Adaptation Infrastructure and its Effects in Property Values in the Face of Climate Impacts*

David L. Kelly[†1] and Renato Molina[‡1,2]

[1]Department of Economics, University of Miami

[2]Department of Marine Ecosystems and Society, University of Miami

August 29, 2020

Abstract

We evaluate the effect of climate adaptation infrastructure investments on property transaction prices, using data on over four hundred thousand property transactions and nearly two hundred adaptation infrastructure projects in the Miami-Dade county, an area that is highly vulnerable to sea level rise due to climate change. Using a difference-in-differences estimator, we find significant gains in property values after completion of infrastructure projects. These gains are concentrated in areas 0-200 meters from the boundary of the project polygon. We then calculate the return on investment for the adaptation infrastructure projects. Summing over a large number of properties protected by each project results in an aggregate benefit net of adaptation cost of about $20 million per project, and about $3 billion in aggregate net benefits for all projects. Most projects generated positive net benefits, indicating that the vast majority of adaptation efforts are being placed in areas of need that pass the benefit-cost test.

JEL Codes: Q51 Q54 Q58 R31 R38

*We would like to thank Matthew Varkony and Steven Koller for excellent research assistantship. We thank Esber Andiroglu, Joel Lamere, Kathleen Sealey, James Sobczak, Prannoy Suraneni, seminar participants at the 2020 Association for Environmental and Resource Economists Summer Conference, the city of Miami, and the University of Miami for comments and suggestions. Funding for this project was provided by the Laboratory of Integrative Knowledge at the University of Miami (U-LINK).

†email: dkelly@miami.edu

‡email: renato.molina@miami.edu

1 Introduction

The global mean temperature has already risen by 0.95°C relative to pre-industrial levels (NOAA 2020). Adverse impacts from climate change are already occurring in many sectors. Given that even aggressive mitigation efforts are unlikely to lessen such impacts in the near term, households, firms, and governments are considering actions to limit the negative impacts from climate change (adaptation). Adaptation is a promising approach for reducing the impacts from climate change. For example, the Fourth National Climate Assessment estimates that coastal property damage from sea level rise may be reduced by 90% through adaptation (EPA 2017).

Still, for successful adaptation households, firms, and local governments must evaluate potential adaptation investments that have up front costs and uncertain future benefits. For instance, local governments must predict sea level rise in order to know which properties might be saved by infrastructure adaptation investments at a cost less than the value of the properties, and which should be abandoned. Households must also understand climate change and the benefits of adaptation, otherwise local governments may not get political approval for such infrastructure investments. Accordingly, successful and efficient adaptation would require adoption of adaptation infrastructure in vulnerable areas for which the marginal adaptation benefits are large. If adaptation investments are instead solely undertaken by local governments with the most funding, or are chosen based on political considerations rather than need, then the benefits of infrastructure adaptation may fall significantly.

This paper evaluates the effectiveness of adaptation infrastructure investments, as measured by their effect on property values. Our data set consists of all real estate property transactions and hundreds of adaptation infrastructure projects in the Miami-Dade county, an area that is highly vulnerable to sea level rise due to climate change. This estimation allows us to answer several interesting, policy-relevant questions. First, significant property value appreciation near the infrastructure project after completion reveals that the local government and property owners are aware that the area is vulnerable and recognize the benefits of adaptation infrastructure. Second, given the assumption that infrastructure benefits are capitalized into property values, we can calculate the benefits of adaptation infrastructure and given our data on infrastructure costs, determine whether or not adaptation infrastructure investments pass a cost-benefit criteria. Third, a larger positive question exists in the literature as to whether climate change is itself reflected in property values. A significant increase in property values following infrastructure investments to protect against sea level rise provides a strong indication that in fact climate change is affecting property values, and allows us to back out the cost of climate change in terms of property damage in the absence of adaptation.

Establishing the effect of infrastructure adaptation investments on property values presents a number of econometric challenges. First, most infrastructure, such as sea walls, have been in place for decades or more, and so one cannot compare property values before and after investments take place. However, all of the infrastructure investments in our data set have been completed since 1980 (and most during 2013-16), as Miami-Dade county has recently been adding infrastructure. Thus, we construct a high resolution panel and evaluate the change in property values after communities receive infrastructure investments, relative to the change in communities that do not.

Second, developers may build lower quality housing in low-elevation areas (or higher quality housing in areas with desirable views), implying that omitted housing quality variables may explain some of the variation in property values across space. The growth rate of lower quality housing may also differ due to, for example, changes in the distribution of wealth. Further, macroeconomic shocks have resulted in trends in property values across Miami-Dade county, potentially leading to spurious correlations between the variables of interest and some neighborhoods' market trends. To address these concerns, we use a difference-in-difference econometric specification, and estimate the causal effect of infrastructure on property values as the difference between the change vis-a-vis in property values following construction of adaptation infrastructure near a transacted parcel. This approach controls for pre-existing trends as well as unobserved neighborhood quality differences. Our specification further controls for heterogeneity in housing quality by focusing on properties sold more than once.

Our data from the Miami-Dade Property Appraiser Office consists of over four hundred thousand qualified transactions from 1980-2019. Since each transaction is based on buyers and sellers evaluating the property, the transaction price is more likely to reflect individual property characteristics and current value, relative to appraisal data based on nearby transactions which have occurred in the past. Our projects data consists of 172 fixed infrastructure projects categorized by the County as dealing with storm surge, flooding, and/or sea level rise. These projects include installation of drainage, pumping stations and/or seawalls, as well as elevating streets, and other investments in adaptation capital. The large number of temporally and geographically diverse projects allows us to estimate the value of projects conditional on characteristics such as type (flood protection versus storm surge) and distance from the coast.

We find significant gains in property values after installation of infrastructure projects. In particular, a 1% increase in the distance to the project was associated with 0.8% higher transaction prices (0.1% higher appreciation rate) prior to project completion, and 0.8%

lower prices subsequent to project completion (0.4% lower appreciation rate). These results provide evidence that projects are being deployed in areas vulnerable to sea level rise (as evidenced by lower initial property transaction prices) and that the projects provided protection, as evidenced by transaction prices catching up to the surrounding area subsequent to completion. These gains are concentrated in areas 0-200 meters from the boundary of the polygon which defines the geographic location of the project.

We then calculate the return on investment for the adaptation infrastructure projects. The gain in transaction prices we find is modest, but Miami-Dade is a dense urban environment, and so most projects are surrounded by hundreds or thousands of properties. This leads to relatively large aggregate net benefits of about $20 million per project, and about $3 billion in aggregate net benefits for all projects. All but two project generated positive net benefits, indicating that the vast majority of projects are being placed in areas of need that pass the benefit-cost test.

Combined, these results provide evidence that property buyers and sellers and local governments perceive risks posed in terms of storm surge and flooding caused by sea level rise and tropical cyclone activity. All of these are exacerbated by climate change. The next section provides a summary of the literature on adaptation, property values, and sea level rise. Section 3 provides a theoretical model that underpins our empirical strategy. Section 4 describes the data in detail. Section 5 gives the empirical specification. Section 6 shows the results and Section 7 concludes.

2 Background

Previous research connecting real estate market dynamics, climate risk, and adaptation has provided important insights. Much of the literature focuses on the loss to property values subsequent to hurricane events.[1] Bin and Polasky (2004), Hallstrom and Smith (2005), Bin and Landry (2013), Gibson, Mullins and Hill (2018), Ortega and Taşpınar (2018), and Davlasheridze and Fan (2019) estimate declines in property values following hurricanes Floyd, Andrew, Floyd and Fran, Sandy, Sandy, and Ike respectively.[2] Similarly, Shr and Zipp (2019) and Hino and Burke (2020) estimate the effect of flooding risk (defined as being in a FEMA flood zone) on property values following changes in flood zone maps.[3] A common result is that prices in well-informed markets decline initially but often the effect fades over time.

[1]More broadly, an expansive and growing literature uses hedonic methods to estimate the effect of other natural hazards, such as earthquakes, volcanoes, and algae blooms, on property values.

[2]Davlasheridze and Fan (2019) in particular analyze properties protected by a seawall versus unprotected properties.

[3]Bin, Kruse and Landry (2008) control for unobserved heterogeneity by using a spatial weighting matrix.

In addition, in most studies the decline in property values exceeds the cost of insurance, indicating some flood and hurricane risks, such as job loss, are not insurable. Our results strengthen this literature by showing that coastal infrastructure can mitigate such losses, and that mitigated losses exceed insurance costs.

The relationship between flooding, sea level rise, and storm risk and property values importantly depends on how homeowners perceive risk. Researchers use a variety of methods to test whether households perceive such risks. Surveys are one way to estimate risk perceptions. For example, Ludy and Kondolf (2012) found that households underestimated the residual risk of flooding after a levee was built, and Bakkensen and Barrage (2017) show that coastal flood zone residents have lower flood risk perceptions than their inland counterparts. One can also infer changes in risk perceptions by changes in purchase of insurance and household adaptation investments following flood or storm events (e.g. Bin and Landry 2013; Gallagher 2014).[4] A general result from this literature is that perceptions of risk increase following a storm or flood, but often fade thereafter. Our results provide corroborating evidence for this literature in that gains in property value resulting from the addition of adaptation infrastructure implies a change in risk perceptions.

Directly relevant to our results are a small number of studies that estimate the total cost of flooding, storms, and sea level rise to coastal communities, in terms of lost real estate value. Keenan, Hill and Gumber (2018) finds a positive association of elevation and property appreciation for most jurisdictions in Miami-Dade county. McAlpine and Porter (2018) integrate flood, surge, and sea level rise data with real estate property transaction from Miami-Dade County. They find lots expected to be affected by tidal flooding in 2032 have already experienced $1,276 declines in value each year between 2005 and 2016. Bernstein, Gustafson and Lewis (2019) show that properties that would be underwater with 1 foot of sea level rise sell at a 14.7% discount, whereas properties that require 6 feet of sea level rise to be inundated experience only a 4.4% discount.

