NBER WORKING PAPER SERIES

FINANCIAL VALUE OF NATURE:
COASTAL HOUSING MARKETS, MANGROVES, AND CLIMATE RESILIENCE

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Working Paper 34329
http://www.nber.org/papers/w34329

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
October 2025

Support was provided by the UCSC Center for Coastal Climate Resilience, USACE Engineering with Nature, NSF Strong Coasts (2209284), and the AXA Research Fund. Data provided by Zillow through the Zillow Transaction and Assessment Dataset (ZTRAX). More information on accessing the data can be found at http://www.zillow.com/ztrax. The results and opinions are those of the author(s) and do not reflect the position of Zillow Group. We appreciate the comments from Jawad Addoum, Marcin Kacperczyk, Johannes Stroebel, Constantine Yannelis, and the participants of Cambridge Workshops on Finance and Biodiversity (Oct 2024 and May 2025), Frankfurt Conference on Biodiversity in Finance and Accounting (Jul 2025), CEPR Climate Change and Environment Symposium (Jul 2025), as well as participants at Climate Risk Seminar at Freddie Mac and Macro Workshop at UC Santa Cruz (Apr 2023). We thank Ian Costello for the help in data visualization. All errors are ours. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

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NBER Working Paper No. 34329
October 2025
JEL No. G12, Q54, R31

ABSTRACT

Measuring the financial value of nature is difficult, often resulting in insufficient funding directed to nature conservation and restoration. As coastal risks increase from development and climate change, a tangible benefit of nature is the protection it offers against storm damages. Many studies from the risk industry and others assess the direct effects of wetlands for reducing damage during storms. However, the value of wetlands for coastal protection could extend to many other benefits, including home prices in areas where storms are common. We use property-level housing transaction data from Zillow and show that proximity to mangroves in Florida moderates home price decline and dispersion following major hurricanes. The effects are substantial in magnitude, reducing the probability of losing a quarter or more of housing value by 2-7 percentage points, which corresponds to 20-40-thousand-dollar value for a million-dollar property, conditional on a hurricane.

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Shareable data and codes is available at
https://github.com/tengtedliu/financial_value_of_nature_mangrove

1 Introduction

The effects of climate change are no longer a future risk. The frequency and severity of climate-related disasters increased in recent years and are expected to increase further (Hsiang and Kopp, 2018). This means that we need to think not only about climate change mitigation efforts, designed to reduce greenhouse gas (GHG) emissions, but also about adaptation efforts that would help protect nature, infrastructure, property, and people from the consequences of climate change. Nature-based solutions (NbS) such as protecting and restoring coastal wetlands are effective at reducing flood risks following hurricanes (Arkema et al., 2013; Menéndez et al., 2020; Beck et al., 2022). However, the benefits of such solutions are difficult to evaluate, which is a barrier to mobilizing private investments in such projects. At the same time, attracting private investment is key to preserving and restoring nature and biodiversity, because financial needs in this area exceed the means of governments and non-profit organizations (Flammer et al., 2025).

We propose a methodology to evaluate the private benefits of nature as protection against climate-related extreme weather events using market-based evidence. In particular, we measure the reduction in hurricane-related market value losses of properties associated with the protection provided by mangrove forests. We account for the effects of mangroves on price dispersion and compute the dollar value of private benefits from such protection. In prior studies, such as del Valle et al. (2019); Hochard et al. (2021); Menéndez et al. (2020); Sun and Carson (2020), the financial benefits of mangroves are derived from direct damage avoidance analysis based on construction costs data. Our analysis of market values of properties is designed to account for differences between perceived values of properties that are protected by nature and those that are not.

The state of Florida provides a relevant setting for our analysis. Multiple counties in the state have been hit by severe hurricanes in recent decades, with substantial impacts on housing prices.[1] At the same time, parts of Florida's coastline are covered with mangroves, which are shown to be a natural protection against hurricane-induced flood damages (Thomas et al., 2020). In terms of the physical storm impact, studies such as Gijsman et al. (2021) and Mazda et al. (2006) find a linear effect of mangroves on flood risk reduction: wave energy and storm surge decay along a transect through mangroves, and wave and surge attenuation is a linear function of the distance inland of the mangrove forest. Beck et al. (2022), Menéndez et al. (2020), and Narayan et al. (2025) demonstrate that mangroves effectively reduce property damages from hurricane and flooding. Similar findings in economics studies are reported in

[1] See the list of continental U.S. hurricanes collected by Atlantic Oceanographic & Meteorological Laboratory at the National Oceanic and Atmospheric Administration (NOAA). Last accessed in March 2025.

del Valle et al. (2019), Hochard et al. (2021), and Sun and Carson (2020).[2]

We combine geographic variation in flood protection provided by mangroves, measured through their distance to properties, with over-time variation in the impact of hurricanes on housing prices. We focus on medium flood risk areas identified through the Federal Emergency Management Agency (FEMA)[3] and estimate the effects of three major hurricane seasons dominated by signature events: Ivan and Jeanne in September 2004, Sandy in October 2012, and Irma in September 2017. Our benchmark analysis focuses on seven coastal counties: Pinellas, Miami, Manatee, Lee, Hillsborough, Collier, and Charlotte.[4] Property level data from Zillow's Transaction and Assessment Database (ZTRAX) allow us to analyze the full distribution of the effects considering actual sale prices. We summarize the effects using the measure of probability value at risk (pVaR), frequently used in pricing the value of extreme events, which measures the probability of housing price values dropping by more than a threshold amount following a hurricane (we choose a 25% threshold as an example). We then translate the measured reduction in pVaR thanks to mangroves into the willingness to pay (WTP) for mangroves protection and restoration, as a share of pre-hurricane house value, conditional on the hurricane occurrence.[5]

