Estimating Option Values and Spillover Damages for Coastal Protection: Evidence from Oregon's Planning Goal 18

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Abstract: Estimating nonmarket benefits for erosion protection can help inform better decision making and policies for communities to adapt to climate change. We estimate private values for a coastal protection option in an empirical setting subject to irreversible loss from coastal erosion and a land-use policy that provides identifying variation in the parcel-level option to invest in protection. Using postmatching regressions and accounting for potential spillovers, we find evidence that the value of the erosion protection option is between 13% and 22% of land price for parcels vulnerable to coastal hazards, implying that owners of oceanfront parcels have a subjective annual probability that they will experience an irreversible loss absent the option to protect between 0.7% and 1.3%. We also find that, because of altered shoreline wave dynamics, a parcel with a private protection option generates a spillover effect on protection-ineligible neighbors, lowering the value of neighboring land by 8%.

JEL Codes: Q51, Q54, Q58

Keywords: option value, irreversible loss, spillover effects, spatial externalities, private value of climate adaptation, erosion

PEOPLE WHO LIVE in coastal zones around the globe are confronted with a variety of natural hazards that can induce damages, including erosion, tidal flooding, and storm surges. Climate change has the potential to intensify damages from natural hazards

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through sea-level rise and shifts in the composition of storm events. Historical advantages and current amenities associated with coastal living have led to massive investment in housing and infrastructure that creates significant potential for damage from natural hazards and, therefore, significant economic value from the ability to protect investments in these capital assets from such damage. Empirical evaluation of the economic value and trade-offs associated with coastal protection can help inform better decision-making, policy, and funding mechanisms for governments and communities to adapt to natural hazard risks given an uncertain future.

This paper estimates the economic benefits derived from the private option to protect coastal oceanfront land from irreversible loss due to erosion. Given the high costs, scale, and coordination issues of protection strategies such as beach nourishment, private protection options are typically limited to hardened, engineered shoreline protection structures (SPSs), such as seawalls and riprap revetments (i.e., rock piles), to fix the shoreline in place and prevent the loss of land and coastal structures.[1] Recent work by Neumann et al. (2015) motivates the importance of further research in this area, as their results suggest that coastal armoring with SPSs will represent the majority of US costs ($\sim$60% or > $300 billion) associated with adaptation to sea level rise by the end of the century. As such, the economic value of the option to protect oceanfront property from erosion represents a private value of climate adaptation.

We first present a simple model of a coastal housing market's capitalization of the option to prevent the realization of an irreversible loss of land due to erosion. We hypothesize that the market response to an erosion protection option is dependent on a landowner's subjective annual probability of the irreversible loss, which is modeled as a function of parcel characteristics that are likely to influence this probability. Our empirical strategy then uses pooled cross-sectional data from coastal land sales in Oregon

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1. A photograph of an SPS (riprap) in Neskowin, Oregon, is provided in fig. A.1, available online.

from 2004 to 2015 and exploits a unique land-use policy and a spatially explicit data set that allows us to estimate the capitalization effect associated with the parcel-level option to install an SPS. The option to privately install an SPS on a coastal property is determined by a statewide land-use policy—Oregon's Planning Goal 18—that prohibits shoreline armoring but allows for exceptions based on a parcel's eligibility. This eligibility is restricted to parcels grandfathered under the planning goal that had physical improvements prior to 1977, and all parcels without such physical improvement by 1977 are ineligible to install protective structures. Goal 18's motivation was to limit armoring of the coastline and thereby prevent beach erosion damages that a landowner's armoring decision induces on neighboring landowners or public beach users through displaced wave action. Our approach exploits substantial cross-sectional variation (both within and between communities) in the ability of landowners to protect their property from an irreversible loss due to erosion, along with a rich set of parcel variables that represent fine-scale risk and amenity characteristics of land. Since the policy change in question occurred 28 years before our data begin, we use propensity score matching methods to trim the housing transactions and create balance in observable characteristics across parcels that are eligible and ineligible for erosion protection under Goal 18. Results from our preferred specification indicate that there is a positive but insignificant price effect of having the option to invest in erosion protection for the average parcel. However, for parcels that are vulnerable to coastal risks (i.e., low elevation and eroding shoreline), the price premium for the protection option is significantly different from zero and can be 13%–22% of their property value. Using our conceptual model, we show that these estimated capitalization effects imply that landowners' subjective annual probability that they will experience an irreversible loss absent the option to protect is between 0.7% and 1.3%.

Unlike beach nourishment and other public (i.e., community-wide) strategies to address shoreline stabilization, coastal armoring in Oregon is a private decision made at the parcel level. This private action may have potential to increase erosion risk to neighboring properties through redirection of wave energy (Ruggiero 2010; Ells and Murray 2012). We econometrically evaluate the potential for and magnitude of expected spillover damages that protection-eligible parcels may impose on neighbors that are protection ineligible. We find that protection-ineligible homes that neighbor protection-eligible homes experience a nonzero spillover damage (spatial externality) of an 8.3% reduction in property value. This price effect implies that the subjective annual risk probability is 0.7 percentage points higher on protection-ineligible parcels subject to the externality. The presence of spillover damages from coastal protection implies that there is a clear economic trade-off associated with a landowner's ability to protect coastlines through private infrastructure choices. Having this option generates benefits to that landowner, but also generates external costs to neighboring landowners through expected damages arising from altered wave action and erosion. Our analysis finds that 7.2% of Goal 18–eligible parcels vulnerable to erosion generate spillover damages that outweigh the benefits to the landowner of the eligible parcel, thereby generating net social costs. Our results further suggest that in settings where all landowners are free to install private protection measures, the spillover damages arising from protection decisions will provide incentive for neighbors to invest in their own SPS, thereby potentially leading to a cascading set of shoreline armoring.

Our paper contributes to literatures that evaluate the economic value of erosion protection and the land market impacts of coastal public policies. Economists have explored the effects of shoreline on housing markets since Brown and Pollakowski (1977). This paper established that it is not simply distance, but the buffer of public open space in between, that determined the capitalized value of shoreline into housing prices. The subsequent literature on the value of erosion protection is relatively sparse with mixed results. Kriesel et al. (1993) and Dorfman et al. (1996) analyze options for erosion protection in Ohio properties that border Lake Erie. The former study constructs a variable capturing erosion risk—the expected number of years until water levels will enter a housing structure—and show that the value of physical structures to mitigate this risk ranges from 7% to 14% of housing value. The latter study finds significantly higher premiums for protective structures with results that are sensitive to small changes in risk probabilities. In a sample of Georgia oceanfront parcels, Landry et al. (2003) find erosion to be a significant driver of home values but find insignificant effects of erosion protection structures. Recently, Walsh et al. (2019) evaluate the waterfront housing market along the Chesapeake Bay in Maryland and show that different types of hardened structures increase housing values up to 22%.

There is a larger literature examining the impact of public infrastructure investment, insurance programs, and land-use regulations on coastal housing markets. Beach nourishment is a prominently studied example of public infrastructure investment and is practiced widely in the eastern United States and Europe. Recent research estimates that public beach nourishment can raise property values (Qiu and Gopalakrishnan 2018), though Dundas (2017) shows that protection benefits can be partially offset by other aspects of beach nourishment, such as reductions in ocean views from large constructed dunes. Beach nourishment also increases the size of the beach, which has been consistently shown to be valued as an amenity in coastal housing markets (Landry et al. 2003; Gopalakrishnan et al. 2011; Landry and Hindsley 2011).

Although our analysis focuses on erosion risk, there is a related and growing literature on housing market impacts of flood risk. Price discounts for flood risk have been estimated as either greater than or equal to the capitalized value of flood insurance premiums (MacDonald et al. 1987; Bin and Kruse 2006; Bin, Kruse, and Landry 2008). Risk perceptions also drive price differentials in coastal housing markets, as shown by studies examining home values before and after major hurricane events (Bin and Polasky 2004; Hallstrom and Smith 2005; Bin and Landry 2013) and flooding events (Atreya et al. 2013). The negative impacts may also attenuate over time if another event does not occur (Atreya et al. 2013; Bin and Landry 2013). The emphasis of this body of work has focused on flood risk and utilized hazard events for identification of the temporary impacts.

Our emphasis on a land-use regulation allowing for a private erosion protection option and on the potential for irreversible loss of land and structures from erosion brings new evidence to bear on challenges associated with current coastal management. Our work contributes to the literature by estimating a parcel-level option value for private coastal protection that protects from erosion risk but arguably provides no other amenities such as are found in beach nourishment (e.g., more recreation value from a wider beach). Importantly, we find a significant long-run capitalization of the option for protection against erosion. This stands in contrast to the related literature on flood risk that generally struggles to find evidence of a market attentive to risks absent a recent disaster. We contend that this difference is primarily due to the fact that chronic erosion drives an irreversible loss of land with potential to destroy a housing structure. Goal 18 eligibility thus represents a land-use policy granting a mitigation option that the market is highly attentive to, whereas a temporary loss from an acute flooding or storm event without concurrent policy changes may be more fleeting. Furthermore, the magnitude of our benefit estimates for having an erosion protection option exhibit convergent validity with recent estimates on the protective benefits from beach nourishment (Dundas 2017; Qiu and Gopalakrishnan 2018), seawalls (Jin et al. 2015), and bulkheads (Walsh et al. 2019).[2]

Second, our conceptual framework allows us to calculate landowners' implicit subjective erosion risk probabilities of irreversible loss of land. We extend the framework of Provencher et al. (2012) to use our empirical results on the capitalization effect of the erosion protection option to then estimate risk perceptions that would justify these market impacts. We provide empirical estimates of these probabilities that may inform policy and benefit estimation in settings where assets are at risk for irreversible loss due to risks, such as wildfires. Third, we identify potential spillover damages of private coastal protection decisions on neighboring property, and our results suggest that the magnitude of these effects may be economically significant. We show that there are conditions where a privately beneficial protection option may be a net cost to society when policy implementation is discontinuous across space. Previously, Smith et al. (2009) and Gopalakrishnan et al. (2016) recognized the need to account for spatial externalities when optimizing beach nourishment frequency, and Gopalakrishnan et al.