These studies do not rely on a particular storm or flood event, but instead correlate sea level rise risk with property values. This allows an estimate of the total cost of sea level rise using property values, rather than a change from an unknown baseline. However, this advantage comes with a trade-off. First, the argument for causality is weaker relative to studies which rely on a single exogenous storm or flood map change. Second, it is unclear to what degree property values have priced in future adaptation investments which can reduce the overall cost of sea level rise. Our results take the next step forward in this literature. Because we contrast property values before and after coastal protection infrastructure, causality is

[4] Other methods include the use of prediction markets Kelly et al. (2012) and property prices (e.g. Kousky 2010).

identified given a parallel trend in property values. Yet, we can estimate both the total cost of sea level rise and the reduction in costs resulting from adaptation infrastructure, using the counter-factual that no infrastructure projects are built.

In addition and closely related to our results, there are a number of estimates of the value of adaptation investments, especially infrastructure. For example, Fell and Kousky (2015) find commercial properties protected by a particular levee in Missouri sell at an 8% premium relative to unprotected properties in 100 year floodplains. Similarly, Jin et al. (2015) finds coastal properties with seawalls have property values 10% higher than unprotected properties in Massachusetts.[5] Walsh et al. (2019) estimate properties with bulkheads and riprap are associated with price premiums of about $66K and $102K, respectively. Barrage and Furst (2019) show that construction activity is negatively associated with sea level rise exposure in areas that polls indicate are worried about climate change. These papers take an important first step in showing the association between property values and adaptation investments. Yet, causality is difficult to ascertain since most infrastructure investments have been in place for decades or more. Because we study a region with hundreds of recently completed infrastructure projects, we can employ methods which reveal plausibly causal estimates.

Finally, Kim (2020) also looks at the effect of infrastructure on property values in Miami-Dade county using a difference-in-differences framework and finds infrastructure projects have very large effects on property values, as much as a 18.1% increase in property values for storm surge projects in one year after completion. Our paper extends this work in a number of ways. First we use a much larger data set, which allows us to better control for individual property characteristics by using repeat sales. Second, we examine changes in property appreciation rates. Our results show generally smaller effects on property values which are incorporated slowly over time. This indicates that controlling for property level heterogeneity is important for estimating the effect of infrastructure projects. Finally, we examine the implications of our estimates for the total cost of sea level rise, and how much of that cost is reduced by adaptation investment.

[5] A number of papers also examine hurricane adaptations. For example, Davlasheridze, Fisher, Vanden, and Klaiber 2017 find a 1% increase in ex ante spending by FEMA reduces hurricane damages by 0.21%.

3 Theory

Consider a simple no-arbitrage pricing model. Properties are initially homogenous, other than their locations. For a property at location x with amenities A at time t, the price is:

$$P(x,t,A) = e^{\gamma(t,x,A)} \int_t^{\infty} R(x,s,A)\, e^{-r(s-t)} ds, \tag{1}$$

where r is the market interest rate and $R(x,s,A)$ is the rent earned from a property with amenities A at location x and time s, net of depreciation and maintenance costs or equivalently the service flows from an owner-occupied property. Following Case and Shiller (1989) and especially Harding, Rosenthal and Sirmans (2007), $\gamma(x,t,A)$ represents conditions in the location/amenity specific housing market at time t, which may cause housing prices to deviate from the present value of the rental flows (hereafter the fundamental value).[6]

Equation (1) can be written as:

$$\log\left[P(x,t,A)\right] = \gamma(t,x,A) + \log\left[\int_t^{\infty} R(x,s,A)\, e^{-r(s-t)} ds\right]. \tag{2}$$

Equation (1) implies a property sold in period $t+\tau$ has price:

$$P(x,t+\tau,A) = e^{\gamma(t+\tau,x,A)} \int_{t+\tau}^{\infty} R(x,s,A)\, e^{-r(s-(t+\tau))} ds. \tag{3}$$

The price change associated with a property sold first in period t and then again in $t+\tau$ has price appreciation of:

$$\log\left[\frac{P(x,t+\tau,A)}{P(x,t,A)}\right] = \gamma(t+\tau,x,A) - \gamma(t,x,A) + r\tau + \log\left[1 - \frac{\int_{t+\tau}^{t} R(x,s,A)\, e^{-r(s-t)} ds}{\int_t^{\infty} R(x,s,A)\, e^{-r(s-t)}}\right]. \tag{4}$$

Using the log approximation:

$$\log\left[\frac{P(x,t+\tau,A)}{P(x,t,A)}\right] = \gamma(t+\tau,x,A) - \gamma(t,x,A) + r\tau - \frac{\int_{t+\tau}^{t} R(x,s,A)\, e^{-r(s-t)} ds}{\int_t^{\infty} R(x,s,A)\, e^{-r(s-t)}}, \tag{5}$$

[6]Market prices may deviate from fundamental values for a variety of reasons, including difference in tax treatment between housing and the market interest, borrowing constraints, and house price inflation. This assumption allows for the theoretical possibility that changes in amenities may be incorporated into housing prices slowly over time, rather than instantaneously.

$$G\left(x,t,\tau,A\right)\equiv\frac{1}{\tau}\log\left[\frac{P(x,t+\tau,A)}{P(x,t,A)}\right]=\frac{\gamma\left(t+\tau,x,A\right)-\gamma\left(t,x,A\right)}{\tau}+r-\frac{1}{\tau}e^{\gamma(t,x,A)}\frac{\int_{t+\tau}^{t}R\left(x,s,A\right)e^{-r(s-t)}ds}{P\left(x,t,A\right)}. \quad (6)$$

Here, G is the geometric mean appreciation rate from t to $t+\tau$. Note that equation (6) can be rewritten as:

$$G+\frac{1}{\tau}e^{\gamma(t,x,A)}\frac{\int_{t+\tau}^{t}R\left(x,s,A\right)e^{-r(s-t)}ds}{P\left(x,t,A\right)}=r+\frac{\gamma\left(t+\tau,x,A\right)-\gamma\left(t,x,A\right)}{\tau}. \quad (7)$$

The left side is the mean capital gains plus the housing dividends, which equals the return on the alternative investment, r, plus a return associated with the change in price deviations.

For the special case in which the dividends are independent of time and no amenity changes occur, equations (8) and (6) simplify to:

$$\log\left[P(x,t,A)\right]=\gamma\left(t,x,A\right)+\log\left[R\left(x,A\right)\right]-\log\left[r\right], \quad (8)$$

$$G\left(x,t,\tau,A\right)=\frac{\gamma\left(t+\tau,x,A\right)-\gamma\left(t,x,A\right)}{\tau}. \quad (9)$$

Note that future dividends are priced into the initial value, and so do not affect the appreciation rate.

Consider now properties located at x and x', where an unanticipated infrastructure adaptation amenity (A changes from 0 to 1) is built in location x at time t^*. Let $t_0<t^*$ denote time periods prior to t^* and $t_1>t^*$ time periods after. We have from equation (8):

$$\log\left[P(x,t_i,i)\right]=\gamma\left(t_i,x,i\right)+\log\left[R\left(x,i\right)\right]-\log\left[r\right]\ \ i=0,1, \quad (10)$$

$$\log\left[P(x',t_i,0)\right]=\gamma\left(t_i,x',0\right)+\log\left[R\left(x',0\right)\right]-\log\left[r\right]\ \ i=0,1. \quad (11)$$

Equations (10)-(11) may be used to form a difference-in-differences estimator, where the interest is in the difference between $\log\left[P(x,t_1,1)\right]$ less the unobserved $\log\left[P(x,t_1,0)\right]$. The difference is identified via the assumption of parallel trends, or

$$\log\left[P(x,t_1,1)\right]-\log\left[P(x,t_1,0)\right]=\log\left[P(x,t_1,1)\right]-\log\left[P(x',t_1,0)\right]-\left(\log\left[P(x,t_0,0)\right]-\log\left[P(x',t_0,0)\right]\right), \quad (12)$$

$$\log\left[P(x,t_1,1)\right]-\log\left[P(x,t_1,0)\right]=\gamma\left(x,t_1,1\right)-\gamma\left(x',t_1,0\right)-\left(\gamma\left(x,t_0,0\right)-\gamma\left(x',t_0,0\right)\right) + \log\left[R\left(x,1\right)\right]-\log\left[R\left(x,0\right)\right]. \tag{13}$$

Therefore, the difference-in-differences estimator picks up not only the difference in rental rates accruing from the adaptation amenity, but also the possibility that the adaptation amenity will cause property to become part of a different housing market with different house price dynamics. As an example, the structure might make location x more attractive to a set of buyers with higher income.

Alternatively, we can create a difference-in-differences estimator using price appreciation data created by repeated sales. Suppose the sale at both t and τ are both prior or both subsequent to the adaptation amenity. The appreciation rate equation (9) then implies for an adaptation amenity built in location x at t^*:

$$G(x,t_i,\tau_i,i)=\frac{\gamma\left(t_i+\tau_i,x,i\right)-\gamma\left(t_i,x,i\right)}{\tau},\ i=0,1. \tag{14}$$

$$G(x',t_i,\tau_i,0)=\frac{\gamma\left(t_i+\tau_i,x',0\right)-\gamma\left(t_i,x',0\right)}{\tau},\ i=0,1. \tag{15}$$

Equations (14)-(15) may be used to form a difference-in-differences estimator, where the interest is in the difference between $G(x,t_1,\tau_1,1)$ less the unobserved $G(x,t_1,\tau_1,0)$. The difference is again identified via the assumption of parallel trends, or

$$G(x,t_1,\tau_1,1)-G(x,t_1,\tau_1,0)=G(x,t_1,\tau_1,1)-G(x',t_1,\tau_1,0)- \left(G(x,t_0,\tau_0,0)-G(x',t_0,\tau_0,0)\right), \tag{16}$$

which implies:

$$G(x,t_1,\tau_1,1)-G(x,t_1,\tau_1,0)=\frac{1}{\tau}\left(\gamma\left(x,t_1+\tau_1,1\right)-\gamma\left(x,t_1,1\right)-\gamma\left(x',t_1+\tau_1,0\right)+\gamma\left(x',t_1,0\right) - \gamma\left(x,t_0+\tau_0,0\right)+\gamma\left(x,t_0,0\right)+\gamma\left(x',t_0+\tau_0,0\right)-\gamma\left(x',t_0,0\right)\right). \tag{17}$$

Equation (17) shows that when using appreciation rates, the difference-in-differences estimator picks up changes in housing price dynamics both over time and potentially through shifts in the housing market caused by the adaptation amenity.