The identification of the price moderation effect of mangroves comes from the differential price response to hurricanes across properties with differing proximity to mangroves. Put differently, we ask: after a major hurricane, do properties near mangroves experience smaller price declines than properties farther from mangroves, even though both are equally exposed to hurricane risks? Importantly, we are not focusing only on properties directly damaged by the hurricanes but also evaluating hurricane effects on the pricing of all properties in the sample. The statistical analysis is conducted at two levels of granularity. At the property level, we evaluate property-specific price changes using repeated sales information and controlling for property and time fixed effects. Property fixed effects absorb any differences in flood exposures and amenities associated with specific properties,[6] while time fixed effects account for aggregate house price dynamics. This analysis provides us with estimates of

[2]In particular, Sun and Carson (2020) finds that coastal wetlands' protection is especially effective in areas with weaker disaster prevention building codes, and in general the average value of these protections (damage avoidance) is around $1.8 million per square kilometer annually.

[3]Areas between a 100-year and a 500-year floodplain. More details in Appendix A.3

[4]FEMA Flood Map data do not always overlap with the property sale data, or with Global Mangrove Watch data. In the estimations that include all FEMA flood zones, the sample also includes Broward County.

[5]To compute unconditional WTP we would need information on the beliefs distribution about climate scenarios and the effect of climate scenarios distribution on hurricane damages and their reduction by the proximity to mangroves. This is beyond the scope of our paper.

[6]Daniel et al. (2009) show that not controlling for amenity values may create biased results when measuring the effects of floods on property prices. Doss and Taff (1996) show that properties with open access to the coastline are generally valued higher than those with forested wetlands, such as mangroves. Atreya et al. (2016) show the importance of distance to amenities for housing prices.

the average housing price effect of hurricanes depending on the properties' proximity to the mangroves. To address the dispersion of the price effects, we also conduct the ZIP code-level analysis of the coefficient of variation of housing prices.

We begin our analysis with a monthly event study of house price dynamics around hurricane events in the sample. We find that, controlling for property fixed effects, prices of properties in the sample decline substantially following hurricanes relative to the Florida-wide house price index, with the magnitude of price decline nearly twice as large in areas that are further away from mangroves. We also show that, on average, properties further away from mangroves tend to have lower prices, but this average effect may reflect many unobserved characteristics and does not necessarily imply that the climate adaptation benefits of mangroves are not reflected in prices throughout the sample. For this reason, our benchmark specification relies on repeated sales analysis with property fixed effects, thus identifying the effect of proximity to mangroves on house price reduction following hurricanes from price dynamics and not cross-sectional variation.

In our benchmark specification, we estimate a regression of property prices on the interaction of hurricane timing with distance to mangroves, which we express as a categorical variable. The regression includes property fixed effects, which absorb factors such as property location, type, flood exposure, and amenity value, and time fixed effects, which absorb any common trends in housing prices. As we rely on actual transaction data and the frequency of housing sales is affected by hurricanes, we allow for up to three years for the measured effects of the hurricanes, including the hurricane year. Other studies have demonstrated that housing price effects of hurricanes might be even more persistent, up to 5-6 years (Bin and Landry, 2013; Ortega and Taṣpınar, 2018). However, the high frequency of major hurricanes in Florida makes it impractical to include more than three years in the estimation. In addition, we verify that there are no pre-trends observed due to differences in distance to mangroves in our data, i.e. price dynamics in the years immediately preceding hurricanes are not correlated with distance to mangroves. That said, when we allow for secular price trends to differ by distance to mangroves, we find that trend price growth is lower for properties located further away from mangroves, which could be consistent with growing awareness of the climate adaptation benefits of the proximity to mangroves.

We limit our benchmark analysis to properties located in the medium risk areas designated by the FEMA flood maps, thus only considering properties with similar inherent flood risk. Importantly, properties in high flood-risk areas are subject to several financial and regulatory requirements as well as subsidized insurance premia, which distorts the response of their values to disasters such as hurricanes (Morgan, 2007).[7] In addition, property values in

[7] A similar distortion is found in the aftermath of wildfires in California that received FEMA rescue funds,

high flood risk areas are shown to be lower in general (Harrison et al., 2001; Zhang, 2016), suggesting that some of the flood effects might be priced in. Properties in the medium flood risk areas are subject to flood risk but not affected by such distortions.[8]

Despite limiting our analysis to medium flood risk areas, a concern remains that the effect of distance to mangroves on the price dynamics following hurricane events is contaminated by the distance to the coast. To test whether the correlation between distance to mangroves and distance to the coast affects our results, we construct a new variable: a portion of the mangrove distance indicator that is orthogonal to the distance to the coast by regressing the mangrove distance indicator on distance to the coast in a cross-section of the properties in our data. We use this new variable, interacted with hurricane timing variables, as well as distance to the coast interacted with hurricane timing variables (the sum of these adds up to our benchmark), to isolate the effect of the mangrove distance. We find that mangrove effects remain essentially the same in this specification as in our benchmark analysis.