2. Dundas (2017) finds that the protection value associated with dune and beach nourishment policy ranges from 20% to 26% when decomposed from ancillary flows (e.g., ocean views, access). Qiu and Gopalakrishnan (2018) find that beach nourishment increases home values in Kitty Hawk, NC, by 12%–17%, and Jin et al. (2015) show that the presence of a seawall may increase housing prices by 10% in Massachusetts. Walsh et al. (2019) find a price premium for bulkheads and riprap in bayfront properties in Anne Arundel County, MD, between 12% and 21%.

(2017) demonstrated the potential for beneficial spillovers to lead to an underprovision of coastal protection with an empirically calibrated numerical model of nourishment decisions made at a community scale. Our results are unique in the literature in that we find empirical evidence of the spillover damages through economically important trade-offs associated with the fact that private coastal protection choices may generate private benefits to the individuals making the choice but external costs to neighbors from altered erosion dynamics. Our results thus provide a rich set of evidence about the economic trade-offs associated with policies regarding private coastal erosion protection. Finally, by finding evidence of a coastal spatial externality from a land-use decision, our paper adds evidence to a set of analyses that quantify the presence of spatial externalities on land use. Past studies have found a wide variety of evidence of spatial externalities across landowner decisions in noncoastal settings, such as suburban development (Irwin and Bockstael 2002), conversion to organic agriculture (Lewis et al. 2011), and adoption of conservation easements (Lawley and Yang 2015).

This article proceeds as follows. Section 1 provides background on Oregon's Planning Goal 18 and erosion concerns in the oceanfront housing market. In section 2, we cast the erosion protection option as a model of expected irreversible loss to build a conceptual framework to link with our empirical analysis. Next, we describe our housing data and the spatial data-generating processes needed to estimate the effect of having the erosion protection option. Section 4 describes our research design, with a focus on overcoming identification challenges with nonexperimental data. Section 5 presents our results, starting with a baseline model, models accounting for spillover effects, robustness checks and then our strategies for direct estimation of the magnitude of the spillovers. The final section provides a summary of our findings and implications for future research.

1. POLICY SETTING

Winter storms in the Eastern Pacific routinely generate huge ocean waves up to 30–45 feet (Ruggiero et al. 2010), making bluff and dune erosion a common occurrence on the Oregon Coast.[3] Erosion can threaten buildings and roads, resulting in a desire to harden the shoreline against wave attack. Irreversible loss due to erosion is the primary concern in Oregon as oceanfront flooding is limited due to coastal geometry and tall foredunes, resulting in "areas being particularly susceptible to erosion, with inundation being relatively rare" (Mull and Ruggiero 2014, 1173). At the same time, Oregonians consider ocean beaches to be a public good providing benefits to all state residents and tourists. This belief arises from the 1967 Beach Bill, which established a permanent public easement for recreation along the ocean shore seaward of the existing

3. Unlike the East and Gulf coasts of the United States, hurricane events and the resulting storm surges are not an issue in Oregon as there are no recorded landfalls of a hurricane or tropical storm in the meteorological history of the state.

line of vegetation. So there exists a fundamental tension in the state between protection of private property from erosion and public access to natural beaches for recreation.

In 1973, Governor Tom McCall made a speech to the Oregon legislature to propose a suite of new land-use regulations to curb "sagebrush subdivisions, coastal condomania, and the ravenous rampages of suburbia" in the state. The first 14 goals of McCall's plan became law in late 1974, and Goals 16–19 related to coastal resources were adopted in 1976. Together, these 19 goals comprise the set of land-use regulations known as Oregon's Statewide Planning Goals (State of Oregon 2019). The goals are guidelines administered by the Department of Land Conservation and Development (DLCD) that inform mandatory comprehensive plans at the local level (i.e., city and county). Our focus is on Goal 18, which provides rules for protecting beach and dune areas of the Oregon Coast from some development outcomes and reducing impacts from natural hazards.

A portion of Goal 18 prohibits coastal armoring but reserves the rights of eligible oceanfront landowners to apply for a permit for an SPS if the home on their parcel is deemed at imminent risk of collapse. This eligibility is restricted to lots where physical improvements (i.e., either a home or a vacant lot with utility connections or nearby street construction) existed prior to January 1, 1977, to avoid conflict with the Takings Clause in the Fifth Amendment of the US Constitution. If a lot was not developed by that date, current landowners have no option to mitigate erosion risk with hardened structures. Local authorities can enact stricter rules if desired, including requiring compliance with construction setbacks from hazard areas to remain eligible (e.g., Rockaway Beach). The primary motivation for Goal 18 was to limit the armoring of the Oregon Coast and incentivize less risky development of oceanfront properties.

The installation of SPSs along Oregon's oceanfront is primarily to stem the irreversible loss of land from erosion. Erosion protection structures fix the shoreline in place but do not increase the height of the barrier between the house and the ocean, suggesting that these structures do not have a major effect on flooding from seasonal storms that raise total water levels. Furthermore, flooding is not currently a salient concern for the Oregon oceanfront due to the topography of the coastline and resultant patterns of development. For example, during our study period (2004–15), NOAA recorded seven coastal flooding events in Oregon.[4] Over 99% of the property damage from these events was due to estuary flooding in Tillamook Bay. This evidence suggests that the value homeowners may place on the option for protection eligibility under Goal 18 is due to concerns about erosion risk.

Of the 9,444 residential oceanfront parcels in Oregon, approximately 49% are eligible for SPS installation, 36% are ineligible, and the remaining parcels are either state-owned or deemed undevelopable under other statutes. An example of the parcel-level variation in Goal 18 eligibility within a community in Lincoln County is shown in

4. See the NOAA storm events database: https://www.ncdc.noaa.gov/stormevents/.

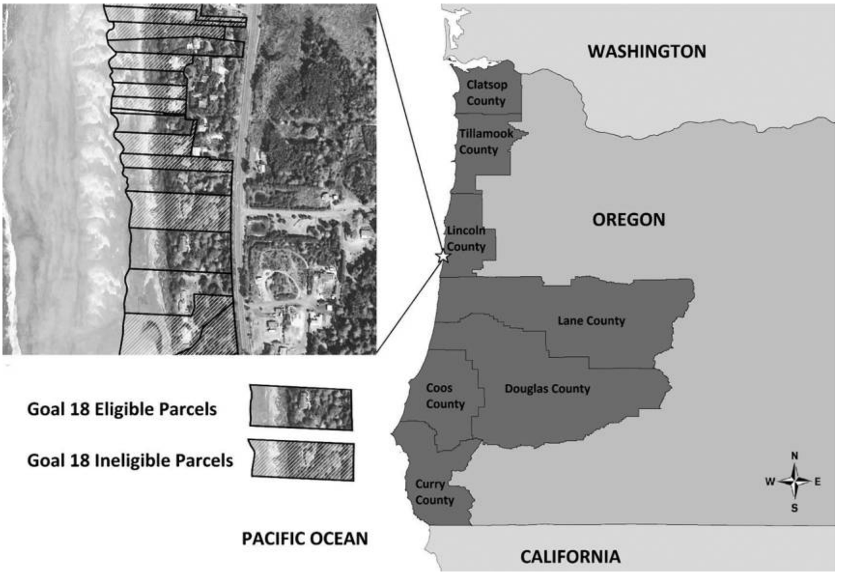

Figure 1. Map of Oregon Coast and example of oceanfront parcels

figure 1. Landowners of protection-eligible parcels can apply to Oregon Parks and Recreation Department (OPRD) for an SPS permit, but a construction permit is only granted if a geological survey determines that the parcel is subject to an immediate threat of irreversible loss from coastal erosion and the parcel complies with all local ordinances.[5] If the threat is validated, the geologist then determines the type, location, and dimensions of the protective structure that would minimize disturbance to the shoreline but still mitigate the erosion problem. As of 2015, one out of four eligible parcels has exercised the option to install an SPS under OPRD's guidelines for permitting. This is a vested property right for landowners, meaning that unarmored eligible parcels (currently ~ 3,300) retain the right to armor in the future and armored eligible parcels retain the right to maintain and/or replace their protective structure. During the period of our analysis (2004–15), 77 permits for an SPS were granted (~ 7 per year) and only three applications were denied.

It is important to note that these shoreline stabilization actions for protecting property in Oregon are typically undertaken at the parcel level, as large, coordinated efforts,

5. OPRD has authority under Oregon Laws 1999, chap. 373, and the provisions of OAR 736-020-0100 and OAR 736-080-0005 through 736-080-0070 to pursue civil and criminal penalties for illegal structures on the ocean shore. Any unpermitted activity is usually reported by the public or conservation-minded nongovernmental organizations (NGOs), and OPRD sends a Letter for Compliance or a Notice of Violation to the property owner. It is our belief that collective enforcement is relatively strong and illegal structures are not currently a major issue.

such as beach replenishment, are not common.[6] In fact, there have been no federal or state interventions to nourish beaches in Oregon, whereas over 2,000 events have occurred in other coastal US states since 1923 (Program for the Study of Developed Shorelines 2017). The focus of our conceptual model (sec. 2) and empirical analysis (secs. 4 and 5) is driven by the variation in the private option for protection from erosion risk codified by this land-use policy.

2. A MODEL OF IRREVERSIBLE EXPECTED LOSS

To provide a conceptual framework for our empirical analysis, we develop a simple model of a coastal housing market's capitalization of the option to prevent the realization of an irreversible loss from erosion. Our emphasis centers on Oregon's Goal 18 land-use policy that allows owners of protection-eligible coastal parcels to exercise their protection option and install an SPS when faced with increasing erosion and irreversible loss of land. In this case, the loss can be considered irreversible because coastal erosion can reduce the size of private property and eventually undermine the structural integrity of a home, rendering the building uninhabitable and the parcel unsuitable for redevelopment. This stands in contrast to the flood-risk literature that uses a state-dependent utility framework to model willingness to pay for a reduction in the probability of flooding that causes temporary loss (MacDonald et al. 1987; Atreya et al. 2013; Bin and Landry 2013). In our model, erosion-protection-eligible parcels where the structure becomes at risk have the option to install an SPS to avoid the possibility of an irreversible loss from erosion. In other words, owners of eligible parcels can pay an option price (e.g., Smith 1985) to prevent an irreversible loss and maintain use of their coastal property. We assume that this land-use policy is the only mechanism for protecting coastal property, which is consistent with coastal management in Oregon as no beach nourishment events have occurred and the Goal 18 policy prohibits landowners from altering beaches without first obtaining a permit.