Equations (13) and (17) give a general formulation of the different effects that adaptation investment might have in the state and evolution of property values. Further specific assumptions on how amenity values are incorporated into housing values over time (γ) give more precise predictions. For example, suppose that prices always reflect fundamental values ($\gamma = 0$), then the creation of the adaptation amenity results in an instantaneous increase in property values ($R(x,1) - R(x,0)$), but no change in appreciation rates. Panel (a) of Figure 1 graphs this case.

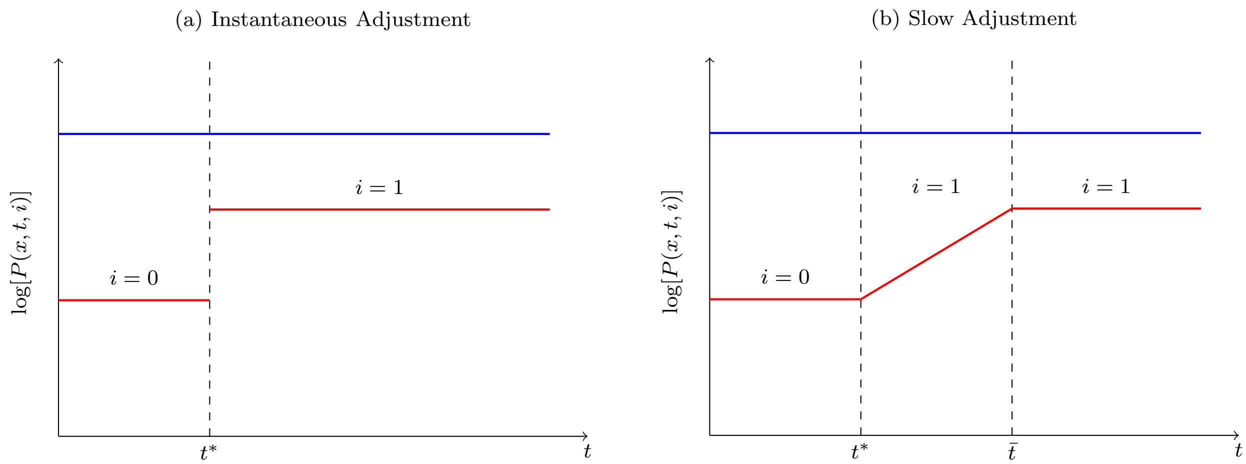


Figure 1: Price evolution after adaptation investment. Panel (a) shows a diff-in-diff with instantaneous adjustment, while panel (b) shows a slow adjustment. The blue line represents the control property, while the red line depicts the property adjacent to the adaptation project. The start and completion of the project is instantaneous at t^*. The absence and presence of the adaptation measure is denoted as $i = 0$ and $i = 1$, respectively. $\bar{t}$ denotes the end of the linear adjustment in prices after the adaptation project is finalized.

Consider a second special case, where housing prices are at fundamental values prior to the structure, and then the value of the structure is incorporated into the housing price at a linear rate over the period $[t^*, \bar{t}]$. In this case $\gamma(x') = 0$ for all t, $\gamma(t_0) = 0$, and:

$$\gamma(x, t_1, 1) = \begin{cases} \frac{-r^*}{\bar{t} - t^*}(\bar{t} - t_1) & t^* \leq t_1 \leq \bar{t} \\ 0 & \bar{t} \leq t_1 \end{cases}, \tag{18}$$

where:

$$r^* \equiv \log[R(x,1)] - \log[R(x,0)]. \tag{19}$$

In this case, $\gamma(x, t^*, 1) = -r^*$ and initially the price is below the fundamental value of the property with the adaptation amenity. It follows that $\gamma(x, \bar{t}, 1) = 0$, so the property is at fundamental value, including the structure, at time $\bar{t}$. In this case,

$$G(x, t_1, \tau_1, 1) - G(x, t_1, \tau_1, 0) = \frac{r^*}{\bar{t} - t^*}, \tag{20}$$

and the difference-in-differences estimator reveals the mean rate at which the value of the structure is incorporated into the property prices. For the log price version,

$$\log\left[P(x,t_1,1)\right]-\log\left[P(x,t_1,0)\right]=r^*\frac{t_1-t^*}{\bar{t}-t^*}. \tag{21}$$

The difference-in-differences estimator using prices picks up the partial price adjustment that has accrued at t_1. Panel (b) in Figure 1 graphs this case.

Other predictions are also possible depending on γ. But in general, if the value of the adaptation amenity is quickly incorporated into the property value, then we expect to see a large positive coefficient on the difference-in-differences estimator using log prices. In contrast, if the value of the adaptation amenity is incorporated slowly over time, we expect to see a larger coefficient for the difference-in-differences estimator using appreciation rates.

4 Data

Analyzing the influence of adaptation infrastructure on the housing market requires spatial integration of transaction data with local infrastructure projects. We obtain individual property transactions along with specific housing characteristics for Miami-Date county from the Miami-Dade County Appraiser's Office.

The data contain housing characteristics including number of stories, beds, baths, and the year of construction for each property. For properties sold at least three times, each property record contains the three most recent transactions. Properties sold once or twice contain one or two transactions, respectively. Each transaction is listed as a qualified or non-qualified sale. The data also give a unique book and page number for each transaction. All property transaction prices are converted to 2019 dollars using the consumer price index for all urban consumers as reported by the U.S. Bureau of Labor Statistics.

We focus on condominiums and single family residential homes. We exclude commercial property transactions because the incentives propagated by climate adaptation infrastructure likely differ for residential and commercial properties (Fell and Kousky 2015). Only qualified sales are included in the final dataset. Finally, we limit the data to the period 2000-2019, as most projects are completed between 2013-2016.

The dataset also has a number of multi-unit sales (e.g., an entire condominium building). The appraiser records the sale price of each individual unit in the transaction as the sale price for *all* units in the transaction.[7] Multi-unit sales are identified in the data as multiple

[7] For example a 20 unit development which sold for $5M is recorded as $5M for each unit in the development.

transactions with the same book and page number. To correct the data, we first remove any transactions which include both residential and commercial properties. For multi-unit sales that are strictly residential, we let the property transaction price equal the total sale price for all properties divided by the number of units sold. There are two potential problems with this adjustment. First, some units may be larger or of higher quality than others, and thus have a value that exceeds the average price. Second, a unit sold as part of a multi-unit transaction which is subsequently sold at least three times is not available in the data, as the appraiser keeps only the last three transactions. Thus, the number of units in multi-unit sales may be underestimated, causing the sale price to be overestimated. For this reason, we add a dummy variable if the transaction is part of a multi-unit sale in the regressions.

Some book and page numbers are missing in the data. Inspection of the data reveals that some transactions with missing book and page numbers appear to be multi-unit transactions. These data points have very large positive (e.g. if the property was sold individually prior to the multi-unit sale) or negative (e.g. if the unit was sold subsequent to the multi-unit sale) appreciation rates. However, there is no clear way to filter these data points. For this reason, in the regressions we will remove outliers in both tails (i.e., top and bottom fifth percentiles).

To measure appreciation, a property must be sold at least twice. Properties sold only once are therefore excluded from the appreciation data. The price data then includes a large number of additional properties, which likely contain unobserved differences relative to properties sold more than once.[8] To facilitate comparisons between the price and appreciation results, we exclude properties sold only once in the price data.

Using spatially designated data for the Florida coastline, we calculate the nearest distance of each property's centroid to the coast. We calculate the elevation at each property's centroid, and assign this value to the property. We assign inherent flood risk for each property using delineated FEMA flood zone designations.

The next step of our data set up requires obtaining and spatially locating adaptation infrastructure projects in Miami-Dade County. These projects are referred to as LMS (Local Mitigation Strategy) Projects. Data for a total of 1958 projects are downloaded from the county open source website. The data include geographic centroid, title, cost, start and end dates, description, and the particular hazard or set of hazards which the project is designed to address. Each data point is potentially recorded by a different administrator, and so the descriptions vary in detail and many observations have missing data.

[8] For example, it is well-known that price inflation and housing stock turnover are positively correlated (Genesove and Mayer 1994; Krainer 2001), implying that the price data may contain properties in markets with less demand, relative to the appreciation data.

We restrict the data to projects which report geographic location. Many projects are ongoing; we consider only completed projects which report an end date. We further restrict the data to those specifically addressing sea level rise, flooding, storm surge, and wind. Within these categories, we include projects related to canals and rivers, coastal erosion, drainage, flooding, road protection/elevation, and bridge protections. We exclude projects designed to protect public buildings (e.g., adding hurricane shutters to a police station), projects without a fixed location (e.g., mobile pumping stations), and feasibility studies.

Most projects are irregular polygons, and some are large enough so that some properties are inside the project boundaries. Further, some projects consist of multiple geographically unconnected sites. For this reason, we geo-locate the boundary of each project and use the distance from each property to the nearest site boundary in the distance regressions below.