To measure the effects of hurricanes on price dispersion and the potential of mangroves to reduce these effects, we conduct ZIP code-level analysis. Since we cannot control for property fixed effects at the ZIP code level, we include the following controls in our regressions, taking the median of them at the ZIP code level: distance to coast, elevation, property age, building area square footage. We compute price moments separately for different property types (single-family house or condominium). In addition, we include ZIP code and time fixed effects.

We apply the results of our statistical analysis to the observed distribution of housing price changes for the properties with repeated sales before and after hurricanes to evaluate the effect of proximity to mangroves on the probability of losing 25 percent or more property value following a hurricane. We find that the effect varies by hurricane and county and is on average 3-4 percentage points but can be as large as 7 percentage point reduction (from over 36% to nearly 29%) of the probability of 25% housing value loss, which is what we estimate for Collier County following Hurricane Irma. Conditional on hurricane occurrence, the willingness to pay for this risk reduction, and therefore for mangroves protection and restoration, corresponds to an average of 20-40 thousand and as much as 60 thousand dollars per 1-million-dollar house under standard assumptions, likely exceeding estimated direct damages or insurance premium differences.

In addition to computing average effects of mangrove protection across all the hurricane years, we allow for the effects to differ across counties that were on the path of hurricanes and those that were off the hurricane path. We find that properties in on-path counties benefit

as shown by (Issler et al., 2024).

[8]In Appendix A.5 we document the differences in the effects of mangroves by flood risk level.

more from the mangrove protection in terms of moderating post-hurricane price reduction, but the effects are also observed for properties located in counties off hurricane paths. This risk reduction effect in off-path counties is about half as large as in on-path counties and is only apparent with about 1-year lag. This is likely because the perception of flood risk protection from mangroves increases following hurricanes, as housing market participants learn from the experience of their neighbors.

We extend our analysis by allowing the effect of mangroves to vary as a function of the width of the mangrove forest at each location. We define "width" to be the cross-shore distance from the water edge to the back of the mangrove belt, band, or forest. Studies have shown that mangroves flood protection effects are larger when mangrove forests are wider (Gijsman et al., 2021; Maza et al., 2021). Our results are consistent with this finding — the decline in property prices following hurricanes is substantially smaller when a mangrove forest is wider in proximity to the properties in question: an additional 10 meters of mangroves (up to 30 meters) have as much protection effect as reducing distance to mangroves by 2 km.

Our study is not the first to estimate the effect of flood risks on housing prices. The negative effect has been found in a number of studies of residential housing, including Bin and Landry (2013), Daniel et al. (2009), Graff Zivin et al. (2023), Bernstein et al. (2019), Baldauf et al. (2020), Hino and Burke (2021), and Keys and Mulder (2020), as well as studies on commercial real estate including Addoum et al. (2024). Bernstein et al. (2019) and Baldauf et al. (2020) show the climate effects on housing prices by measuring the climate belief effects, while Ortega and Taṣpınar (2018) attribute a long-term reduction in New York property values following hurricane Sandy to change in climate beliefs. Our paper is also related to Benetton et al. (2022) and Kelly and Molina (2023) who estimate the value of "grey" infrastructure (seawalls) using house listing prices in Venice and transaction data in Miami-Dade County, respectively. To our knowledge, our study is one of the first to measure the mitigating effect of mangroves or NbS more generally on flood risk-related housing value loss. Additionally, our analysis of price dispersion due to hurricane events is similar to studies such as Gete et al. (2024) showing that the riskiest Florida counties could experience a mortgage rate spread increase as high as 13% compared to before the landfall. Our paper also contributes to the literature on the financial value of wetlands preservation and conversely of wetland loss, as in Taylor and Druckenmiller (2022) and Rizzi and Lewis (2025).

More generally, our analysis contributes to the literature on valuing nature, ecosystems, and biodiversity. In particular, Nolte (2020) uses housing data to estimate the costs of conservation in the United States. Most studies focus on the amenity values of the ecosystem rather than climate risk reduction (Atreya et al., 2016; Belcher and Chisholm, 2018; Cho et al., 2006; Doss and Taff, 1996; Mahan et al., 2000). In contrast, our analysis contributes to the smaller literature on the costs and benefits of flood risk reduction measures, which includes studies by Brouwer and Schaafsma (2013); Corderi-Novoa et al. (2021); Lind (1967); Zhu et al. (2007), although very few of these studies focus on NbS. More recently, analytical models from Giglio et al. (2025) show that the marginal value of nature's adaptation effect increases as climate change intensifies, and as climate-related extreme events become more frequent.

To summarize, we find that the protection effects of mangroves can be large in terms of reducing potential residential property value losses after hurricanes, especially in areas that are not currently designated as high flood risk. While we only measure the effects on the housing values, other benefits of NbS are many and need to be taken into consideration in a broader cost-benefit analysis.[9] Specifically to mangroves, in addition to flood protection of non-housing assets such as agricultural areas, public infrastructure, open spaces, and other properties, co-benefits include biodiversity protection through preservation and restoration of the habitats, and other ecological benefits. Moreover, further private benefits can be generated through carbon offset markets due to the potential of mangroves to sequester carbon, or through the positive effect of mangroves on the sustainability of fisheries (zu Ermgassen et al., 2025).