Consider coastal housing as a capital asset that generates an annual flow of rents (R) to a landowner. In the coastal land market, there are two sets of assets differentiated by a land-use policy—one set is eligible for a future erosion-protection option and the other is ineligible. If buyers in this market believe that ρ, the subjective annual probability of the irreversible loss, is greater than zero, then an asset with protection eligibility will command a positive price differential relative to the ineligible asset, ceteris paribus. We

6. Coordination among neighboring parcels to construct an SPS is possible. However, all parcels must be Goal 18 eligible and meet hazard risk criteria to be approved for a permit. In other words, installation of an SPS at a larger spatial scale than the parcel is possible but only under certain conditions. In the permitting data, each permit is associated with an average of 1.96 parcels. Based on our discussions with state agencies (DLCD and OPRD) and local engineering firms, we found that SPSs are relatively inexpensive investments (when compared to the value of the structures protected), on the order of 5%–7% of oceanfront property values (i.e., \$30,000–\$50,000 per parcel).

define this price differential as the capitalization effect (CE) of erosion-protection eligibility. We assume that ρ is a function of parcel characteristics (x) that are likely to influence this subjective probability of the irreversible loss, such as shoreline change rates (i.e., accretion or erosion) (SC), elevation (Elev), and the protection eligibility status of neighboring parcels (EN). Our initial (and testable) hypotheses for the effect of these characteristics on ρ are as follows:

$$\frac{\partial \rho}{\partial \mathrm{SC}} \leq 0, \tag{1}$$

$$\frac{\partial \rho}{\partial \mathrm{Elev}} \leq 0, \tag{2}$$

$$\frac{\partial \rho}{\partial \mathrm{EN}} \geq 0\,. \tag{3}$$

The first and second expression, respectively, suggest that as SC increases (i.e., accretion) or Elev increases, an asset owner's subjective probability of an irreversible loss should be lower because the parcel has less exposure to erosion risk. Conversely, if SC is negative (i.e., erosion) or if Elev decreases, then ρ should increase. Expression (3) implies that there may be potential for negative spillover effects from private coastal armoring decisions. If a given parcel's neighbor is protection eligible, then that parcel owner's ρ may increase due to the potential risk of redirected wave action from the protected neighbor which thereby increases their own risk of irreversible loss.

Assume that owners of both types of assets receive rents R each year that the property is viable (i.e., not threatened with irreversible loss) and eligible owners can exercise their protection option and continue to receive R each year if the asset becomes threatened and subsequently protected. If the asset is compromised and the landowner does not have a protection option (i.e., land erodes and the structure is undermined/uninhabitable), an irreversible loss occurs and the landowner receives no rent ($R = 0$).[7]

We derive the land market's price differential for the erosion-protection option, expressed as an annual CE. Assuming a constant annual $\rho(x)$, we adapt Provencher et al.'s (2012) logic to our application and link the CE for the protection option to the asset owner's subjective probability that the irreversible loss will occur.[8] This

7. In general, the lot sizes and topography of the Oregon Coast make it difficult to move a structure to another location on a parcel to avoid erosion risk.

8. For simplicity, we assume that the subjective risk of an irreversible loss (ρ) is constant over time. There are two elements to erosion risk that are beyond the scope of this paper to address empirically: (1) expectations about sea-level rise and (2) variation in subjective risk perceptions between individuals across space. Intuitively, if expectations of future erosion risk due to sea level rise increase, the subjective risk probabilities will likely also increase, thereby driving the price premium for eligibility higher. In a related context, Bakkensen and Barrage (2018) find that ignoring heterogeneity in coastal flood risk beliefs could significantly overestimate future

probability in the current period ($t = 0$) is $\rho(x)$, and so the CE of the ability to protect against a loss that occurs in $t = 0$ is equal to the expected irreversible loss ($\rho(x) \cdot R$). Conditional on the asset remaining viable through the current period, the CE of the ability to protect against a loss from occurring in the second period ($t = 1$) is the same value discounted $(\rho(x) \cdot R)/(1 + r)$, where r is the discount rate. The probability that the asset does not experience an irreversible loss in $t = 0$ is $1 - \rho(x)$; therefore, the unconditional CE for the ability to protect against a loss that occurs in $t = 1$ is $(1 - \rho(x)) \cdot (\rho(x) \cdot R)/(1 + r)$. Extending this logic to an infinite horizon, the annual CE of the protection option can be written as:

$$\begin{aligned} \text{CE}(x, r, R) &= \rho(x)R + \rho(x)R\left(\frac{1 - \rho(x)}{1 + r}\right) + \rho(x)R\left(\frac{1 - \rho(x)}{1 + r}\right)^2 \\ &\quad + \rho(x)R\left(\frac{1-\rho(x)}{1+r}\right)^3 + \ldots \\ &= \rho(x)R\sum_{t=0}^{\infty}\left(\frac{1 - \rho(x)}{1 + r}\right)^t, \end{aligned} \tag{4}$$

where this infinite series simplifies to:

$$\text{CE}(x, r, R) = \frac{\rho(x) \cdot (1 + r)}{\rho(x) + r} R. \tag{5}$$

Equation (5) is an expression for the CE of the erosion-protection option in terms of the annual rents to the asset that are at risk for irreversible loss, the subjective probability of the irreversible loss, and the discount rate. The CE is an increasing function of $\rho(x)$ and R, and a decreasing function of r. In our empirical application, we value the option created by Oregon's Goal 18 policy by estimating differences in sales prices between comparable protection-eligible and protection-ineligible parcels (i.e., the CE). We then use fine-scale spatial data on x to test our hypotheses on how changes in a set of geomorphological and locational factors impact ρ and the CE of having a coastal protection option.

We motivate our exploration into the spatial spillover effects of private coastal protection decisions by returning to equations (3) and (5). Consider the price difference between two assets that are both protection ineligible and identical in every way except that one is located next to a protection-eligible asset and the other is not. The parcel with the protection-eligible neighbor could face deflected wave action due to their neighbor's option for an SPS, which gives them a higher risk of the irreversible loss when

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coastal housing prices. Given the wide variation in both erosion and accretion rates and beliefs about climate change during our study period, identifying the influence of expectations about sea level rise on risk probabilities and variation in risk perceptions across space would require additional individual-level data that are not currently available in our study area.

compared to the parcel that has no protection-eligible neighbors. In this situation, the presence of $\rho > 0$ implies a market price premium for having no protection-eligible neighbors. In other words, further price differentials expressed as a capitalization effect may emerge between protection-ineligible assets due to the increased risk that arises from proximity to protection-eligible assets. This simple example implies that if equation (3) holds, there is potential for a negative externality resulting from private coastal protection decisions which may be capitalized in the coastal land market. Our empirical analysis uses this logic to identify and estimate the direction and magnitude of these spillover effects and the impact of the spillover effects on subjective risk of irreversible loss.

3. DATA

The Oregon DLCD monitors Goal 18 and recently produced a geographic information system (GIS) data set characterizing each oceanfront parcel as eligible or not eligible, allowing us to identify parcel-level variation in the option to invest in erosion protection (Gardner 2015). To analyze the impact of protection eligibility on housing prices, deed records and tax assessor data from 2004 to 2015 were purchased from CoreLogic's University Data Portal. These data contain transaction price, sales date, street address, and numerous housing characteristics, including number of bedrooms, number of bathrooms, year built, square footage, lot size, among others. Transaction prices are adjusted to 2015 dollars using the Housing Price Index from the Federal Housing Finance Agency. This information is then merged with GIS tax parcel maps obtained from the state of Oregon. Data characterizing the risks and amenities for oceanfront parcels are obtained from existing technical reports, such as shoreline change rates (Ruggiero et al. 2013), federally designated flood risk zones, and parcel geomorphology (i.e., dune or bluff) (Harper et al. 2013). We augment these data by obtaining aircraft-based Light Detection and Ranging (LiDAR) imagery of the Oregon Coast from 2002, 2009, and 2014 from NOAA's Digital Coast. Combined with digital satellite images, we determine the building footprint of the housing structure on each oceanfront parcel. From this assessment, we take measurements that proxy for both coastal risks and amenities, including the distance from the parcel structure to the shoreline, the distance from the structure to the actual vegetation line (the likely location of an SPS) and minimum elevation of each transacted parcel.[9] We leverage GIS processes to assign each parcel a proximity to lighthouses and state parks and a distance to mean high water. We then incorporate an OPRD database on the location and timing of installation of all existing SPSs. We then determine which parcels are protected by these structures, which structures are installed on private property, and which are located on public beach managed by OPRD at the time of observed transaction. Finally, to control for potential correlations

9. Beach width, a commonly used measure to quantify beach quality in other research, is captured in our data as the difference in our measures of structure distance to mean high water and distance to the actual vegetation line. Econometrically, we do not include beach width in our model as it is perfectly colinear with these other variables.

between subsidy streams in flood insurance markets and Goal 18 eligibility, we construct indicator variables for properties that were grandfathered into the Federal Emergency Management Agency's (FEMA) National Flood Insurance Program (NFIP) with subsidized rates (pre–Flood Insurance Rate Map [pre-FIRM] properties) and those within participating communities with insurance subsidies through FEMA's Community Rating System program (CRS).

Our final data set contains 1,738 transactions of oceanfront homes in Oregon with a Goal 18 eligibility determination from 2004 to 2015. We restrict our analysis to single-family residences and then remove transactions that are not deemed arms-length or contain missing data (e.g., no bedrooms). Potential outliers (i.e., lowest and highest 1% of sales prices) are also dropped from the data set. We then have 1,519 arms-length transactions of single family, oceanfront residences for the analysis. Goal 18–eligible parcels comprise 72% of the sample (1,101 transactions), and summary statistics by eligibility status are displayed in table 1, columns 1 and 2. Goal 18–eligible homes have slightly lower average sale prices than noneligible homes in our sample. The noneligible homes are also newer, larger, constructed on larger lots, and set back further from the actual vegetation line at a higher elevation.