In addition, a majority of the adaptation projects include many different infrastructure items. The mean project cost is $1.12 million, and so many of the projects are relatively small scale. These projects provide some protection for sea levels reasonably close to current levels, but are unlikely to protect against very high sea levels that might occur in the long run. As an example, North Bay Village is a township that sits on a man-made island in Biscayne Bay. A recent project consisted of 30 total items, including sea wall repair, installing and repairing drainage systems and pumping stations, bay restoration, boardwalk restoration, and moving power lines underground.[9]

The final datasets report 431,410 property transactions and 175 adaptation projects in Miami-Dade county between years 2000 and 2019. In addition, out of the total of 172 projects, 158 are reported as measures against flood and surge, and 14 against flood only. Table 1 gives a summary of the filtering process. It is important to note that relative to the literature, our set of projects and transactions this filtering process is indeed minimal (e.g., Kim 2020).

[9]Note that some of these items may provide amenity benefits independent of coastal protection.

Table 1: Data Filters Applied.

Transaction Data		Projects Data	
Initial Transactions	2,178,033	Initial Projects	1,958
Filters			
Only condos and single family homes		Only fixed water infrastructure projects	
Only qualified sales		Only completed projects with an end date	
Only data since 1980		Only projects with location data	
Only properties sold at least twice		Only sea level rise, flooding, surge and wind	
Only multi-unit sales that are not mixed use			
Top/bottom 5% prices and appreciation removed			
Final Transactions	431,410	Final Projects	172

Figure 2 shows the intensity of property transactions by location. Most municipalities across the county have a large number of transactions. However, property transactions were especially common in many coastal and island locations, such as the island of Miami Beach in the top right. Importantly, the average elevation for MDC is only about 1.8 meters, so even most inland properties face some flood risk.

Figure 2: Property transactions heat map.

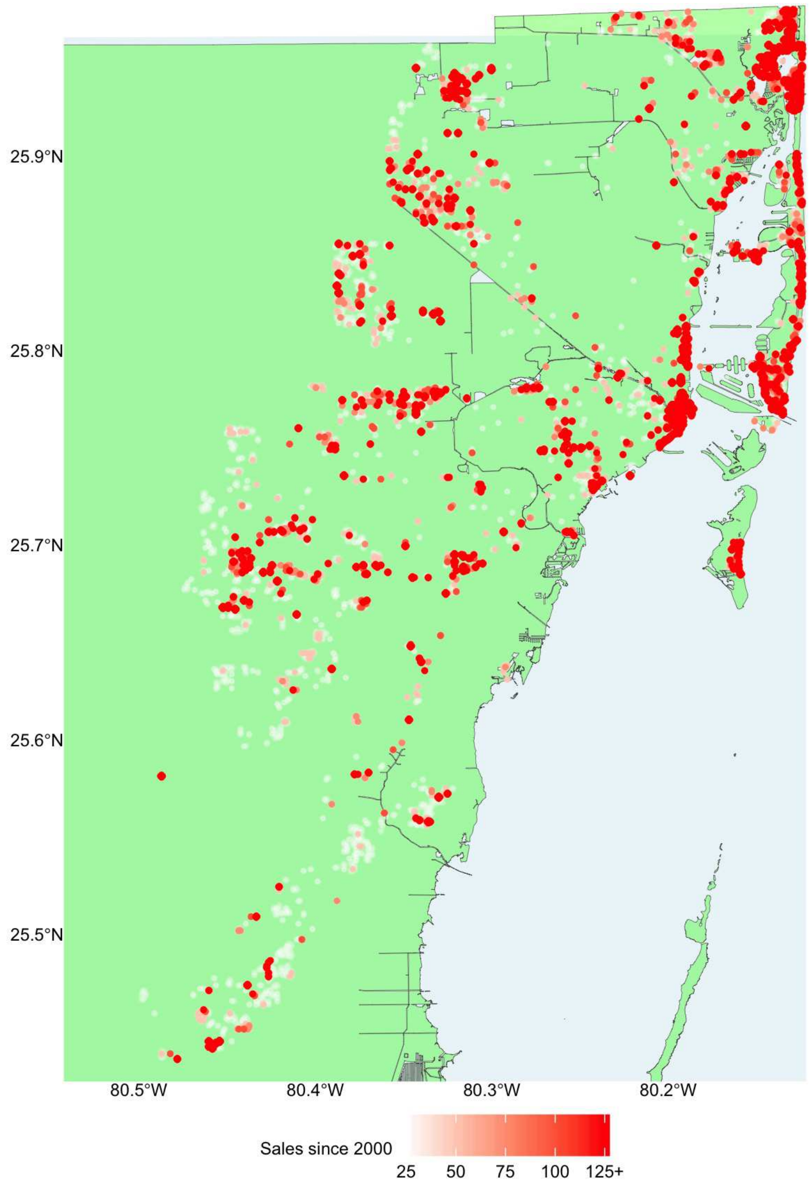
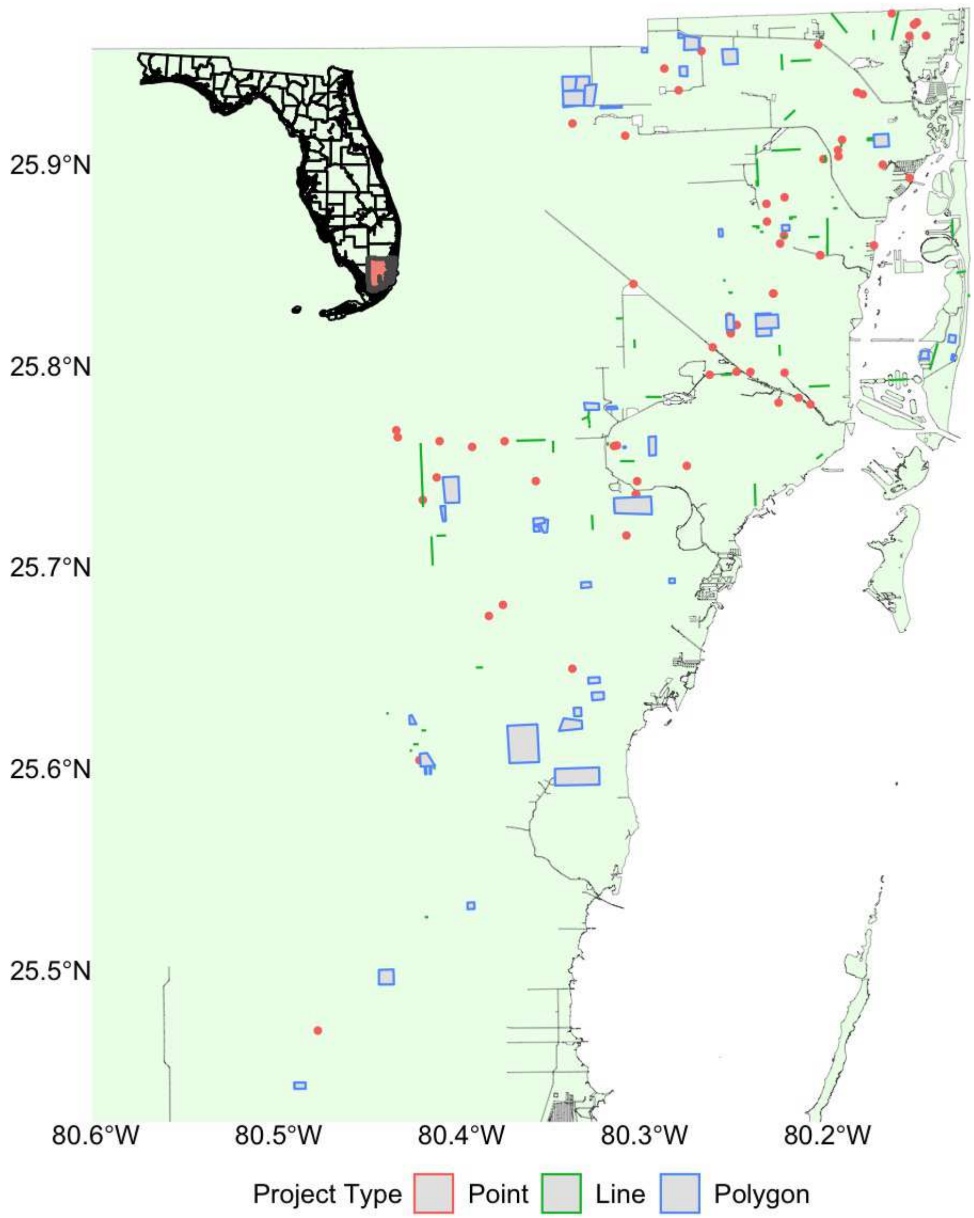


Figure3 shows the geographic location of the projects. The projects are also dispersed throughout the county, reflecting that flooding and storm surge are problems even in inland locations. Common locations include drainage and flood protections around rivers and canals (often single points sites) and road modifications (often lines). Sometimes, projects are defined by the rectangular grid of roads that border the project area, generating rectangular polygons.

Figure 3: Project locations.



5 Empirics

To measure the effect of adaptation investment on real estate in Dade County, we rely on a difference-in-differences approach. In addition, we report results separately for two types of adaptation projects: those designated as i) flood protection and those designated as ii) surge control. As discussed above, projects designated for both flood and surge are included in both sets of results. Note that many flood/surge projects are also designated for sea level rise and wind. The model is as follows:

$$\log[y_{it}] = \alpha + \lambda\ \log[DISTANCE_i] + \beta\ POST_{it} + \gamma\ POST_{it} \times \log[DISTANCE_i] + \eta\ DISTWATER_i + \zeta\ ELEVATION_i + \theta' X_{it} + \epsilon_{it} \tag{22}$$

Here, the dependent variable, y, is either the transaction price in 2019 dollars per square foot or the annualized appreciation, adjusted for inflation, from the previous qualified sale $(\log\left[P_{t+\tau}/P_t\right]/\tau)$.[10] Further, *DISTANCE* is the distance in meters to the closest border of the closest adaptation project on record. Because properties adjacent to, or inside project boundaries have a distance of zero, we add one meter to each recorded distance before taking logs.