There are two main takeaways from our analysis. First, to the extent that residential property values reflect the present value of the future actual costs of hurricane-related damages, protection and restoration of mangroves could be an important part of the adaptation to climate change and an associated increase in hurricane frequency. Second, given that mangroves provide benefits to residential property owners as well as developers, insurance companies, and financial institutions, these private agents have a financial interest in investing in the protection and restoration of mangroves. Designing financial instruments that would allow for such contributions will help alleviate climate adaptation costs for federal, state, and local governments while reaping the co-benefits in terms of ecosystem and biodiversity protection. Our analysis provides actual estimates as well as the methodology to quantify the private benefits of nature that can be incorporated in such financial instruments.

The paper proceeds as follows. In section 2 we provide an overview of the biodiversity and carbon sequestration benefits of mangroves—though our study is focused on the flood risk reduction benefits. Next, we present the data sources in section 3 and discuss the identification strategy and econometric specifications we employ to uncover the effect of mangroves in section 4. The benchmark results are in section 5: we start by first showing the stabilization effects of mangrove on housing prices following hurricanes, and how these

[9]Allaire (2018) surveys the literature on the broad impacts of extreme flooding that NbS may help reduce.

effects materialize differently when properties are on and off the hurricane path. Besides the level effect analysis, we also show the effect in terms of the probability of value at risk, based on which we can derive the willingness to pay for mangrove protection. We also demonstrate that the benchmark results are robust to alternative specifications. The final section concludes and discusses the policy implications of the results.

2 Mangroves Biodiversity and Carbon Benefits

Before diving into our analysis of the private value of climate adaptation benefits that mangroves provide, we briefly summarize the state of knowledge on the benefits of mangroves for biodiversity conservation and climate mitigation.

Mangroves are exceptionally productive tropical forests that thrive in the intertidal zones between land and sea (Figure A.1). These ecosystems have evolved to withstand the harsh conditions of saltwater exposure, shifting tides, and strong wave action (Bunting et al., 2018). Their unique adaptations, including aerial root systems, enable them to mitigate wave energy and wind impacts while absorbing pollutants from surrounding waters.

These adaptations not only protect the mangrove ecosystem but also provide crucial benefits to nearby human communities. Mangroves serve as natural barriers against storm surges and coastal erosion and help maintain water quality (Das and Vincent, 2009; Hochard et al., 2021), as illustrated in Figure A.2. In addition to their protective functions, they bolster local economies by supporting ecotourism, recreational activities, and both commercial and subsistence fisheries. They also supply a range of forest products, from timber and medicinal plants to pollination services that sustain agricultural livelihoods (Tomlinson, 2016; Walters et al., 2008).

Mangroves play a vital ecological role by offering habitat that enhances biodiversity. They serve as breeding, feeding, and nursery grounds for a wide variety of species, including endemic fish, macroinvertebrates, birds, and mammals (Tomlinson, 2016; Corte et al., 2021; Mohd-Azlan et al., 2015; Ng et al., 2021). Beyond their ecological and economic value, mangroves also contribute significant non-material benefits, such as cultural heritage, spiritual fulfillment, educational opportunities, aesthetic appeal, and a strong sense of place for local communities (Onyena and Sam, 2020; Friess, 2016; Walters et al., 2008).

On a global scale, mangroves are among the most carbon-dense ecosystems in the tropics, storing an average of 1,023 $\pm$ 88 megagrams of carbon per hectare (Donato et al., 2011). Despite covering just 0.5% of coastal areas worldwide, they are responsible for approximately 14% of global oceanic carbon sequestration through both aboveground biomass and soil carbon (Alongi, 2012, 2014). However, the actual amount of carbon stored can vary significantly (Jennerjahn, 2020). These differences depend on several environmental and ecological factors, such as soil salinity and composition (Song et al., 2023; Matsui et al., 2015), tree species diversity and functional traits (Rahman et al., 2021), forest maturity and spatial configuration (Wu et al., 2020; Tue et al., 2014), local climate conditions (Dobbs et al., 2014), and the geomorphic and hydrological setting (Chaikaew and Chavanich, 2017; Sasmito and et al., 2020). Socio-political elements like land ownership and governance also play a role (Friess, 2016; Lovelock et al., 2022).

Despite their high carbon storage potential, the long-term durability of mangrove carbon sinks remains uncertain. Key knowledge gaps persist regarding ecological processes such as mineralization rates (Wu et al., 2020), the effects of climate change on mangrove metabolic activity (Alongi, 2014), and future changes in land use driven by human development (Sasmito and et al., 2020).

3 Data Sources

We develop a novel dataset that combines high-resolution geospatial data with housing financial transactions. One key distinguishing feature of our dataset is that we are able to identify property-level variations of flood risks and the benefits provided by coastal wetlands.

We combine the datasets of Global Mangrove Watch (GMW) and Zillow's Transaction and Assessment Database (ZTRAX) to assess the value of mangroves in flood risk reduction. The data merging process is based on the geo-coordinates of the properties (details of the data merging process are in Appendix A.3). We supplement the data with additional geographic information system (GIS) data, such as house elevation from U.S. Geological Survey and the U.S. Census.[10] We use the National Flood Hazard Layer (NFHL) from FEMA to identify the perceived flood risks.