A second data set of housing value, known in Oregon as real market value (RMV), was purchased from assessor's offices in Oregon's coastal counties (Clatsop, Coos, Curry, Douglas, Lane, Lincoln, and Tillamook). All Oregon properties have an RMV assessed each calendar year defined as what a parcel would sell for at an arms-length transaction on January 1 of that tax year. RMVs are determined by a combination of physical property inspection and a comparison of sales transaction data from similar properties. In other words, RMVs are not assessed values, but an assessor determination of market value for each year.[10] Here the RMV data are joined to each oceanfront parcel with an eligibility determination and are used to develop a separate analysis as a robustness check on our hedonic models with transaction data as described in section 5.4.

4. EMPIRICAL METHODOLOGY

We use a hedonic pricing model to estimate the capitalization effect of having the private erosion-protection option in the Oregon oceanfront housing market. We assume that buyers and sellers are attentive to differences in erosion-protection eligibility as defined by State Planning Goal 18 since this policy was in force on the Oregon Coast for 28 years before the first transaction in our data and Oregon's Statewide Planning Goals are the foundation for land-use planning and local comprehensive plans in the state.[11] However, this does raise identification concerns that we must address within

10. Previous work has used RMVs to investigate the effects of urban growth boundaries in Oregon (Grout et al. 2011; Bigelow and Plantinga 2017).

11. In addition, information about eligibility by parcel is available on a website maintained by the state of Oregon: https://www.coastalatlas.net/index.php/tools/planners/67-ocean-shores-viewer.

Table 1. Summary Statistics by Protection Eligibility Status

	Treated Full Sample (N = 1,101) (1)		Control Sample (N = 418) (2)		Treated Trimmed Sample (N = 448) (3)		Reduction in Standardized Bias (4)
	Mean	SD	Mean	SD	Mean	SD	
Price (US$ 2015)	$589,666	$375,973	$622,667	$421,994	$613,848	$422,239	74.8
Market improvement value	$221,482	$184,634	$327,888	$230,327	$316,497	$170,861	88.9
Shoreline Δ rate (m/y)	.38	.83	.85	1.22	.58	1.11	49.5
Minimum elevation (ft)	21.03	26.63	42.2	59.9	29.7	26.6	41.0
Structure setback (ft)	158	194	345	333	323	441	92.0
Age	42.1	25.0	20.1	12.7	17.3	15	82.7
Bedrooms	3.08	1.33	2.95	1.14	2.91	.91	62.9
Bathrooms	2.30	1.05	2.61	.93	2.57	.85	85.7
Square footage	2,144	1,076	2,642	1,105	2,383	973	45.4
Lot size (ft^2)	19,254	27,404	32,067	50,450	33,429	47,416	91.4
Garage	.75	.43	.82	.39	.72	.45	+
Air conditioning	.06	.24	.14	.35	.07	.26	15.4
Distance to lighthouse (ft)	59,210	40,494	40,886	36,610	43,489	38,927	17.1

Bluff location	.15	.36	.21	.41	.21	.41	100
Dune-backed location	.35	.48	.39	.49	.33	.47	50.0
Distance mean high water (ft)	102	104	173	162	151	177	75.7
100-year floodplain	.71	.46	.46	.50	.58	.49	53.5
SPS on parcel	.31	.46	.06	.25	.18	.38	45.9
Distance to nearest SPS (ft)	2,562	5,281	6,406	8,212	5,339	7,722	76.5
FEMA CRS participant	.16	.37	.14	.34	.14	.35	80.6
NFIP pre-FIRM subsidy	.59	.49	.07	.25	.12	.33	93.7
Year sold	2008.4	3.59	2008.4	3.72	2008.3	3.44	60.1
County	3.16	1.51	3.77	2.15	3.80	1.91	94.4
Latitude	44.66	.98	44.24	1.35	44.23	1.16	98.3
Longitude	−124.06	.12	−124.13	.17	−124.14	.17	87.1

Note. Authors' calculations from transaction, tax assessor, and geospatial data sets. "SPS on parcel" for Goal 18–ineligible parcels is not zero due to grandfathering of structures existing prior to 1977 and a few limited cases where SPSs are constructed on unregulated private property where state-permitting agencies do not yet have jurisdiction. Trimmed sample in col. 3 generated using a 1-nearest-neighbor matching algorithm with replacement matching on propensity score (probability of being treated; Goal 18 eligible). The resulting sample keeps all Goal 18–noneligible parcels (col. 2) and 448 eligible parcels that provide the best balancing of the covariates between the two groups. The reduction in standardized bias (SB) is $|SB_F - SB_M|/SB_F$ where F and M subscripts denote full and matched sample, respectively. SB is the difference in the sample means divided by the average sample standard deviation. SPS = shoreline protection structure; CRS = Community Rating System program; NFIP = National Flood Insurance Program.

$^{+}$ Denotes variables where full sample matched well and therefore standardized bias increased slightly in the matched sample.

our research design since we are using nonexperimental data and lack a more familiar quasi-experimental framework with pre- and postpolicy observations. First and foremost, the treatment (protection-eligible) and control (protection-ineligible) groups are not balanced on observable characteristics, as shown in table 1, columns 1 and 2. This is not unexpected, as treatment was defined by the state planning goal in 1976, but does cause concern about estimating the treatment effect. To remedy this issue, we trim the transactions data to improve the balance on observables through a matching procedure (Rosenbaum and Rubin 1983; Imbens 2015) before estimation of the hedonic regression. Walls et al. (2017) recently used a similar methodology to estimate the effects of energy certification on housing prices amid a broader methodological push for combining matching and fixed-effect regression techniques (Imbens and Wooldridge 2009; Ferraro and Miranda 2017). Specifically, our matching exercise relies on the conditional independence assumption, which assumes that the only source of potential bias arises from omission of observable characteristics. Using a matching estimator only would still be biased due to any remaining differences in covariates between the two groups. To overcome this, we estimate a hedonic regression on the trimmed sample keeping the observable characteristics in the model to control for any remaining covariate imbalance. Furthermore, we use spatial and temporal fixed effects in our regressions to systematically control for unobservable characteristics that may bias our results. The combination of matching and regression approaches leads to a relatively robust estimation of the treatment effect (i.e., improves the internal validity of the analysis) at the potential expense of reduced external validity of our results (Imbens and Wooldridge 2009).

We start with a simple and parsimonious approach to matching given the construction and constraints of our data set. Specifically, we use logit regressions with independent variables included in our hedonic model and additional geographic controls (latitude and longitude) to generate propensity score estimates of the probability that each parcel is treated with erosion-protection eligibility.[12] Panel *A* of figure 2 shows the distribution of propensity scores for the treatment (gray) and control (black dash) groups, highlighting the imbalance in covariates. Since our data have more treated observations than controls, a k-nearest neighbor matching (NNM) algorithm ($k = 1$) with replacement keeps all controls and matches to treated observations based on the estimated propensity score. This data-trimming procedure reduces the number of observations to 866 transactions but significantly improves the balance on observables between the two groups of homes.[13] Panel *B* of figure 2 provides visual evidence of the improvement

12. We use market improvement value as a proxy for housing characteristics (e.g., square footage, garage indicator) for parsimony.

13. For reference, in the full sample of 1,519 transactions, 912 (60%) of the homes were built after 1977, including 515 of 1,101 (47%) of the protection-eligible homes. Of the home sales in our trimmed data sample, 800 of 866 (92.3%) structures were built after 1977, including 403 of 448 (90%) of protection-eligible parcels.

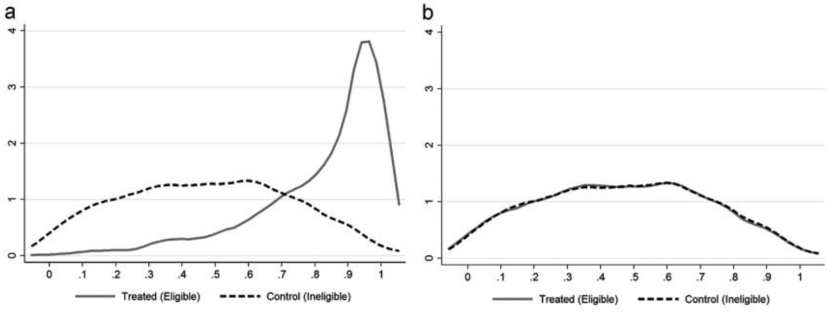

Figure 2. Propensity score histograms. *a,* Full sample ($N = 1{,}519$). *b,* Postmatch sample ($N = 866$). Histograms for different nearest-neighbor match specifications are provided in figure A.2.

in balance and table 1 (cols. 2–4) includes summary statistics for each group and the reduction in standardized bias for the matched sample. Figure 3 provides a comparison of observations in the full and trimmed samples, demonstrating that the matching process does not fundamentally change the spatial distribution of the market transactions used in our models. Section 5.4 presents a series of robustness checks to different assumptions regarding the matching process.