Next, *POST* is a binary indicator that takes a value of one if the closest adaptation project to property i has been completed at time t. $POST \times DISTANCE$ is an interaction between distance and time of completion of the nearest adaptation project. The parameters of interest, λ, β, and γ, denote the elasticity of property transaction prices with respect to distance, the change in mean property value or appreciation after project completion, and the difference-in-differences parameter which gives the change in the distance elasticity following completion of the project, respectively.

For control variables, *DISTWATER* denotes the distance from the water, while *ELEVATION* denotes the vertical elevation for each individual property. Finally, X_t is a battery of property and time fixed effects. The error term in the econometric model is ϵ. To control for serial and spatial correlation, we cluster standard errors by zip code and year.

Our hypothesis is that the key interaction term, γ, will be negative so that properties closer to the project experience higher property transaction values subsequent to completion of the project. Clearly, the hypothesis assumes that the parcel-level cost-benefit analysis of the adaptation project is positive. Nonetheless, γ could certainly be positive if the project obstructed views or traffic, or created other negative amenity values.

6 Results

In this section, we will show that adaptation infrastructure affects the housing market. In particular, that houses sold near finished adaptation projects see a consistent and statistically significant transaction premium. The data used to implement this analysis is summarized

[10] We use $P_{t+\tau}/P_t/\tau$ rather than the percent change so that properties which decline in value may be included in the logged data.

in Table 2.

Table 2: Summary Statistics for the Miami-Dade Property Data.

	Non-Condo				Condo				Difference	
	Min	Max	Mean	Std.Dev.	Min	Max	Mean	Std.Dev.	Mean Diff.	Std. Error
Response Variables										
Price ($\$/ft^2$)	65.71	514.46	169.24	80.24	65.72	514.55	213.91	107.58	44.67***	0.30
Appreciation (%/year)	-12.82	49.71	4.41	9.16	-12.82	49.72	3.40	8.63	-1.00***	0.03
Distance to the closest project (km)	0.00	12.29	1.55	1.37	0.00	8.91	1.94	1.56	0.39***	0.00
Features										
Distance from water (km)	0.00	16.79	3.71	3.68	0.00	15.12	2.69	3.77	-1.01***	0.01
Elevation (m)	-0.07	11.92	2.39	0.65	-0.38	30.95	2.03	1.02	-0.36***	0.00
Wholesale (0/1)	0.00	1.00	0.00	0.04	0.00	1.00	0.01	0.10	0.01***	0.00
Bedrooms (#)	0.00	32.00	3.28	0.83	0.00	1694.00	1.93	4.96	-1.35***	0.01
Bathrooms (#)	0.00	14.00	2.09	0.84	0.00	12.00	1.67	0.67	-0.42***	0.00
Parcel size (ft^2)	90.00	31615.00	2121.52	1013.19	77.00	8668.00	1180.39	468.62	-941.13***	2.54

Notes: The unit of observation is a property transaction. The table is split into three panels. The first two panels show the summary statistics for the subsamples of Non-Condos and Condos, respectively. This third panel reports the difference in means between these two sub-samples and its statistical significance using a two-sided t-test for difference in population means. The units for the attributes are shown in parentheses. "Multi-unit" is a dummy variable indicating whether or not the transaction included multiple units. Prices are adjusted to 2019 US dollars.

The vulnerability of Miami-Dade is evident in Table 2, with the transacted properties' mean elevation of about two meters, and an average distance of 3-4km from water. The table also shows that statistically significant differences exists between condo and non-condo entries. In particular, recorded condo transactions have higher prices on average, but appreciate at a lesser rate. Since most land designated for single family homes in Miami-Dade county is already developed, the supply of condos is more elastic, which may limit the price growth path from demand shocks. In addition, transactions for condos are farther away from adaptation projects, closer to water bodies, built on lower ground, and smaller in overall size. Using these data, we now turn to the formal analysis below.

6.1 Flood Project Analysis

The first analysis pertains projects designated by the county as flood protection or as having multiple designations that includes flood protection (e.g. flood and surge or flood and sea level rise). The results of the difference-in-differences approach are shown in Table 3, and suggest that adaptation infrastructure has a positive effect on property values.

Table 3: Difference-in-Differences regression results for flood infrastructure projects.

	log-Price					log-Appreciation				
Post	0.134***	0.136***	0.129***	0.131***	0.128***	0.041***	0.042***	0.041***	0.041***	0.041***
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
log-Distance	0.007***	0.007***	0.008***	0.008***	0.008***	0.001**	0.001*	0.001**	0.001**	0.001**
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Post X log-Distance	-0.016***	-0.017***	-0.016***	-0.016***	-0.016***	-0.005***	-0.005***	-0.005***	-0.005***	-0.005***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Size Control		0.027***	0.005	0.005	0.001		0.004***	0.003***	0.003***	0.003***
		(0.00)	(0.00)	(0.00)	(0.00)		(0.00)	(0.00)	(0.00)	(0.00)
Condo FE			-0.085***	-0.083***	-0.082***			-0.007***	-0.007***	-0.007***
			(0.01)	(0.01)	(0.01)			(0.00)	(0.00)	(0.00)
Multi-unit FE				-0.078	-0.081				0.018*	0.018*
				(0.05)	(0.05)				(0.01)	(0.01)
Flood Zone FE					-0.000					0.001*
					(0.00)					(0.00)
Elevation					0.028***					-0.001*
					(0.00)					(0.00)
Distance to Water					-0.011***					-0.000
					(0.00)					(0.00)
Observations	431410	431410	431410	431410	431410	295722	295722	295722	295722	295722
Size Controls		X	X	X	X		X	X	X	X
Condo FE			X	X	X			X	X	X
Multi-unit FE				X	X				X	X
Location FE					X					X
Zip-by-Year FE	X	X	X	X	X	X	X	X	X	X

Clustered standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: Each column is a separate regression. The table is split into two panels as a function of the response variable in the regression analysis. "Size Controls" include controls for size, number of bedrooms, and number of bathrooms. "Condo FE" and "Multi-unit FE" are dummies indicating if the property is a condo or part of a transaction that includes multiple units, respectively. "Location FE" are fixed effects for flood zone, elevation, and distance to water.

The results are highly robust to the inclusion of a variety of control variables. Condos see lower prices per square foot and appreciation, because the conditional condo supply is more elastic, which limits price increases from demand shocks. The price falls by 1.1% for each km of distance to water. As is well-documented in the literature Bin et al. (2008), properties closer to water sell at a higher price due to the amenity value. In addition, an additional 1 meter of elevation translates to a statistically significant 2.8% increase in sale price, which is similar to other estimates in the literature.[11] The flood zone fixed effect is

[11] See for example, Keenan, Hill and Gumber (2018), although the comparison is not exact since that paper

not significant in the price regressions and is only marginally significant in the appreciation regressions. A plausible explanation is that the projects are being built in flood prone areas, and so the log-distance conveys more flood risk information than the FEMA flood maps, which are often decades old.

With regard to the key parameters of interest, the project completion coefficient is positive and significant as expected for all specifications. Most projects were completed during the period 2013-2016, a period during which the Miami-Dade property values were rapidly appreciating after the subprime crisis. In particular, Table 3 shows that properties sold after the nearest project was completed sold for about a 12.8-13.6% higher price, relative to properties sold prior to project completion. Further, the appreciation rate was 4.1-4.2% higher for properties sold after projects were completed.[12] These results highlight the importance of controlling for county-wide trends in the real estate market.

The distance variable is also positive and significant for all specifications. Properties farther from the infrastructure project initially sell at a higher price and appreciate faster. A plausible explanation is that the city is building infrastructure projects in vulnerable areas, as evidenced by the relatively depressed market near the projects. An alternative explanation is that it is easier to acquire permits and/or less expensive to obtain land to build infrastructure in areas with lower property values. A one percent increase in the distance from the project corresponds to a statistically significant 0.7-0.8% higher sale price and a 0.1% increase in appreciation rates.

With regard to the interaction term, the distance elasticity falls following completion of the project. In particular, after completion of the project, the 1% distance sales price premium falls by 1.6-1.7%, and the distance appreciation rate premium falls by 0.5%. Thus (using the preferred regressions will all controls), prior to completion, a 1% increase in the distance from the project corresponded to a 0.8% higher sale price (and a 0.1% higher appreciation rate). But after completion, a 1% increase in the distance corresponded to a 0.8% *lower* sale price (and a 0.4% lower appreciation rate). Thus, the infrastructure project significantly increased sale prices and appreciation rates near the project, which provides evidence that the projects were built in vulnerable areas, and that the projects were successful in that sale prices rose near the project post completion.[13]

The coefficients for the price regressions are generally larger in magnitude versus the appreciation regressions. This occurs in part because the appreciation rate is annualized

reports neighborhood level estimates.

[12] We control for zip-by-year fixed effects. Yet the Miami real estate market is very heterogeneous even within zip codes. Therefore, it is possible that the post variable picks up additional time variation.

[13] If projects were simply built in areas where obtaining land was less expensive, we would expect to see an interaction term which is smaller than the distance term, or not significant.

and the price variable is not. On average, properties sold 2.5 years after the nearest flood project was completed. A property one percent closer to the project that was sold 2.5 years after project completion appreciates 0.4% faster per-year, for a total of a 1.0% over 2.5 years, which is close to the price regression which measures the total effect of 0.8%. In addition, the price regressions use a larger data set. Both start with properties sold at least twice. However, first differencing reduces the the number of data points from three to two for a property sold three times, and from two to one for a property sold once.