Housing Data. ZTRAX is a dataset of house final sales that provides a rich set of information on sale price, date of sale, square footage, and other key property characteristics.[11] We analyze Florida because of the high frequency of hurricanes and substantial mangrove presence in several counties. Our overall sample includes eight coastal counties: Pinellas,

[10]From the U.S. Census, we use the Topologically Integrated Geographic Encoding and Referencing (TIGER) database.

[11]Importantly, these data are collected from county assessors' offices, and are not the listing prices from the Zillow website. As far as we know, ZTRAX does not provide information on the properties' listing dates.

Hillsborough, Manatee, Charlotte, Lee, Collier, Broward, and Miami-Dade.[12] The time coverage of our data is 1993 to 2019. There are over 6.4 million records of transactions in our sample, in which there are around 2.04 million unique properties. The majority, around 68%, of these properties in the sample are single-family houses. All the sale price data have been converted to real terms (in terms of 2015 dollars).

We supplement these data with the average values of S&P CoreLogic Case-Shiller housing price indices (HPI) for the Miami and Tampa metropolitan areas in Florida, available from Federal Reserve Economic Data (FRED).[13] We use the housing price index to control for trend in specifications where we are not able to include time fixed effects.

Mangroves Data. We have collected mangroves data from Global Mangrove Watch (GMW), which is an online platform established by the Japan Aerospace Exploration Agency's Kyoto and Carbon Initiative. The initiative is an international collaboration among Aberystwyth University, solo Earth Observation (soloEO), and the International Water Management Institute. The platform provides remote sensing data and tools for monitoring mangroves (Bunting et al., 2018). Remotely sensed data are created from satellite radars that are able to detect mangroves extent across the entire world at 30-meter resolution (Bunting et al., 2022). This dataset additionally displays the change in mangroves coverage between select years during 1996 and 2020.[14] While Florida has lost many mangroves in the past, the distribution of mangroves changed very little over the 25-year period of our study (Table A.3). Thus, we cannot use mangroves dynamics as a source of identification, and we use a time-invariant measure of the distance to mangroves and mangroves width.

Figure 1 shows the distribution of mangroves in our sample. While all eight counties in the sample have mangrove coverage, the southwestern Florida counties have a higher mangrove density. To measure the effect of mangroves on flood risk reduction, we use property-specific distance to mangroves and the width of the mangrove forest. Property-specific distance is calculated as a geodesic (shortest distance) to the closest mangrove forest. We bin the distance measure into groups: 0-2km, 2-4km, 4-8km, 8-16km, and more than 16km. Table A.1 shows that there is a balanced distribution of transactions across distance to mangroves and years relative to hurricane events.

[12]We are precluded from considering the remaining coastal counties due to the limitations of the GIS data.

[13]The Federal Housing Finance Agency publishes monthly data only for Census Divisions, thus we approximate Florida HPI with the mean values of indices for Miami and Tampa metro areas: S&P CoreLogic Case-Shiller FL-Miami Home Price Index (MIXRNSA) and S&P CoreLogic Case-Shiller FL-Tampa Home Price Index (TPXRSA).

[14]Specifically, we use data from years 1996, 2007, 2008, 2009, 2010, 2015, 2016, 2017, 2018, 2019, and 2020. The average of these years' data is used as the mangrove distance measure.

For each property, we also record the width of the mangrove forest that is closest to the property. We calculate the width of the mangrove forest using the GIS data by generating transects between the boundaries of mangroves and location of properties, and by calculating the geodesic distances from the properties to the boundaries. Additional details are described in Appendix A.3.

Figure A.3 documents the distribution of housing prices per square meter as a function of distance to mangroves, controlling for Florida's overall housing price index. We find that without considering the hurricane effects, housing price per square foot decreases the further away the properties are from mangroves, which is consistent with a recent finding by Kajaria et al. (2023) that mangrove benefits are reflected in housing prices.[15]

Hurricane Data. The dates and paths of hurricane landings are obtained from the National Hurricane Center, National Oceanic and Atmospheric Administration (NOAA) and North Carolina Institute for Climate Studies. We select three main hurricane years during which major hurricanes affected Florida in our sample. While hurricanes Ivan and Jeanne as well as Irma passed through Florida (see Figure 2), Sandy did not. The choice to include hurricane Sandy in the analysis allows us to illustrate that the benefits of mangroves are not only due to direct flood risk reduction for those counties on the hurricane paths. Hurricane effects on housing markets in the counties that are not directly affected are likely due to changes in the perception of risks from future hurricanes stemming from observing their neighbors' experiences.

FEMA Data. Using the National Flood Hazard Layer (NFHL) for 2020, we categorize properties into three flood risk categories: low, medium, and high. More specifically, in line with the taxonomy and definitions of FEMA, an area is a medium (or moderate) risk zone if it is located in a 100-to-500-year floodplain. This means the area has a reduced, but still substantial, risk of flooding — roughly a 0.2% to 1% chance of flooding in any given year. When an area is designated as a high-risk zone, also known as a Special Flood Hazard Area (SFHA) or 100-year floodplain, it means the area is at risk of flooding from an event that occurs with probability 1% or higher in any given year. Figure 3 shows that substantial areas of the coastal counties are either in medium or high flood risk zones.