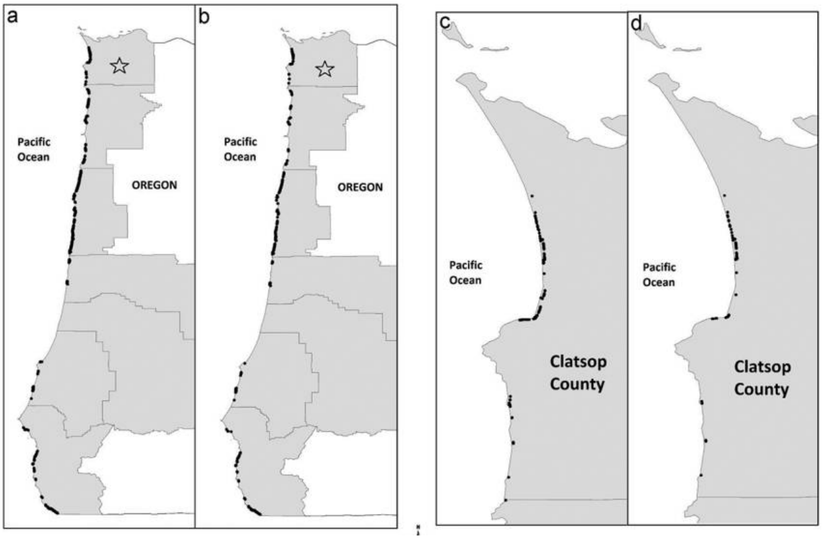

Figure 3. Spatial distribution of transactions. Dots represent transactions and the gray shading indicates Oregon's seven coastal counties. The star on the maps on the left indicates Clatsop County (*inset on right*). *a,* Full transaction sample. *b,* Trimmed transaction sample. *c,* Full transaction sample. *d,* Trimmed transaction sample.

A second identification concern is the potential for correlation of amenities and risk in coastal housing markets (e.g., Bin and Kruse 2006; Bin, Crawford, et al. 2008; Bin, Kruse, and Landry 2008; Dundas 2017). We use data on structure setback from the actual vegetation line (as a proxy for ocean views), lighthouse proximity, and an indicator for bluff location of a home to control for housing-related amenities. To characterize coastal risks, we use parcel-level estimates of elevation, shoreline change rates, distance to mean high water, and location in the 100-year floodplain. We also control for an existing SPS on a parcel. The parcel-level scale of our coastal risk data also allows us to interact the risk variables with a dummy indicating protection eligibility and formally test our hypotheses from equations (1) and (2). Given that some combination of risks and/or amenities may be unobservable, we present a robustness check on whether we have adequately disentangled amenities and risks using an alternative spatial first-differences estimator in the next section.

We use the matched sample of transaction data to estimate the impact of erosion-protection eligibility on housing prices as follows:

$$\begin{aligned}\ln \mathrm{P}_{it} = {} & \alpha + \beta \mathrm{G18}_i + \mathrm{Elev}_i[\delta_1 + \delta_2 \mathrm{G18}_i] + \mathrm{SC}_i[\omega_1 + \omega_2 \mathrm{G18}_i] \\ & + \mathrm{NFIP}_{it}[\psi_1 + \psi_2 \mathrm{G18}_i] + \mathbf{X}_{it}\sigma + \eta_{j(i)t} + \nu_t + \varepsilon_{it},\end{aligned} \tag{6}$$

where the natural log of sales price (P) of home i at time t (adjusted to 2015 dollars) is the dependent variable. The term $\mathrm{G18}_i$ is the policy variable of interest equal to one if the parcel is erosion-protection eligible, while Elev_i, SC_i, and NFIP_{it} are variables quantifying minimum parcel elevation (feet above sea level), the long-term shoreline change rate (meters per year) at parcel i, and the presence of an NFIP subsidy. The vector $\boldsymbol{X}$ represents structural and locational attributes of each home, which are included in the regression to control for any remaining imbalances in the variables after matching. County-by-year fixed effects ($\eta_{j(i)t}$) are used to control for county-specific attributes that change over time (e.g., the Great Recession, weather shocks), and quarter-sold fixed effects (ν_t) are used to account for seasonal housing market trends. The model is estimated with robust standard errors clustered by municipality so the estimates are robust to heteroskedasticity and spatial correlation across parcels within a municipality.

5. RESULTS

5.1. Baseline Model

Table 2 displays our baseline model results using the trimmed, postmatching transaction data.[14] The initial specification (col. 1) with only housing characteristics suggests

14. Regression results for the full, unbalanced transaction sample are included in table A.1.

Table 2. Postmatch Regression Results for Baseline Model

	Initial Model (1)		No Fixed Effects (2)		Main Baseline Model (3)+	
Variables	Estimate	SE	Estimate	SE	Estimate	SE
Goal 18	.009	.062	.233*	.126	.273***	.097
Goal 18 × shoreline Δ rate			−.087	.060	−.102**	.049
Goal 18 × elevation			−.004*	.002	−.005**	.002
Goal 18 × NFIP subsidy			−.098	.178	−.166	.159
Minimum elevation (ft)			−.001	.001	−.0002	.0008
Shoreline Δ rate (m/y)			.062	.048	.029	.048
Setback (ft)			−.001*	.0003	−.001*	.0002
Bedrooms	.511***	.116	.471***	.076	.193**	.094
Bathrooms	.053	.069	.023	.057	−.003	.060
Square footage	.0002	.0002	.0001	.0001	.0002**	.0001
Lot size (ft^2)	−2.5e-06	1.7e-06	−5.4e-07	1.5e-06	1.8e-07	1.5e-06
Age of home	−.004	.012	.009	.011	.017*	.009
Garage	−.089	.183	.001	.138	.164	.105
Air conditioning	.081	.216	.290	.189	.080	.150
Distance mean high water (ft)			.001	.001	.0001	.0008
Bluff location			−.142	.105	.040	.084
Dune-backed location			−.199**	.081	−.035	.060
100-year floodplain			.018	.125	−.122	.126
Distance to lighthouse (ft)			−2.5e-06	2.4e-06	1.6e-07	1.1e-06
SPS on parcel			.098	.198	.018	.157
Distance to nearest SPS			−6.9e-06	6.6e-05	−3.3e-10	6.0e-10
FEMA CRS participant			.275**	.122	.144	.208
NFIP pre-FIRM subsidy			−.165	.114	−.076	.133
Quarter fixed effects	No		No		Yes	
County-by-year fixed effects	No		No		Yes	
Constant	11.88***	.241	11.90***	.321	12.34***	.343
Observations	866		866		866	
R-squared	.149		.268		.503	

Note. Restricted to single family residences. Robust standard errors are clustered by municipality (there are 29 in our sample; see table A.2 for the full list). Squared terms for housing characteristics (bedrooms, bathrooms, square footage, lot size, age) and distance variables (mean high water, nearest SPS) and indicators for finished basement and landslide risk are included in estimation but suppressed in the table for parsimony. SPS = shoreline protection structure; CRS = Community Rating System program; NFIP = National Flood Insurance Program.

+ Preferred specification.

* $p < .1$.

** $p < .05$.

*** $p < .01$.

that the coefficient on Goal 18 eligibility is not significantly different from zero. The second column adds parcel amenity and risk characteristics as well as interactions with the policy variable of interest, and the third column further adds two sets of fixed effects. Results from specification (3) suggest that protection eligibility has a positive, statistically and economically significant impact on housing values. The coefficient estimate implies that erosion-protection eligibility produces a price premium of 31% for protection-eligible homes compared to similar protection-ineligible homes.[15] We also find that this value varies with risk exposure (parcel elevation and shoreline change rates) and the direction and magnitude of these interaction effects support our hypotheses in equations (1) and (2) in our conceptual framework. Specifically, we find that the value placed on protection eligibility is likely to decline 0.5% per 1 foot increase in elevation above sea level and decline 10.7% for each additional meter of accretion per year. These results also imply that value for protection eligibility is likely to be higher at lower elevations and may increase as shoreline change rates become more negative (i.e., erosion). The interaction with NFIP subsidy is insignificant, and all housing characteristics in the hedonic model have expected signs and relative magnitudes. The coefficient on the indicator for an installed SPS is positive but insignificant.

5.2. Spillover Concerns and Main Results

Given the spatial discontinuities in erosion-protection eligibility, an additional concern for identification is that the control group may be impacted by the treatment—a violation of the stable unit treatment value assumption. Results from our baseline model above are likely biased due to the potential presence of a spatial spillover (externality) on protection-ineligible parcels related to their eligible neighbor's option to armor (i.e., eq. [3]). A private choice to armor shoreline with an erosion-protection structure may alter the pattern of sediment dynamics along the coastline such that erosion risks are accentuated on the shoreline of parcels that are nearby to armored neighbors.[16] Indeed, the potential for altered shoreline sediment dynamics was a primary justification for the original Goal 18 policy that prohibited shoreline armoring. Intuitively, including all parcels in the primary estimation of (6) leaves open the possibility that the estimated effect of the Goal 18 policy is a combination of the effect of protection eligibility and the effect of the spatial externality associated with close proximity to a potential future SPS.

To test for the potential spillover from erosion-protection eligibility, we redefine the control group where protection-ineligible homes within a specified linear distance

15. Percentage effects derived using an adjustment of the estimated coefficient following Halvorsen and Palmquist (1980).

16. While the existence and magnitude of these potential impacts is still an open empirical question dependent on the position of the SPS, beach slope, and other geomorphological and hydrodynamic parameters (Ruggiero 2010; Ells and Murray 2012), it does have the potential to impact risk perceptions of buyers and sellers in a coastal housing market.

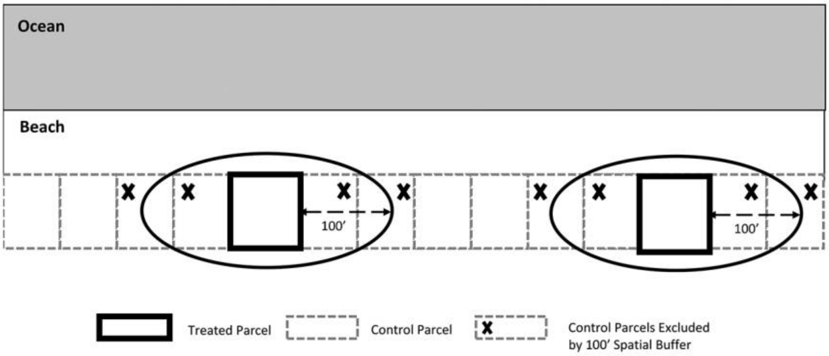

Figure 4. Schematic representation of identification of the spillover effect (100 ft). In the full model, all treated (*black*) and control (*gray dash*) parcels are included. In the spatial buffer model, all control parcels marked with an *X* are removed prior to estimation.

of treated parcels are removed from the estimation set. We test five spatial buffers (100 ft, 200 ft, 300 ft, 400 ft, and 500 ft). Figure 4 provides a schematic representation of our strategy for estimating a full identified model by removing parcels within a 100-foot radius of a treated parcel that may be subject to these spillover effects.