The results are also different because the appreciation rate regressions have more controls for property level heterogeneity. Although both sets of regressions contain zip-by-year fixed effects, appreciation inherently controls for time invariant property characteristics by first differencing. The difference in results between price and appreciation plausibly indicates that the some property level amenity heterogeneity exists which the price regressions does not control for.[14]

Finally, our estimates are far smaller than Kim (2020), who find as high as an 18.1% increase in price one year after completion for properties less than 400m from a project. This reflects our use of transactions beyond the initial year of completion and our reliance on properties sold at least twice. Prices adjust dynamically over time, and so the long run effect on prices differs from the short run effect. These results make sense in that most projects are marginal improvements such as installing pumping stations and drainage systems. These improvements result in more protection, but not the complete elimination of flood risk. Therefore, we expect the price increases to be correspondingly small.

6.2 Surge Project Analysis

The second analysis pertains projects designated as storm surge or storm surge combined with other protections. Given the high degree of overlap with flood projects, one would expect minimal difference with the results presented above. Table 4 shows confirms this observation.

[14]Unfortunately, imposing property-by-year fixed effects highly correlates with the diff-in-diff strategy of relying on distance by time.

Table 4: Difference-in-Differences regression results for surge infrastructure projects.

	log-Price					log-Appreciation				
Post	0.143***	0.144***	0.136***	0.138***	0.135***	0.043***	0.044***	0.043***	0.043***	0.043***
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)
log-Distance	0.009***	0.009***	0.010***	0.010***	0.010***	0.001	0.001	0.001*	0.001*	0.001*
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Post X log-Distance	-0.017***	-0.017***	-0.017***	-0.017***	-0.017***	-0.005***	-0.005***	-0.005***	-0.005***	-0.005***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Size Control		0.027***	0.005	0.005	0.001		0.004***	0.003***	0.003***	0.003***
		(0.00)	(0.00)	(0.00)	(0.00)		(0.00)	(0.00)	(0.00)	(0.00)
Condo FE			-0.085***	-0.083***	-0.082***			-0.007***	-0.007***	-0.007***
			(0.01)	(0.01)	(0.01)			(0.00)	(0.00)	(0.00)
Multi-unit FE				-0.078	-0.081				0.018*	0.018*
				(0.05)	(0.05)				(0.01)	(0.01)
Flood Zone FE					-0.000					0.001*
					(0.00)					(0.00)
Elevation					0.028***					-0.001*
					(0.00)					(0.00)
Distance to Water					-0.011***					-0.000
					(0.00)					(0.00)
Observations	431410	431410	431410	431410	431410	295722	295722	295722	295722	295722
Size Control		X	X	X	X		X	X	X	X
Condo FE			X	X	X			X	X	X
Multi-unit FE				X	X				X	X
Location FE					X					X
Zip-by-Year FE	X	X	X	X	X	X	X	X	X	X

Clustered standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: Each column is a separate regression. The table is split into two panels as a function of the response variable in the regression analysis. "Size Controls" include controls for size, number of bedrooms, and number of bathrooms. "Condo FE" and "Multi-unit FE" are dummies indicating if the property is a condo or part of a transaction that includes multiple units, respectively. "Location FE" are fixed effects for flood zone, elevation, and distance to water.

As with the flood protection regressions, the results are highly robust across specifications that differ by included controls. Condos again see lower conditional prices and conditional price-appreciation, and the premia for elevation and being close to water are nearly identical to the flood regressions. A large number of projects are designated both flood and surge and are therefore in both regressions, so the coefficients are similar.

The project completion coefficient is again positive and significant. Most surge projects were also completed during the 2013-16 period, a time of strong appreciation in real estate prices county-wide.

For the distance elasticity, a 1% increase in the distance from the project was associated with a statistically significant 0.9-1% higher sale prices, prior to completion. Further, a 1% increase in the distance from the project resulted in a 0.1% increase the appreciation rate (significant for the preferred regression with all controls). Like the flood projects, these results are consistent with the idea that surge projects are assigned to areas that are vulnerable to storm surge and have depressed prices prior to completion.

The coefficients of the interaction terms are slightly stronger for surge projects. In particular, the distance elasticity falls by a statistically significant 1.7% for the price regressions, and 0.5% for the appreciation regressions. Prior to completion, the distance premium in the preferred regression with all controls was 1%. The distance premium fell to -0.7% after completion for the price regressions, indicating that after completion sale prices were higher near the project rather than farther away. Similarly, the distance elasticity with respect to elasticity falls by a statistically significant 0.5%, from 0.1% prior to completion to -0.4% after completion. Thus, properties near the project appreciate slightly more slowly prior to the project completion, but faster after, indicating that surge projects are also being built in vulnerable areas and that buyers and sellers view the projects as offering some protection.

6.3 Dynamic Effects of Adaptation Infrastructure

To complement the results in the previous section, we implement the analysis as an event study. In particular, we will track the effect of the adaptation project $\pm$ 10 years from the completion date. We impose further structure in the analysis by analyzing transaction at different distances from the project. The result of this new framework is shown in Figure 4. For consistency, we split the estimates by the purpose of the project (i.e., flood and surge).

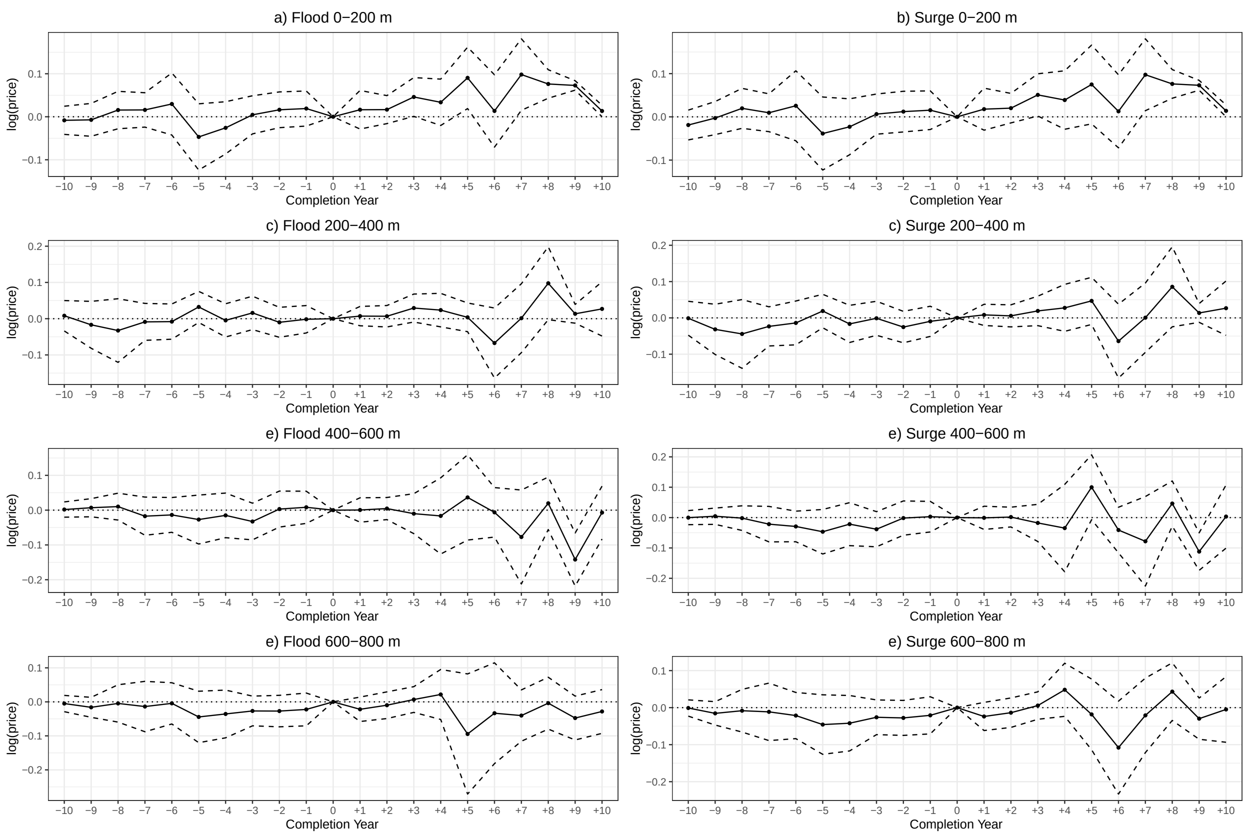


Figure 4: Event study of property prices before and after completion of adaptation infrastructure. Results are relative to a control group of all properties outside the given radius. Solid lines indicate point estimates, while dotted lines circumscribe the 95% confidence interval.

Figure 4 shows no significant differences in trends prior to completion of infrastructure projects. Post completion, however, the top two panels show that sales in all periods within 200 meters of the project sold at a higher price relative to properties farther away, after accounting for all controls. Six of ten periods are significant at the 5% level, with three more being significant at the 10% level. The effect is small initially, indicating that the value of projects are incorporated into property values slowly over time.

The effect tends to fade after 9-10 years, so that the cumulative effect is not large.[15] Nonetheless, most projects were completed between 2013-2016, while a smaller number were completed in the early 2000s. Hence the graphs represent not so much a decline over time, but instead the average effect of all projects, some of which do not have the full ten years of data. For example, the projects completed in 2016 have at most five years of data. When

[15]Such fading is common in studies that look at property values following a hurricane event or change in flood maps (e.g. Bin and Landry 2013). To our knowledge no other studies look at the evolution of the effect of adaptation investments on property prices over time.

these projects drop out at $t = +6$, the composition of the properties and projects change. In fact, a much higher percentage of the properties sold at $t = +6$ were in fact sold during the Great Recession in 2008, which accounts for the lower coefficient at that period in Figure 4.[16]

The bottom 4 panels of Figure 4 show that the effect of infrastructure on property values is largely localized to the first 200 meters from the project.[17] This pattern is consistent with the project data in that most of the projects provide only localized protection, such as installation of fixed pumping stations, drainage systems, and raising roads. Such projects are unlikely to provide much protection farther away, especially versus macro events such as hurricane-induced storm surge or flooding.

