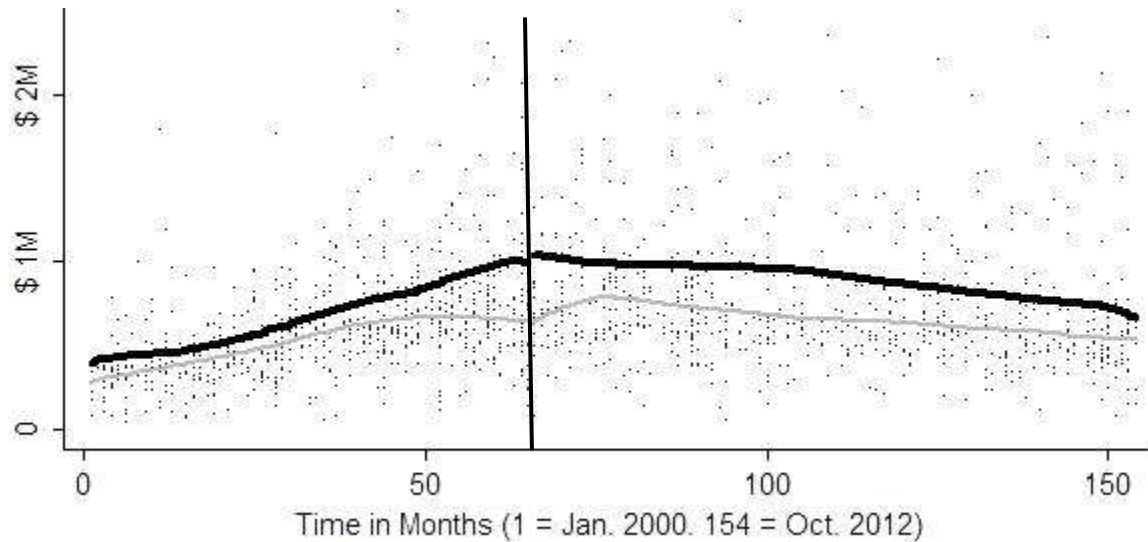
Notes: The trend lines are estimated separately for the time periods before and after the signing of the Project Cooperation Agreement between USACE and the NJDEP using nonparametric regressions with Cleveland's (1979) tri-cube weighting function and a bandwidth of 0.5. The vertical line represents the date the Project Cooperation Agreement was signed (August 2005).

A.3: Development of Viewshed Algorithm

High-resolution (1' pixels) color orthophotos are utilized to construct building footprints and centroids for all transacted homes in the sample. Coastal LiDAR elevation data from 2005 and 2010 were then obtained from NOAA's Digital Coast Center. LiDAR is a remote sensing technology that can measure different types of elevation by beaming lasers from low-flying aircraft and analyzing the reflected light. The data provide both baseline and first-returns digital elevation models (DEM) for Long Beach Island smoothed with an inverse distance weighting algorithm at 6' spatial resolution. The baseline DEM depicts the elevation of the barrier island and the first-returns DEM represents the top of all buildings and vegetation on the island. The 2005 first-returns LiDAR provides a pre-dune baseline for the analysis since construction on the first dune did not begin until September 2006. The most recent LiDAR data available (2010) contains both the Surf City and the Harvey Cedars dune. The Brant Beach dune, built in 2012, was incorporated into the 2010 first-returns DEM raster in ArcGIS using the concept *burn streams into DEM* to complete the post-dune DEM for analysis. This process is designed to add decrements in DEMs for streams and other water features. I simply altered the decay coefficient algorithm to instead add increments of elevation to the shoreline in Brant Beach where the dune was eventually constructed. The process can be characterized by the following equation:

$$DE = E + (G / (G + D))^k \times H \tag{A.1}$$

where *DE* is the newly calculated elevation representing the dune, *E* is the old elevation from the DEM, *G* is the grid resolution, *D* is the distance from the dune peak, *k* is the decay coefficient, and *H* is the elevation increment. An appropriate facsimile of the Brant Beach dune was generated with $k = 2$ for the decay coefficient and $H = 10$ for the average increase in the shoreline height from the construction of the dune.

An iterative geo-processing algorithm utilizes the data described above to capture the degree of ocean view from each home. For each parcel in each time period, the building footprint is zeroed out to the baseline elevation. This step ensures that the observer "sees" past the confines of the house. Then, an observation point is defined for both the first (10') and second floor (20') of the house. The tool then determines the amount of the Atlantic Ocean that can be seen from each observation point across the first-returns DEM, with a maximum view of 180°. This view is then calculated with the following formula:

$$\text{View}° = \text{ArcLength}/\pi * 180° \qquad\qquad\qquad (A.2)$$

where *ArcLength* is the value returned by the tool capturing the arc of circle in the ocean that is visible from each observation point. Once both views are recorded, the algorithm then replaces the building footprint in the first-returns DEM and moves on to the next parcel.

Figure C.1 provides an example of the algorithm results for first floor view from a parcel in Surf City. The results indicate a nearly 62° reduction in this view as a result of the dune construction in 2006.