We report results for the 100-, 200-, and 300-foot spillover exclusions, which remove 187, 219, and 252 parcels from our sample, respectively, in table 3 alongside our baseline model results in column 1.[17] The coefficients on the policy variable are consistent with the baseline model, suggesting a premium ranging from 29% to 32%. The interaction with elevation suggests a similar 0.4% to 0.5% decline per 1-foot increase in elevation. The interaction with shoreline change rate increases slightly, from 10.7% decline per meter increase in accretion in the baseline to 13.6%–16.5% in the spillover models. The only notable change is that the interaction of the policy variable and indicator for NFIP subsidy is now significant and negative, suggesting that the premium for Goal 18 eligibility declines if the parcel is eligible for subsidized flood insurance.[18] Across all of our spillover exclusion models, the effect of having an SPS installed on a property is positive, ranging from 1.2% to 6.5%, but insignificant. This is likely a

17. Results for models with the 400- and 500-ft spillover exclusions are fundamentally similar to the results shown in table 4 and are displayed in tables A.3 and A.4.

18. The magnitude of the interaction term of NFIP subsidy and Goal 18 eligibility suggests that pre-FIRM parcels, even if they are low elevation and eroding, do not get the erosion-protection eligibility premium. However, the combination of attributes that would produce this effect are only present in seven parcels in our sample.

Table 3. Postmatch Regression Results for Models Accounting for Spillovers

	Main Baseline Model (1)		Spillover Model (100′) (2)⁺		Spillover Model (200′) (3)		Spillover Model (300′) (4)	
Variables	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Goal 18	.273***	.097	.257**	.116	.277**	.118	.276**	.112
Goal 18 × shoreline Δ rate	−.102**	.049	−.153***	.047	−.144***	.048	−.128***	.056
Goal 18 × elevation	−.005**	.002	−.004**	.002	−.004**	.002	−.005**	.002
Goal 18 × NFIP subsidy	−.166	.159	−.532**	.233	−.688***	.169	−.642***	.171
Minimum elevation (ft)	−.0002	.0008	−.001	.001	.001	.001	.001	.001
Shoreline Δ rate (m/y)	.029	.048	.080*	.004	.058	.052	.048	.062
Setback (ft)	−.001*	.0002	−.001***	.000	−.001***	.000	−.001**	.000
Bedrooms	.193**	.094	.384**	.144	.351**	.145	.350**	.149
Bathrooms	−.003	.060	−.019	.056	−.022	.055	−.028	.061
Square footage	.0002**	.000	.000	.000	.0001	.000	.0001	.000
Lot size (ft^2)	1.8e-07	1.5e-06	−5.0e-07	1.4e-06	−6.4e-07	1.5e-06	1.3e-06	1.4e-06
Age of home	.017*	.009	.020*	.010	.023**	.009	.022**	.010
Garage	.164	.105	.163	.123	.178	.113	.177	.119
Air conditioning	.080	.150	−.105	.261	−.064	.260	−.059	.240

Distance mean high water (ft)	.000	.001	–.000	.001	–.000	.001	–3.8e-06	.001
Bluff location	.040	.084	–.024	.100	–.087	.095	–.101	.091
Dune-backed location	–.035	.060	–.043	.075	–.072	.080	–.085	.087
100-year floodplain	–.122	.126	.053	.135	.083	.138	.051	.150
Distance to lighthouse (ft)	1.6e-07	1.1e-06	1.2e-06	1.3e-06	1.2e-06	1.1e-06	1.2e-06	1.3e-06
SPS on parcel	.018	.157	.012	.171	.039	.168	.039	.177
Distance to nearest SPS	–3.3e-10	6.0e-10	.000	.000	–7.8e-10	6.7e-10	.000	.000
FEMA CRS participant	.144	.208	–.091	.205	–.158	.195	–.074	.229
NFIP pre-FIRM subsidy	–.076	.133	.381*	.219	.587***	.192	.522**	.189
Constant	12.34***	.343	12.31***	.441	12.33***	.464	12.34***	.458
Observations	866		679		647		614	
R-squared	.503		.576		.593		.605	

Note. Restricted to single family residences. All models include quarter-sold and county-by-year fixed effects. Robust standard errors are clustered by municipality. Squared terms for housing characteristics (bedrooms, bathrooms, square footage, lot size, age) and distance variables (mean high water, nearest SPS) and indicators for finished basement and landslide risk are included in estimation but suppressed in the table for parsimony. Results for models with spillovers of 400′ and 500′ are provided in table A.3. SPS = shoreline protection structure; CRS = Community Rating System program; NFIP = National Flood Insurance Program.

+ Preferred specification.

* $p < .1$.

** $p < .05$.

*** $p < .01$.

precision issue as our small sample lacks the data variation to separately identify both the option for and the existence of an armoring structure.[19]

Since we have interactions of discrete and continuous variables that impact the overall effect on housing prices, we derive point estimates and standard errors for the discrete change effect of erosion-protection eligibility evaluated at average elevation, shoreline change rates, and NFIP subsidy eligibility for all parcels. We also do this for three subset of homes based on risk profile (eroding parcels, lower than average elevation parcels, and eroding, low-elevation parcels) using a linear combination of the parameter estimates β, δ_2, ω_2, and Ψ_2 from equation (6) for each model specification.

Estimates for the discrete change effect of Goal 18 eligibility are shown in table 4. Panel A uses coefficients from the baseline model and panels B, C, and D show the estimates for the 100-, 200-, and 300-foot spillover models. Across all panels, the erosion-protection eligibility for the average oceanfront parcel in the sample (30 ft above sea level, +0.6 meter/year [m/y] accretion) has an insignificant effect on price. Furthermore, no significant effects are found for parcels with accreting shorelines or above average elevation, indicating that the housing market does not value erosion-protection eligibility if exposure to erosion risk is low. We focus our discussion of the results for at-risk parcels to panel B, the model with the 100-foot spillover exclusion. Parcels that are only low elevation do not have significant price premium for Goal 18 eligibility. We do find positive and significant effects for parcels with eroding shoreline (13.4%) and for parcels with both an eroding shoreline and located at a below average elevation (22%). Figure 5 illustrates how the option value for erosion protection for an average low-elevation parcel (~10 ft above sea level) varies with shoreline change rates (panel A) and for an average eroding parcel (–0.47 m/y) varying with minimum parcel elevation (panel B). As shown, the effect of having the option for erosion protection is substantively higher for more vulnerable parcels.

Applying our conceptual framework, we can compute an approximation of the annual subjective probability of irreversible loss ($\rho(x)$) implied by the results of our empirical estimation. First, equation (5) can be rearranged to solve for $\rho(x)$:

$$\rho(x) = \frac{r \cdot \mathrm{CE}(x, r, R)}{R(1 + r) - \mathrm{CE}(x, r, R)}. \tag{7}$$

We assume a 5% discount rate ($r = 0.05$) for simplicity. For the parcels at risk for irreversible loss, the average home in each subset sold for \$616,000 (eroding shoreline only) and \$675,000 (both eroding and low elevation). These average prices imply

19. An alternative explanation for the insignificance of the SPS coefficient is unobserved heterogeneity in risk perceptions across time and space that our controls for risk (elevation, shoreline change rate, distance to mean high water, and parcel geomorphology) could not fully capture.

Table 4. Discrete Change Effect of Goal 18 Eligibility

Subset of Parcels	*N*	Estimate	SE
A. Baseline model:			
All parcels	866	.059	.059
Eroding parcels	246	.163**	.082
Low-elevation (<= 30′) parcels	534	.142**	.071
Eroding, low-elevation parcels	155	.255***	.097
B. Model including spillovers (100′)[+]:			
All parcels	679	−.023	.066
Eroding parcels	198	.134*	.075
Low-elevation (<= 30′) parcels	404	.050	.091
Eroding, low-elevation parcels	119	.220**	.102
C. Model including spillovers (200′):			
All parcels	647	−.024	.067
Eroding parcels	187	.124	.086
Low-elevation (<= 30′) parcels	386	.054	.092
Eroding, low-elevation parcels	113	.215**	.111
D. Model including spillovers (300′):			
All parcels	614	−.038	.086
Eroding parcels	178	.093	.086
Low-elevation (<= 30′) parcels	374	.061	.097
Eroding, low-elevation parcels	112	.203**	.103

Note. Standard errors are calculated using the delta method. Results for models with spillovers of 400′ and 500′ are provided in table A.4.

[+] Preferred specification.

* $p < .1$.

** $p < .05$.

*** $p < .01$.

annual rents of $R_{\text{Erode}} = \$30{,}800$ and $R_{\text{Both}} = \$33{,}750$. The estimated CE (annualized) for protection eligibility estimated with our preferred specification with a 100-foot spillover exclusion are \$82,500 (\$4,125) and \$148,500 (\$7,425), respectively. We can then solve for $\rho(x)$ for both subsets of parcels. Here, we show the calculation for parcels that are both low elevation and eroding:

$$\rho(x)_{\text{Both}} = \frac{0.05 \cdot 7{,}425}{33{,}750 \cdot (1.05) - 7{,}425} = 0.013. \tag{8}$$

A similar calculation for the other parcel subset yields $\rho(x)_{\text{Erode}} = 0.007$. Our estimated capitalization effects imply that the subjective annual probability that a home will experience an irreversible loss absent the option for protection varies with the risk profile of the parcel and is approximately between 0.7% and 1.3% (with a 5% discount rate).