[15] Ex ante, the price variation in this graph could be capturing the price premia of beachfront or urban area properties. However, the relative flatness of the slope between 1km and 10km suggests there are factors other than being close to the ocean driving the price difference.

4 Empirical Strategy

Following real estate economics literature including Mueller et al. (2009) and Graff Zivin et al. (2023), we use a hedonic regression model to estimate how housing price dynamics following hurricanes, both in terms of level and dispersion, reflect the climate adaptation value of mangroves. To uncover the level effect, we rely on the variation arising from the repeated sales of properties. In other words, if a house is sold after a recent hurricane, its price should reflect how buyers and sellers perceive the risk exposure of the property and the potential value of mangroves in alleviating the risks.

We focus on three major hurricane events that fall in the time frame of the sample: Hurricanes Ivan and Jeanne in September 2004; Hurricane Sandy in October 2012; and Hurricane Irma in September 2017.[16] Given that perception of the flood risk in Florida can be affected by the hurricanes that land in neighboring states along the Gulf of Mexico and eastern seaboard, some of the effects we find for Irma in 2017 could also be affected by hurricanes Harvey and Maria. Figure 2 shows the paths of these hurricanes across the six counties in our sample. We allow for differential effects of hurricanes on counties that are directly on the paths of hurricanes and those that are not. As the paths of hurricanes show, different hurricanes landed in different counties in our sample (and Sandy did not land in Florid,a) providing sufficient variation for identification of separate effects. To generalize the effects of these hurricanes, we combine three hurricane years into a single hurricane variable in the benchmark estimations while disaggregating the effects in the robustness tests (Tables A.5).

4.1 Identification and Measurement of the Mangroves Effect

A major source of flood risk comes from buildings' proximity to the coast, as ocean waters can travel inland during storms (Gijsman et al., 2021). However, the risk is mitigated by natural barriers like mangroves when they are between buildings and the coastline (Das and Vincent (2009)). Everything else equal, even when faced with identical flood risks, properties closer to mangroves are less likely to be damaged by hurricanes and floods or, if affected, are likely to have smaller damages.

It is not straightforward to identify how housing prices would reflect the presence of mangroves. There are at least two mechanisms at work. On the one hand, if people perceive that mangroves can reduce the impact of flooding, therefore protecting their home value,

[16]Ivan and Jeanne both occurred in September 2004 and are considered as one single hurricane event in this study. Throughout the paper, we may use "Ivan" as an abbreviation for "Ivan and Jeanne".

they would be willing to pay more for houses in closer proximity to mangroves. On the other hand, the presence of mangroves can potentially reduce the value of the amenities that one would experience when living by the ocean, such as view and access to the waterfront, therefore pushing down the house price. Our identification strategy relies on the assumption that perceived risk reduction is affected by the flooding events, such as those associated with major hurricanes, while the amenity value is not.

Our benchmark specification relies on differential changes in house prices in the aftermath of the hurricanes, depending on the proximity of the property to mangroves. We control for year-month fixed effects to absorb any price trends common to our sample, including the average impact of hurricanes on housing prices. We include property fixed effects to account for distance to the coast, elevation, amenity values resulting from mangroves, as well as all other property characteristics. The variable of interest is an interaction of a post-hurricane indicator, which only varies over time but not across properties, and our measure of property proximity to mangroves, which only varies across properties but not over time. Main effects of these variables are absorbed by fixed effects. We also include an indicator for 2 years before the hurricane to capture any pre-trends.

One important identification issue remains — since mangroves grow at the water edge, proximity to mangroves is correlated with proximity to the water edge and therefore with the exposure to flood damages. Some of this concern is alleviated by the fact that we focus our benchmark specification on NFHL medium flood risk areas, and therefore only rely on properties with similar inherent flood risk. Importantly, NFHL risk designations combine information on proximity to the water edge, elevation, and any existing grey flood protection measures. In our pre-testing, we find that the properties in the medium flood risk are most likely to benefit from proximity to mangroves (Appendix A.5). In addition, we explicitly test for possible contamination of the distance to mangroves effect by the distance to the coast effect on price dynamics following hurricanes. To do so, we replace the measure of distance to mangroves with the sum of distance to the coast and the component of distance to mangroves that is orthogonal to it.

One more potential confounding factor is the presence of man-made, or grey, flood protection infrastructure. To the extent that it does not vary much over time, property or ZIP code level fixed effects and FEMA flood risk designation are likely to capture it. Unfortunately, no systematic public data are available for us to control for grey infrastructure directly; thus, any time-varying effects of its presence on housing prices will appear in the error term. Potential bias can arise if the presence of grey infrastructure is correlated with mangroves. Given that the most likely correlation is negative, because grey infrastructure tends to be present where mangroves are not, the likely bias will be against us finding larger price declines for properties that are further away from the mangroves following hurricanes.