Figure A.3: First Floor Viewshed from a Surf City Oceanfront Parcel
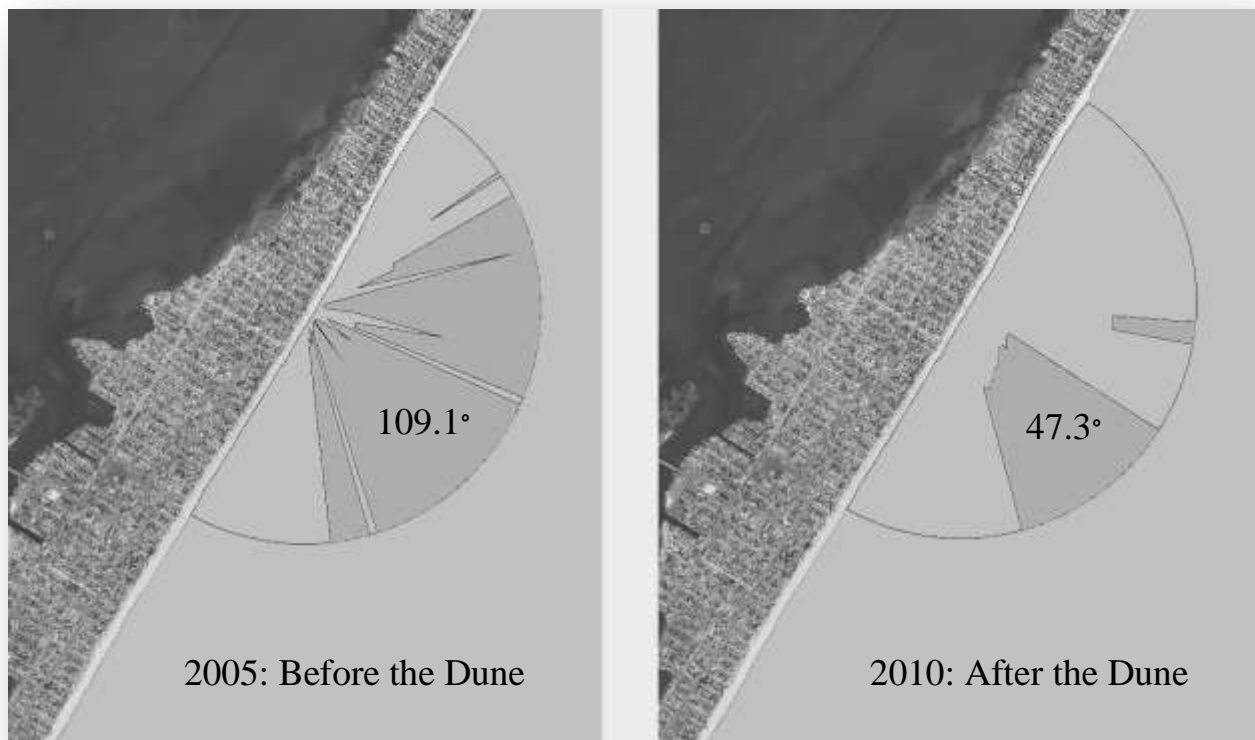
*Notes: The half circle outlined in black represents extent of possible ocean view from the first floor of a specific parcel. Shaded grey areas represent the area of the ocean visible to an observer on the first floor of the home. The degree measures of ocean view shown above were calculated as follows: View° = Arc Length/π * 180.*

A.4: Alterative Weights for Oaxaca-Blinder Decomposition

Table A.1: Tests of Alternative Weights for Oaxaca-Blinder Estimation

	Weighting Matrix	Coefficient	Standard Error	95% Confidence Interval	
		A. *Timing Assumption 1*			
Oaxaca (1973)	$\Omega = 0$	0.051**	0.020	0.012	0.090
Oaxaca (1973)	$\Omega = 1$	0.092	0.066	-0.038	0.222
Reimers (1983)	$\Omega = (0.5)I$	0.072*	0.040	-0.006	0.149
Cotton (1988)	$\Omega = sI$	0.054***	0.020	0.014	0.094
Oaxaca & Ransom (1994)[a]	$\Omega = (\mathbf{X'X})^{-1}(\mathbf{X_0'X_0})$	0.036***	0.010	0.016	0.055
		B. *Timing Assumption 2*			
Oaxaca (1973)	$\Omega = 0$	0.040*	0.021	-0.001	0.082
Oaxaca (1973)	$\Omega = 1$	0.053	0.067	-0.078	0.185
Reimers (1983)	$\Omega = (0.5)I$	0.047	0.044	-0.039	0.133
Cotton (1988)	$\Omega = sI$	0.041***	0.015	0.012	0.071
Oaxaca & Ransom (1994)	$\Omega = (\mathbf{X'X})^{-1}(\mathbf{X_0'X_0})$	0.028***	0.008	0.012	0.048

Notes: *** denotes p-value < 0.01, ** denotes p-value < 0.05, * denotes p-value < 0.1.

[a] The preferred model is this work utilizes the Oaxaca & Ransom weighting matrix and the after construction treatment timing.

A.5: Single Year Hedonic Price Functions

Table A.2: Results for Single-Year Hedonic Price Functions

Oaxaca-Blinder Estimator	Coefficient	Standard Errors	95% Confidence Interval		Percentage Effects
Full Sample	0.036***	0.008	0.02	0.051	3.62 %
2007	0.044**	0.018	0.008	0.080	4.50 %
2008	0.038**	0.017	0.005	0.072	3.87 %
2009	0.013	0.016	-0.019	0.045	1.30 %
2010	0.055***	0.019	0.018	0.092	5.65%
2011	0.029**	0.013	0.004	0.054	2.94%
2012	0.055***	0.012	0.031	0.079	5.65%