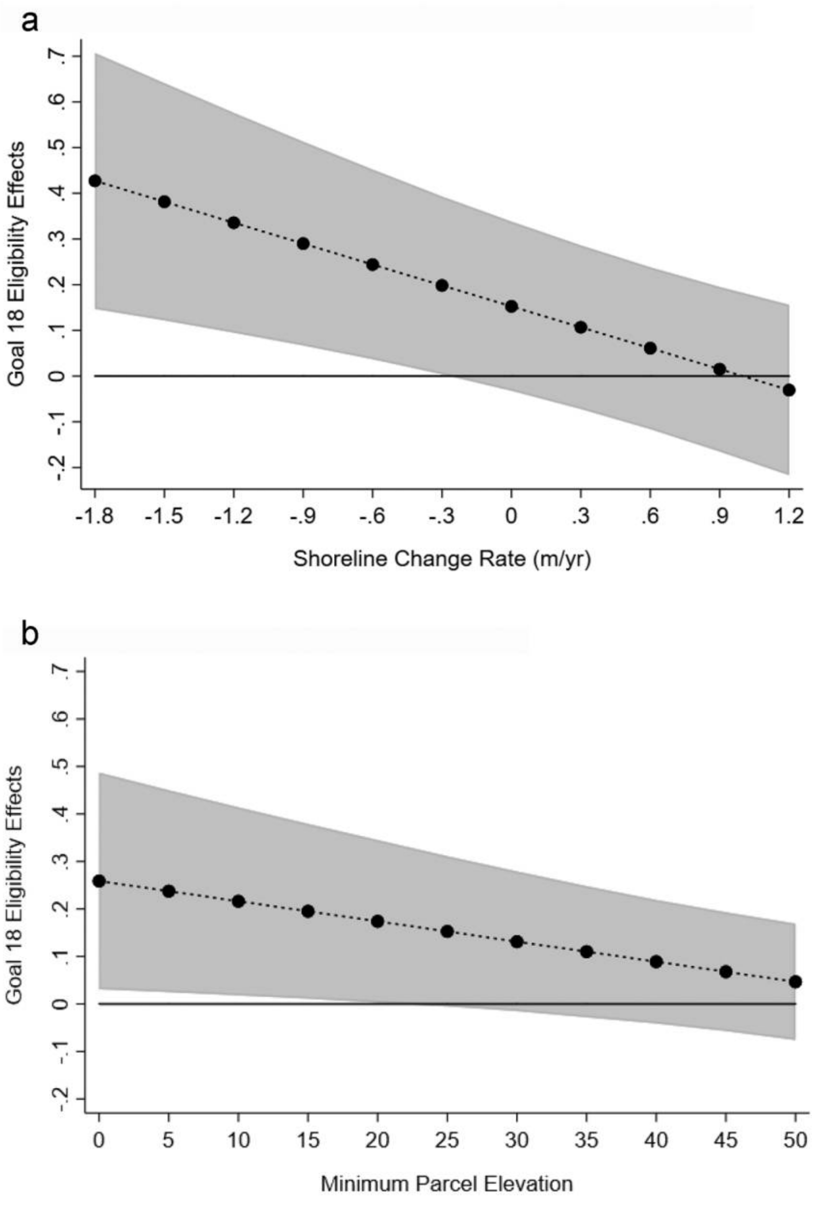

Figure 5. Effect of Goal 18 eligibility for vulnerable parcels. Dots represent point estimates, and the gray shading indicates the 95% confidence interval. *a*, Average low-elevation parcel at varying shoreline change rates. *b*, Average eroding parcel at varying elevation.

5.3. Estimating the Spillover Effect

Given the longevity of the Goal 18 policy and the apparent long-run salience of the erosion-protection option in Oregon's oceanfront housing market, we attempt multiple strategies to identify and estimate the effect of potential spillovers. First, we estimate a model simply adding a spillover dummy (SP) for control parcels subject to the spatial externality to equation (6). These results are presented in table 5, column 1, and the effect is negative, albeit insignificant, for the first three spatial exclusion models. To better identify the spillover effect, we exclude all Goal 18 protection-eligible (treated) observations from the estimation set and run a regression with the spillover dummy (SP) as follows:

$$\begin{aligned}\ln \mathrm{P}_{it} = {} & \alpha + \beta \mathrm{SP}_i + \mathrm{Elev}_i[\delta_1 + \delta_2 \mathrm{SP}_i] + \mathrm{SC}_i[\omega_1 + \omega_2 \mathrm{SP}_i] \\ & + \mathrm{NFIP}_{it}[\psi_1 + \psi_2 \mathrm{SP}_i] + \mathbf{X}_{it}\sigma + \eta_{j(i)t} + \nu_t + \varepsilon_{it},\end{aligned} \tag{9}$$

We run two versions of equation (9), one that suppresses the interaction terms and one that includes the interactions. These results are reported in columns 2 and 3 of table 5. The models show a range of spillover damages attributable to the spatial externality (between 2.8% and 8.3%), with the only significant estimate of 8.3% in the 100-foot spillover exclusion in the interaction model. This suggests that the market may be attending to the potential for spillovers, but only as it relates to the eligibility status of their immediate neighbors.[20] Summary statistics showing balance on observables among the control parcels for estimation of equation (9) are provided in table A.5 (tables A.1–A.9 are available online).

We attempt one additional process to evaluate the potential magnitude of the spillover effect. Here, we use coefficient estimates from both our baseline (sec. 5.1) and spillover exclusion models (sec 5.2) to back out an estimate for the spillover effect. In this exercise, we define β_{Base} as the discrete change effect of Goal 18 erosion-protection eligibility estimated from the baseline model and β_{Exc} as the effect estimated from the spillover exclusion models. The effect on excluded control parcels subject to the externality (β_{SPE}) can be calculated assuming the effect from the baseline model is a weighted

20. Alternatively, we attempted to capture the direct effect of SPS installation by comparing eligible parcels with an installed SPS to ineligible parcels without an SPS (i.e., SPS effect) and comparing eligible parcels without an SPS to noneligible homes without an SPS. The difference between these estimates could also reflect an approximation of the spillover effect. We find evidence that supports the relative magnitude of the spillover effect from our current method but with much larger standard errors. In the first model capturing the direct effect of SPSs, the matched sample size is reduced to 269 observations and we find an insignificant effect of approximately 17% ($p = .398$) for an SPS in vulnerable (low-elevation, eroding) parcels. For the second exercise, the sample size is reduced to 506 observations and we find an insignificant effect of 10.8% ($p = .302$). Taken together, these estimates are suggestive of a spillover effect of $\sim$ 6.2%, which is comparable to what we find in our preferred analyses using all of the data (see table 5).

Table 5. Estimation of Spillover Effect

Variables	Add Spillover Indicator to Main Specification Eq. (6) (1)		Spillover Estimation Eq. (9) with Control Obs. Only (2)		Spillover Estimation Eq. (9) with Control Obs. Only with Interactions (3)+		Back-of-the-Envelope Calculations Using Eqs. (10) and (11) (4)
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate
Spillover effect: 100′	−.043	.066	−.028	.018	−.083***	.028	−.078
Spillover effect: 200′	−.011	.062	−.004	.052	−.067	.055	−.076
Spillover effect: 300′	−.045	.062	−.051	.074	−.079	.078	−.086
Spillover effect: 400′	.016	.059	.002	.044	−.043	.055	.032
Spillover effect: 500′	.003	.062	−.010	.058	−.057	.068	.026

Note. Standard errors for model 1 are clustered by municipality, model 2 are clustered by county, model 3 are calculated by the delta method, and model 4 does not have standard errors. Model 1 uses all data, models 2 and 3 use only the control observations, and model 4 is a back-of-the-envelope calculation based on multiple models with the full data set described in eqs. (10) and (11).

+ Preferred specification.

* $p < .1$.

** $p < .05$.

*** $p < .01$.

average of the effects from the control group in exclusion models and the control parcels subject to the spillover externality (SPE) as follows:

$$(\%C_{\text{Exc}} \cdot \beta_{\text{Exc}}) + (\%C_{\text{SPE}} \cdot \beta_{\text{SPE}}) = \beta_{\text{Base}}, \tag{10}$$

where $\%C_{\text{Exc}}$ is the percentage of control parcels not impacted by the spillover externality (included in the spillover exclusion models) and $\%C_{\text{SPE}}$ is the percentage of control parcels subject to the spillover externality (excluded from spillover exclusion models). We can then solve (10) for β_{SPE} and then calculate the spillover effect as:

$$\text{SPE} = \beta_{\text{Exc}} - \beta_{\text{SPE}}. \tag{11}$$

For this back-of-the-envelope exercise, we calculate this impact for each of the five spatial exclusion zones. Estimating SPE using equations (10) and (11) with low-elevation and eroding parcel results, we find consistent spillover damages ranging from 7.6% to 8.6% for the first three spatial buffers. The effect appears to attenuate past the 300-foot buffer, with the estimates for the 400- and 500-foot buffers positive but close to zero (table 5, col. 4). A drawback to this approach is that we do not have standard errors on these back-of-the-envelope estimates, but they do support the magnitude and pattern of the effect found in our regression estimates.

Taken together, these results suggest that the spillover is most relevant within 100 feet of an erosion-protection-eligible parcel. Replacing the betas in equations (10) and (11) with rhos, we can calculate the difference in the implicit probability of irreversible loss between the protection-ineligible parcels differentiated on exposure to the externality. Using the $\%C_{\text{Exc}}$ (55.3%) and $\%C_{\text{SPE}}$ (44.7%) for the 100-foot buffer, $\rho_{\text{Base}} = 0.016$ as calculated from our baseline model for vulnerable parcels, and calculating $\rho_{\text{Exc}} = 0.013$ from our preferred model results, we estimate $\rho_{\text{SPE}} = 0.020$. This calculation shows that the capitalization of the spatial externality associated with proximity to protection-eligible parcels implies an increase in annual subjective probability of an irreversible loss of 0.7 percentage points.