6.4 County-wide Implications

We next turn to the county-wide implications of the results. The interaction term measures the percent change in value from the project to a property at the given distance from the project. From equation (22), the percent benefit of completing project j to a property i for which j is the closest project is:

$$\log\left[P_{i,j=1}\right] - \log\left[P_{i,j=0}\right] = \beta + \gamma \log\left(d_i\right), \tag{23}$$

where d_i is the distance from the property to the project. Thus, the dollar benefit to property i is approximately:

$$P_{i,1} - P_{i,0} = \left(\beta + \gamma \log\left(d_i\right)\right) P_{i,0}. \tag{24}$$

Here $P_{i,1}$ is the price of property i after completion of project j and $P_{i,0}$ is the price before completion. Summing over properties reveals:

$$\text{Total Project Value}_j = \frac{1}{n_{1m}} \sum_{i=1}^{n_{1m}} \left(\beta + \gamma \log\left(d_i\right)\right) P_{i,0} \left(n_1 + n_2\right). \tag{25}$$

Here n_{1m} are the transactions for which project j is the closest project, including multiple transactions on the same property, n_1 are the transactions excluding multiple transactions, and n_2 are the properties for which project j was closest, but for which no transactions exist.

[16] Again, the Great Recession may not be completely captured by the zip-by-year fixed effects, due to within zip heterogeneity. The Great Recession affected condos more than single family homes, and lower priced markets recovered more slowly.

[17] Note that 200 meters corresponds to the distance to the boundary of the project, with properties inside the boundary counted as zero. Hence the geographic area of properties that benefit from the project is larger than the area of the radius 200 meter circle.

That is, we use the average increase in value for the transacted properties to estimate the increase in value for properties near the project that were not transacted.

Because of the overlap between intended hazards, we conduct this analysis using flood projects. We compute the estimated benefit for each project, and give the summary statistics in Table 5. Note that we calculate the total benefits and the average net benefit per household (hh) considering only the houses within 200 meter of the adaptation project.

Table 5: Summary statistics for cost/benefit analysis of infrastructure projects.

	Total Benefits (USD$\times 10^6$)	Project Cost (USD$\times 10^6$)	Total Net Benefits (USD$\times 10^6$)	Household Net Benefits (USD$\times 10^3$/hh)
Min	$0.00	$0.01	-$5.20	-$943.10
Max	$195.13	$28.00	$193.05	$69.96
Mean	$20.06	$1.12	$18.94	$6.24
Median	$9.61	$0.27	$8.82	$5.49
Std.Dev	$28.45	$3.34	$28.18	$29.48
Total, all projects	$3169.69	$176.70	$2992.99	—

Notes: The analysis only considers projects meant for flood adaptation. In addition, from a total of 163 reported flood projects with known end dates, 5 have no cost information and are thus not considered in this analysis. All values in 2019 USD.

Table 5 shows that the average project generated about $19M in net benefits, measured as the change in property values. Indeed, only 13 of the 158 projects for which we have cost data had costs which exceeded benefits. Note that this calculation assumes that the tax cost of the projects is dispersed throughout the nearby properties and therefore has a negligible effect on properties far from the project.

Municipalities are often concerned as to how much tax revenue is generated from the project through higher property values, which offsets the cost of the project to the city or county. Using the average property tax rate of 2.1% for Miami-Dade municipalities, the average project generates about 0.5M in tax revenue, enough to offset the average cost in two to three years.[18]

The total value of all projects is on the order of $3B. While large in magnitude, the benefits are far smaller than the cost of a direct hit by a hurricane or sea level rise. Indeed, the Fourth National Climate Assessment estimates that $900B in savings is available nationwide in terms of reduced damage to coastal properties through armoring the coast (EPA 2017). We interpret this result as evidence of the housing market internalizing part, but not all of the benefits of adaptation.

[18]Note that Miami-Dade's Homestead Exemption law prevents increases in appraised values until a property is sold. Therefore, these gains in tax revenue will accrue only in the long run.

7 Conclusions

This paper uses a difference-in-differences estimator to analyze the effect of adaptation infrastructure projects on property values. We find that property values near projects grow more slowly prior to project completion, and grow more quickly after completion. In particular, a one percent increase in the distance from the project results in a significant 0.8% higher transaction price prior to completion of the project, and a significant 0.8% lower transaction price after completion.

Although the gains are small per property, our data consists of about 200 projects, many of which protect hundreds or thousands of properties. Thus, the total net benefits for all projects is about $3 billion. Together, these results provide evidence that property buyers and sellers are both aware of the cost of flooding and storm surge resulting from climate risk, but also aware about the benefits from adaptation.

While our results are highly robust to specifications and assumptions, they come with several caveats. First, we are only able measure how property buyers and sellers perceive risk, but the actual risk to properties may be higher or lower. Second, most adaptation projects provide only limited protection. If sea levels rise by enough, these protections will not be helpful. Therefore, it is unclear if the long-run risk is priced-in or if the benefits are simply due to less flood and surge risk at current sea levels. Third, our analysis builds on public adaptation investment in Miami-Dade county, and it is unclear how general the internalization of climate risk and adaptation would be elsewhere. Whether our results extend to other types of infrastructure and other locations is unclear and is an interesting subject for future research.

Sea level rise is an important problem for coastal communities across the world. Even if carbon emissions are drastically reduced, inertia in the climate will result in continued sea level rise for many years. Thus, such communities must adapt. The Fourth National Climate Assessment argues that adaptation can significantly reduce the impacts of sea level rise, and indeed that the benefits of increased protection currently outweigh the costs in many locations. We demonstrate that these benefits are partly captured by the real estate market.

Further understanding and realization of the benefits from adaptation will likely require effort on the part of local governments and coastal communities. Whether or not coastal communities realize such theoretical gains in practice will only become an increasingly important question in the future.

References

Bakkensen, Laura A, and Lint Barrage. 2017. "Flood risk belief heterogeneity and coastal home price dynamics: Going under water?" National Bureau of Economic Research. 4

Barrage, Lint, and Jacob Furst. 2019. "Housing investment, sea level rise, and climate change beliefs." *Economics letters*, 177: 105–108. 5

Bernstein, Asaf, Matthew T Gustafson, and Ryan Lewis. 2019. "Disaster on the horizon: The price effect of sea level rise." *Journal of Financial Economics*, 134(2): 253–272. 4

Bin, O., and S. Polasky. 2004. "Effect of Flood Hazards on Property Values: Evidence Before and After Hurricane Floyd." *Land Economics*, 73: 490–500. 3

Bin, Okmyung, and Craig E. Landry. 2013. "Changes in Implicit Flood Risk Premiums: Empirical Evidence from the Housing Market." *Journal of Environmental Economics and Management*, 65(3): 361–76. 3, 4, 23

Bin, Okmyung, Jamie Brown Kruse, and Craig E. Landry. 2008. "Flood Hazards, Insurance Rates, and Amenities: Evidence from the Coastal Housing Market." *Journal of Risk and Insurance*, 75(1): 63–82. 3

Bin, Okmyung, Thomas W. Crawford, Jamie Brown Kruse, and Craig E. Landry. 2008. "Viewscapes and Flood Hazard: Coastal Housing Market Response to Amenities and Risk." *Land Economics*, 84(3): 434–448. 18

Case, K. E., and R. J. Shiller. 1989. "The Efficiency of the Market for Single-Family Homes." *American Economic Review*, 79: 125–37. 6

Davlasheridze, Meri, and Qin Fan. 2019. "Valuing Seawall Protection in the Wake of Hurricane Ike." *Economics of Disasters and Climate Change*, 3: 257–79. 3

Davlasheridze, Meri, Karen Fisher-Vanden, and H. Alen Klaiber. 2017. "The Effects of Adaptation Measures on Hurricane Induced Property Losses; Which FEMA Investments have the Highest Returns?" *Journal of Environmental Economics and Management*, 81: 93–114. 5

EPA. 2017. "Multi-Model Framework for Quantitative Sectoral Impacts Analysis: A Technical Report for the Fourth National Climate Assessment." 1, 25

Fell, Harrison, and Carolyn Kousky. 2015. "The value of levee protection to commercial properties." *Ecological Economics*, 119: 181–188. 5, 10

Gallagher, J. 2014. "Learning about an infrequent Event: Evidence from Flood Insurance Take-Up in the United States." *American Economic Journal: Applied Economics*, 6(3): 206–233. 4

Genesove, David, and Christopher J Mayer. 1994. "Equity and time to sale in the real estate market." National Bureau of Economic Research. 11

Gibson, Matthew, Jamie T Mullins, and Alison Hill. 2018. "Climate change and flood risk: Evidence from New York real estate." Working Paper. 3

Hallstrom, D., and V. Smith. 2005. "Market Response to Hurricanes." *Journal of Environmental Economics and Management*, 50: 541–61. 3

Harding, John P., Stuart S. Rosenthal, and C. F. Sirmans. 2007. "Depreciation of Housing Capital, Maintenance, and House Price Inflation: Estimates from a Repeat Sales Model." *Journal of Urban Economics*, 61(2): 193–217. 6

Hino, Miyuki, and Marshall Burke. 2020. "Does Information About Climate Risk Affect Property Values?" NBER Working Paper 26807. 3

Jin, Di, Porter Hoagland, Donna K Au, and Jun Qiu. 2015. "Shoreline change, seawalls, and coastal property values." *Ocean & Coastal Management*, 114: 185–193. 5