4.2 Housing Prices after Hurricanes

To confirm that housing prices are negatively affected by hurricanes, we first conduct a panel event study at monthly frequency. We line up our housing sales observations around the hurricane months in our data, and estimate 12 leads and 36 lags at monthly frequency,[17] with property fixed effects as follows:

$$log(P_{it}) = \sum_{s=-12}^{36} \beta_s + \delta_i + HPI_t + \epsilon_{it}, \tag{1}$$

where $log(P_{it})$ is the log of house prices, s is the index of monthly leads and lags, δ_i is a property fixed effect, and HPI_t is the monthly Case-Shiller housing price index for Florida that serves as a statewide trend of housing price fluctuations.[18] We repeat this estimation for a subset of properties with different distances to mangroves.

4.3 Benchmark Econometric Specification

We estimate the effect of mangroves on flood risk-related effects on the level and the dispersion of properties' sale prices. The benchmark specification of the hedonic regression is the following:

$$log(P_{it}) = \beta'(m_i \times H_t) + \delta_i + \delta_t + \epsilon_{it}, \tag{2}$$

where $log(P_{it})$ is the logarithm of sale price of property i in month t. m_i indicates mangroves distance group in which the property is located. The baseline group is within 2km of mangroves presence, and there are 4 additional groups: 2-4km, 4-8km, 8-16km, and more than 16km. H_t is a vector of indicators of whether house i is sold 1 or 2 years before, within the year after, or 2 or 3 years after a hurricane. For example, Hurricane Irma occurred in September of 2017, if a property is sold in October 2017, the "within the year after hurricane" indicator for that observation is 1. The specification includes property fixed effects δ_i to obtain estimates of within-property variation, identified by repeated sales. We also control for year-month fixed effects δ_t to account for common housing price dynamics and seasonality. Note that in this specification, the main effect of the mangroves distance group

[17]Note that the panel is very unbalanced since we are relying on transaction, not listing data.

[18]In this setting, we cannot include time fixed effects because they will absorb the effects of post-hurricane price dynamics.

is absorbed by property fixed effects since it does not vary over time, while the main effect of the components of H_t is absorbed by the time fixed effects. Standard errors are clustered on time to allow for correlation across properties.

4.4 Price Dispersion

To estimate the probability value at risk (pVaR) impact of mangroves, we need to also obtain a measure of price dispersion as a function of proximity to the mangroves in the aftermath of the hurricanes. To do so, we aggregate the property data to the ZIP code level and estimate the following regression of the price dispersion measure σ_{zt}/μ_{zt}, measured as the coefficient of variation of the sales price within a particular ZIP code (where σ_{zt} is the standard deviation and μ_{zt} is the average sales price of properties in ZIP code z in month t).

$$\frac{\sigma_{zt}}{\mu_{zt}} = \xi m_z + \beta'(m_z \times H_t) + \gamma' X_z + \delta_z + \delta_t + \epsilon_{zt}, \tag{3}$$

where m_z now represents median distance group of properties in ZIP code z to mangroves. In this regression, since we cannot include property fixed effects, we include ZIP code fixed effects δ_z and a vector of ZIP code level control variables X_z that includes average distance to coast, elevation, property age, building area square footage, and dummy variables for the property type: a single-family home or a condominium. We continue to include time fixed effects δ_t, which absorb the main effect of the hurricane indicators. Standard errors are also clustered on time to allow for errors to be spatially correlated in each month.[19]

4.5 Direct and Indirect Effects

After establishing the average effects of the mangroves distance, we allow for heterogeneous effects depending on whether a given county is on the path of hurricane or not. To do so, we create an indicator θ_{ct} for whether a hurricane that landed in year t moved through county c. We extend this definition to indicators of "before" and "after" the hurricane. We also create an "off-path" indicator for counties that were not hit by a given hurricane, $1 - \theta_{ct}$. We then split the interaction term in our regression 2 into two separate variables: one for "on-path" properties and one for "off-path" properties.

For the property-level regression we estimate

$$log(P_{it}) = \beta_1'(\theta_{ct} \times m_i \times H_t) + \beta_2'((1 - \theta_{ct}) \times m_i \times H_t) + \delta_i + \delta_t + \epsilon_{it}, \tag{4}$$

[19] In Robustness tests, we discuss the sensitivity of our results to different choice of fixed effects and standard error clusters.

similarly, for ZIP code level coefficient of variation equations we estimate

$$\frac{\sigma_{zt}}{\mu_{zt}} = \xi m_z + \beta_1'(\theta_{ct} \times m_z \times H_t) + \beta_2'((1-\theta_{ct}) \times m_z \times H_t) + \gamma' X_z + \delta_z + \delta_t + \epsilon_{zt}. \quad (5)$$

We interpret the effect we find for off-path counties as potential evidence of homebuyers' learning about the effects of mangroves protection on property values.

4.6 Price Level and Width of the Mangrove Forest

As Gijsman et al. (2021) point out, forest width is an important factor in mangroves' functionality in reducing flood risks.[20] Thus, we estimate

$$log(P_{it}) = \beta'(m_i \times H_t) + \gamma'(\omega_i \times H_t) + \rho'(\omega_i \times H_t \times m_i) + \delta_i + \delta_t + \epsilon_{it}, \quad (6)$$

where, as before, the main effects of the width of the mangrove forest ω_i and distance group as well as their interaction are absorbed by the property fixed effects δ_i. We use the measure of the inverse of the mangroves' width in meters.