Our main results suggest that there is a significant premium for erosion-protection eligibility for homes vulnerable to that risk but that option may create spillovers if a parcel has ineligible neighbors within 100 feet. With Oregon's Goal 18, grandfathering of eligibility and subsequent land development decisions have created a fragmented spatial configuration of policy eligibility that may generate these externalities and perhaps create a set of perverse incentives for erosion-protection-eligible parcels. To the former, we apply our model estimates to all 4,768 oceanfront parcels in Oregon that are most vulnerable (eroding shoreline, low elevation).[21] We calculate the potential cost of spillovers for every protection-eligible parcel using our estimates for the discrete change

21. This represents about 50% of all oceanfront parcels in Oregon. The remaining 50% of parcels are either at higher than average elevation (>30 ft) or are located on accreting shorelines, or both.

effect of eligibility (22%) and the spillover effect (−8.3%), the RMV for each parcel in 2014, and the count of ineligible parcels within 100 feet of each eligible parcel. For example, consider an eligible parcel A with an RMV of $400,000 and two ineligible neighboring properties (B and C), each valued at $800,000. Our model results suggest that Goal 18 eligibility provides capitalized benefits to the owner of parcel A of $88,000. Yet the eligibility of parcel A imposes spillover effects of $66,400 on both parcels B and C, suggesting a potential net cost of the policy in this setting. Of the 2,700 protection-eligible parcels, 33% (895 parcels) have potential to generate spillover effects on protection-ineligible parcels due to proximity. Importantly, 7.2% (194 parcels) may generate more spillover damages than the benefits to the protection-eligible landowner, leading to these parcels being a net cost to society. Of these net cost parcels, over 70% are located in the three northern counties of Clatsop, Tillamook, and Lincoln.

To the latter point regarding perverse incentives, our results suggest that in settings where all landowners have the option to install an SPS, the potential for spillover damages provide incentive for neighbors to invest in their own protection, which could lead to a cascading of spatially adjacent shoreline armoring decisions. Suggestive evidence of this can be seen in Rockaway Beach in Tillamook County. In this community, nearly all 233 parcels are protection eligible under Goal 18, and 36% have armored to date. Yet, armoring is located in a spatially continuous line that stretches for over 1 mile of shoreline, protecting all 85 parcels that have made the choice to armor in Rockaway Beach.[22]

5.4. Robustness Checks

We perform a series of sensitivity analyses on our matching approach, including alternative variables for the propensity score estimation, alternative NNM approaches, and other matching algorithms (kernel and caliper). First, we construct a matched sample using a propensity score estimation by dropping variables that have potential to be endogenous responses to the Goal 18 policy, such as structure setback. Next, we construct alternative NNM samples by varying the number of matches (k), matching with and without replacement, and requiring exact matches on county. Propensity score histograms from these alternative approaches are displayed in figure A.3 (figs. A.1–A.4 are available online). Furthermore, we use caliper matching to construct two additional trimmed samples (radius $= 0.001$; radius $= 0.002$) and kernel matching to generate two untrimmed but weighted (biweight; Gaussian) samples. The coefficients on the policy variable and interaction terms with shoreline change rate and parcel elevation maintain the same sign, significance, and relative magnitude in nearly all of the alternative postmatching regressions. Importantly, the premium for erosion-protection eligibility is significant ($p < .05$) and positive in all models, ranging from 19.2% to 31%. The

22. Aerial imagery with parcel designations and existing SPSs for Rockaway Beach are provided as fig. A.2.

interactions of the policy variable with elevation and shoreline change rate also suggest similar impacts, ranging from 0.3% to 0.5% declines per foot increase in elevation and 7.5% to 15.5% decline for each meter of accretion. The interaction of the policy variable and NFIP subsidies is insignificant in all alternatives. These finding suggest that our baseline model results are likely not an artifact of a particular subsample and are not sensitive to our matching assumptions. The results of these alternative models are displayed in tables A.6 and A.7 and figure A.4.

While our preferred model includes specific independent variables that measure risks and amenities of oceanfront property, it is still possible that there are unobservable elements of parcel-level risks and amenities that could potentially confound our identification of the Goal 18 treatment (protection-eligibility) effect. We develop a spatial first-differences model to difference out risks and amenities that are spatially invariant across neighboring parcels that otherwise vary in their protection eligibility. Since transaction data on neighboring parcels with differing eligibility is very sparse, we use real-market value (RMV) data as the dependent variable in a model that is the spatial analogue to the repeat-sales model commonly used in the hedonic literature to mitigate bias from time-invariant unobservables.[23] RMV is available for all oceanfront parcels in Oregon (including those that sold during our period and those that did not), and we identify actual neighbors (i.e., parcels that share a common boundary) that differ in protection eligibility to generate first-differences in RMV across the neighboring parcels.[24] Since amenities and risks are expected to be almost identical for neighboring parcels, this spatial first differences approach is likely to eliminate any confounding effects to identifying the impact of erosion-protection eligibility. Details of the model are provided in the online appendix.

Using GIS processes, we find 258 matched pairs of neighboring single-family residences along the Oregon Coast. Given the panel structure of the RMV data, this implies the potential for 3,096 observations. After removing observations with missing data, we have 2,662 observations for this analysis. We analyze two version of this model, one with all parcels ($N = 2{,}662$) and one excluding all parcels with an existing SPS ($N = 2{,}398$). The estimates for the discrete change effect of erosion-protection eligibility match reasonably well to the results from our preferred hedonic model with transaction data. That is, we find a positive and insignificant effect for all parcels and a positive and significant effects for parcels with an eroding shoreline only and parcels with both eroding shorelines and low elevation (between 10% and 27%).[25] Since this spatial-first differences model is designed to difference out parcel-level amenities, this result provides evidence that the correlation between amenities and risk are likely not biasing

23. The downside to using RMV values is that it may differ from actual sales transactions.

24. Unfortunately, the logic of this estimator cannot be applied to the transaction data as only two sets of homes meeting the actual neighbor criteria were found.

25. Results are displayed in table A.8, panels C and D.

our preferred model results, and our amenity control variables appear to be sufficient for identifying the Goal 18 treatment effect.

As an additional robustness check, we include variables in our hedonic model that account for a second coastal risk. We use the tsunami hazard line created in 1995 by Oregon Senate Bill 379 as an acute risk signal for the housing market.[26] In addition, a 9.0 magnitude earthquake occurred 45 miles off the coast of the Tōhoku region of Japan on March 11, 2011, which falls during the time frame of our analysis. This event provided information to coastal landowners about risk associated with far-field tsunami events that may have changed subjective risk assessments for buyers and sellers in the oceanfront housing market. We add tsunami hazard variables and their interactions with our treatment indicator to equation (6). Coefficients on erosion-protection eligibility and the interactions with elevation, shoreline change rates, and the NFIP subsidy are relatively stable between models, and none of the tsunami hazard covariates or their interactions with Goal 18 eligibility are significantly different from zero. This suggests that information about a second coastal risk did not change assessment of subjective erosion risk in the housing market.[27]

6. CONCLUSION

Given the potential for continued sea level rise and increased storm events, efforts to stabilize shorelines and protect existing coastal infrastructure are likely to continue at local, state, and federal levels. A recent review by Gopalakrishnan et al. (2018) highlights the economic literature's focus on beach nourishment and community-level decision making for coastal management. Our work here contributes by estimating nonmarket values for private, parcel-level erosion-protection options and identifying the potential for spillover damages arising from these private decisions. We analyzed data on oceanfront housing transactions in Oregon where a statewide land-use regulation provides substantial cross-sectional variation in the parcel-level option to invest in protection from erosion. We estimate positive option values for the ability to protect shoreline of between 13% and 22% of land value for parcels vulnerable to erosion risk. We also demonstrate that these values are dependent on the risk profile of the parcel, and parcels at low risk to erosion have no value for the option to invest in protection. These estimated nonmarket values for coastal protection are arguably decoupled from coastal amenities that typically accompany beach nourishment events (i.e., beach

26. The geography of the Oregon Coast is advantageous from a modeling perspective as it allows parcel-level variation in this acute risk. For other acute coastal hazards (e.g., a major hurricane landfall), the risk is not likely to vary at a spatially relevant scale for a given oceanfront housing market, making it difficult (if not impossible) to identify variation related to acute risk in housing prices. For oceanfront parcels in Oregon, 76% are within the tsunami hazard zone.

27. Description of this model are provided in the online appendix. Model results are displayed in table A.9 and table A.8, panel E.

width, recreation access). Our conceptual model demonstrates that the capitalization effects we find imply that the subjective annual probability of an irreversible loss from coastal erosion is approximately 0.7% to 1.3% (with a 5% discount rate).

Spatial externalities have been acknowledged before as a potential issue in community-level beach nourishment decisions (Smith et al. 2009; Gopalakrishnan et al. 2016; Gopalakrishnan et al. 2017) and in land-use decisions in noncoastal settings (Irwin and Bockstael 2002; Lewis et al. 2011; Lawley and Yang 2015). Here we provide the first empirical evidence of the magnitude of negative spatial spillover damages associated with private erosion-protection options. Our results indicate that spillover effects associated with parcel-level coastal protection may result in an approximate 8% reduction in the value of neighboring, protection-ineligible land, which is consistent with a 0.7 percentage point higher subjective risk of irreversible loss for parcels subject to the spillover damage. Thus, Goal 18 protection eligibility has the potential to generate net social costs when the spillover damages outweigh the benefits to the protection-eligible parcel. We estimate that approximately 7.2% of Goal 18–eligible parcels vulnerable to erosion generate net social costs due to potential for spillover damages on their neighbors. However, our estimate of the percentage of Goal 18 parcels that generate net social costs ignores potential external costs from coastal protection on beach access to non-landowning beach users, and so should be thought of as a lower bound. While we have no data on the potential nonmarket costs to beach users from Goal 18 coastal protection eligibility, it is likely to be nonzero. Indeed, the original policy motivation for Goal 18 restrictions on coastal armoring was to protect public beach access from displaced wave action that can scour and lower the beach profile. Future work is needed to assess the magnitude of potential social costs from SPS armoring on public beach users.

Coastal management can benefit from the integration of nonmarket values for service flows, estimates of subjective risk probabilities, and the identification of trade-offs and perverse incentives from private actors into the decision-making process. In Oregon, a land-use regulation seeks to provide a public good (beach access) at the expense of a private good (erosion protection), but the grandfathering features of the policy create winners, losers, and the potential for spatial externalities. Future work is needed to understand the economic drivers of both private and public coastal protection decisions along with integration of economic and geophysical models of shoreline change to better predict where certain policies may or may not be needed in the future.

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