Keenan, Jesse M, Thomas Hill, and Anurag Gumber. 2018. "Climate gentrification: from theory to empiricism in Miami-Dade County, Florida." *Environmental Research Letters*, 13(5): 054001. 4, 18

Kelly, David L., David Letson, Forrest Nelson, David Nolan, and Daniel Solís. 2012. "Evolution of Subjective Hurricane Risk Perceptions: A Bayesian Approach." *Journal of Economic Behavior and Organization*, 81(2): 644–63. 4

Kim, Seung Kyum. 2020. "The Economic Effects of Climate Change Adaptation Measures: Evidence from Miami-Dade County and New York City." *Sustainability*, 12(3): 1097. 5, 12, 20

Kousky, Carolyn. 2010. "Learning from Extreme Events: Risk Perceptions after the Flood." *Land Economics*, 86(3): 395–422. 4

Krainer, John. 2001. "A theory of liquidity in residential real estate markets." *Journal of urban Economics*, 49(1): 32–53. 11

Ludy, Jessica, and Matt Kondolf. 2012. "Flood Risk Perception in Lands "Protected" by 100-Year Levees." *Natural Hazards*, 61: 829–842. 4

McAlpine, Steven A, and Jeremy R Porter. 2018. "Estimating recent local impacts of sea-level rise on current real-estate losses: a housing market case study in Miami-Dade, Florida." *Population research and policy review*, 37(6): 871–895. 4

NOAA. 2020. "Climate at a Glance." National Oceanic and Atmospheric Administration. 1

Ortega, Francesc, and Süleyman Taṣpınar. 2018. "Rising sea levels and sinking property values: hurricane Sandy and New York's housing market." *Journal of Urban Economics*, 106: 81–100. 3

Shr, Yau-Huo Jimmy, and Katherine Y Zipp. 2019. "The Aftermath of Flood Zone Remapping: The Asymmetric Impact of Flood Maps on Housing Prices." *Land Economics*, 95(2): 174–192. 3

Walsh, Patrick, Charles Griffiths, Dennis Guignet, and Heather Klemick. 2019. "Adaptation, Sea Level Rise, and Property Prices in the Chesapeake Bay Watershed." *Land Economics*, 95(1). 5

A Binned Analysis

In addition to the results in the main text, and to account for potential non-linearities in the distance decay of the adaptation effect, we structure the empirical analysis in bins. In particular, we create four bins for the observable distance from the closest adaptation project instead of a continuous measurement for distance. Operationally, the model is now as follows:

$$\log[y_{it}] = \alpha + \sum_k \mathbb{1}_{k=BIN_i}\lambda_k + \beta\ POST_{it} + \sum_k \gamma_k\ \mathbb{1}_{k=BIN_i}POST_{it} + \eta\ DISTWATER_i + \zeta\ ELEVATION_i + \theta' X_{it} + \epsilon_{it} \tag{A.1}$$

As in the main analysis, the dependent variable, y, is either the transaction price in 2019 dollars per square foot or the annualized appreciation, adjusted for inflation, from the previous qualified sale ($\log\left[P_{t+\tau}/P_t\right]/\tau$). *BIN* is the distance bin in meters to the closest border of the closest adaptation project on record. Specifically, $k = \{1, 2, 3, 4\}$ for $0 \leq DISTANCE_i \leq 200$, $200 < DISTANCE_i \leq 400$, $400 < DISTANCE_i \leq 600$, and $DISTANCE_i \geq 600$, respectively. Because of the bin approach, we no longer add one meter to each recorded distance.

The rest of the model is relatively similar to the one used in the main text. *POST* is a binary indicator that takes a value of one if the closest adaptation project to property i has been completed at time t. The parameters of interest, λ, β, and γ, denote the elasticity of property transaction prices with respect to a distance bin, the change in mean property value or appreciation after project completion, and the difference-in-differences parameter which gives the change in the distance-bin elasticity following completion of the project, respectively. Note that the reference bin is the $0 \leq DISTANCE_i \leq 200$ bin.

Control variables remain unchanged. *DISTWATER* denotes the distance from the water, while *ELEVATION* denotes the vertical elevation for each individual property. Finally, X_t is a battery of property and time fixed effects. The error term in the econometric model is ϵ. To control for serial and spatial correlation, we cluster standard errors by zip code and year.

Our working hypothesis for the bin analysis is that β is positive so as to reflect a positive effect of the adaptation project. Because nearby properties are taken as the reference category we then expect that properties farther away from will have a negative γ coefficient. As a validity check, and to check that property characteristics are properly accounted for, we also expect no differences pre-adaptation project across bins.

A.1 Results

The first analysis pertains projects designated by the county as flood protection or as having multiple designations that includes flood protection. The results of the difference-in-differences binned approach are shown in Table A.1, and suggest that adaptation infrastructure has a positive effect on property values.

Much like the main analysis, the results are highly robust to the inclusion of a variety of control variables and suggest that the effect of project completion is positive and significant. Table A.1 shows that properties within 200 meters of the adaptation project sold for about

Table A.1: Difference-in-Differences binned regression results for flood infrastructure projects.

	log(price)					log(app)				
Timing and distance										
Post	0.079***	0.079***	0.073***	0.074***	0.073***	0.058***	0.059***	0.057***	0.057***	0.059***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
$200 < \text{Distance} \leq 400$	-0.004	-0.003	-0.005	-0.004	-0.007	-0.005	-0.003	-0.004	-0.003	-0.003
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.01)	(0.01)
$400 < \text{Distance} \leq 600$	0.004	0.003	0.002	0.002	0.001	-0.005	-0.005	-0.005	-0.006	-0.007
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
$\text{Distance} > 600$	0.002	0.003	0.007	0.008	0.007	0.004	0.004	0.006	0.006	0.004
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Interaction										
$\text{Post}\times 200 < \text{Distance} \leq 400$	-0.020	-0.020	-0.017	-0.017	-0.016	-0.016*	-0.016*	-0.015	-0.015*	-0.015*
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
$\text{Post}\times 400 < \text{Distance} \leq 600$	-0.041*	-0.040*	-0.037*	-0.037*	-0.036*	0.004	0.003	0.003	0.004	0.004
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
$\text{Post}\times\text{Distance} > 600$	-0.069***	-0.069***	-0.068***	-0.068***	-0.065***	-0.033***	-0.035***	-0.034***	-0.034***	-0.033***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Observations	431410	431410	431410	431410	431410	330352	330352	330352	330352	330352
Size Control		X	X	X	X		X	X	X	X
Condo FE			X	X	X			X	X	X
Multi-unit FE				X	X				X	X
Location FE					X					X
Zip-by-Year FE	X	X	X	X	X	X	X	X	X	X

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: Each column is a separate regression. The table is split into two panels as a function of the response variable in the regression analysis. "Size Controls" include controls for size, number of bedrooms, and number of bathrooms. "Condo FE" and "Multi-unit FE" are dummies indicating if the property is a condo or part of a transaction that includes multiple units, respectively. "Location FE" are fixed effects for flood zone, elevation, and distance to water.

7.3-7.9% higher price, relative to properties sold prior to project completion within the same distance bin. Moreover, the appreciation for these properties was 5.7-5.9% higher if sold after projects were completed.

For properties farther than 200 meter from the project, there are two features to highlight. First, Table A.1 shows that there are no statistically significant differences, in terms of price or appreciation, between properties near and far from the adaptation project prior completion. Second, this lack of differences dissipates once we consider the timing of the project. Properties farther than 200 meters from a project see penalizations in both price and appreciation. As expected this negative effect is largest for transactions taking place 600 meters from the adaptation project. In other words, the effect of the adaptation project is mostly capitalized by properties nearby.

For completeness, we replicate the binned analysis for projects designated as storm surge or storm surge combined with other protections. Again, given the high degree of overlap with flood projects, one would expect minimal difference with the results presented above. Table A.2 shows confirms this observation and reassures the consistency of our results with those in the main text.

Table A.2: Difference-in-Differences regression results for surge infrastructure projects.

	log(price)					log(app)				
Timing and distance										
Post	0.100***	0.101***	0.095***	0.096***	0.093***	0.049***	0.050***	0.048***	0.048***	0.048***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
$200 < \text{Distance} \leq 400$	-0.008	-0.008	-0.010	-0.009	-0.012	-0.004	-0.002	-0.003	-0.002	-0.003
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
$400 < \text{Distance} \leq 600$	0.004	0.003	0.002	0.002	0.001	-0.008	-0.008	-0.008	-0.008	-0.010
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
$\text{Distance} > 600$	0.009	0.011	0.015*	0.015*	0.013	0.002	0.004	0.006	0.005	0.003
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Interaction										
$\text{Post}\times 200 < \text{Distance} \leq 400$	-0.017	-0.016	-0.014	-0.014	-0.012	-0.015	-0.014	-0.013	-0.013	-0.013
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
$\text{Post}\times 400 < \text{Distance} \leq 600$	-0.042*	-0.042*	-0.040*	-0.039*	-0.038*	0.011	0.011	0.011	0.011	0.012
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
$\text{Post}\times\text{Distance} > 600$	-0.075***	-0.076***	-0.073***	-0.074***	-0.071***	-0.039***	-0.040***	-0.039***	-0.039***	-0.039***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Observations	431410	431410	431410	431410	431410	330352	330352	330352	330352	330352
Size Control		X	X	X	X		X	X	X	X
Condo FE			X	X	X			X	X	X
Wholesale FE				X	X				X	X
Location FE					X					X
Zip-by-Year FE	X	X	X	X	X	X	X	X	X	X

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: Each column is a separate regression. The table is split into two panels as a function of the response variable in the regression analysis. “Size Controls” include controls for size, number of bedrooms, and number of bathrooms. “Condo FE” and “Multi-unit FE” are dummies indicating if the property is a condo or part of a transaction that includes multiple units, respectively. “Location FE” are fixed effects for flood zone, elevation, and distance to water.