5 Results

Before turning to our benchmark analysis, we document basic patterns in the data. First, we show that house prices decline following hurricanes, using the event study analysis (equation 1), then we show the effects of distance to mangroves on property prices, allowing for cross-sectional variation.

To show the effects of hurricanes on housing prices in our sample, we estimate a monthly panel event study regression with 12 leads and 36 lags (equation 1). We limit our analysis to medium flood risk properties and conduct our estimation separately for properties within 2km of mangroves, 2-4km, and 4-8km. The dependent variable is the log of property sales price and the dates are aligned around the hurricane events in our sample: Ivan and Jeanne (September 2004), Sandy (October 2012), and Irma (September 2017). Since we want to focus on the dynamic effects, we include property fixed effects in the regressions as well as the monthly Case-Shiller housing price index for Florida. Figure 4 shows the coefficients along with their 1 standard deviation error bands. We can see that for the properties near

[20] The importance of examining the width of the mangrove forest is supported by additional studies: del Valle et al. (2019) examines the impact of the width of the mangrove forest on economic activities; while Maza et al. (2021) shows that in conditions characterized by short waves, mangrove forest widths exceeding 300 meters are necessary to diminish incoming waves and surge by over 50%.

mangroves, there was no real decline in house sale prices relative to the HPI in the first year after a hurricane, while the decline in years 2-3 was 10-17 percent. For properties 2-4 km away from mangroves, hurricanes were followed by an average of 3-6 percent decline in property prices in the first year, and 17-26 percent decline in years 2-3. For properties 4-8 km away from mangroves, the price decline in the first year was 4-7 percent, and in years 2-3 it was 18-25 percent. Given these differences in dynamics across years, we separate the year-1 effect from the years 2-3 effect in our benchmark regression. Most importantly, we do see that prices decline by less for properties located near mangroves.

To document the effect of mangroves, we estimate a regression that does not include property fixed effects, allowing us to report the main effect of the distance to mangroves on housing prices, in addition to the mangroves' effect on mitigating housing price decline following hurricanes. To do so, we replace property fixed effects in our main specification (equation 2) with controls for property characteristics, including distance to the coast, elevation, property age, size, and type. The results are reported in Table 1. We can see that during normal times, properties further away from mangroves have higher prices than properties that are closer to them (once we account for all other property characteristics).[21] This is likely reflecting location effects on house prices since mangroves tend to concentrate further away from urban areas. We do, however, see that properties that are closer to mangroves (lower mangrove distance) experience smaller prices declines (have higher prices) following hurricanes — the effect we observed in the event study (Figure 4) and that we will confirm in our benchmark analysis. The unobserved differences between properties, such as the value of location, amenities, and other characteristics that might be correlated with distance to mangroves highlight the importance of relying on dynamic, within, variation in the data, that is, regressions with property fixed effects.

5.1 Benchmark Results: Price Levels and Price Dispersion

We first show the estimation results of mangrove effects on the level and dispersion of property sale prices, distinguishing between properties located in the counties on and off the hurricane paths in the aftermath of the hurricanes. We use point estimates to calculate the probability of losing 25% or more of property value following a hurricane as a function of property distance to the mangroves and translate the results into the willingness to pay for mangrove protection and restoration. We then extend our analysis to account for the intensive margin of the effect as measured by the width of the mangrove forest.

[21] Note that this is in contrast with raw prices that decline with distance to mangroves when we do not condition on anything (Figure A.3).

Throughout our analysis, we focus exclusively on properties located in the medium flood risk zone shown in Figure 3. The effect of mangroves on prices of high flood risk properties in the aftermath of hurricanes is distorted because of special policies and insurance rules that apply to such properties. For instance, if properties located in the high flood risk zone have federally backed mortgages or are financed by federally regulated lenders, they are required to have at least federal flood insurance (Federal Emergency Management Agency, 2025). While such mandatory insurance policy has the potential to protect homeowners against losses, it is also likely to distort property prices.[22]

With this institutional context, we conduct preliminary analysis and show the results of estimation from equation 2, disaggregated by the flood risk zones. In the low flood risk area, the effects of mangroves are not likely to be large or appreciated, since the risk of flood is low to begin with and is not likely to be reflected in housing prices. In contrast, in high flood risk areas, regulation requires mandatory insurance and imposes requirements on the design and construction of properties. In these areas, the effects of mangroves could be mitigated by other adaptation measures already taken, or housing prices may be distorted by insurance payouts or restrictions on sales and reconstruction of properties in the areas affected by the hurricanes.

The results are reported in Appendix Table A.4, where at least for the 1st year after hurricanes, for low- and high-risk areas, we do not detect differences in sale price differentials between properties close to mangroves versus those that are not. It helps to visualize these results as shown in Appendix Figure A.4 for the year following hurricanes, which plots the effects of mangroves on housing price change following hurricanes. We can see that the effect of mangroves is only transparent for the medium flood risk properties. For reasons suggested by the existing literature and our results, in the benchmark analysis, we rely on the estimates for medium flood risk properties.

Effect on the price level: property-level analysis. Table 2 reports the results of our benchmark estimation of the effects of mangroves on the level of property prices following hurricanes (equation 2). All regressions include year-month fixed effects as well as property fixed effects. To test for the pre-trends, we include separately an indicator of 1-24 months before each hurricane. To allow for different effects in the first year following the hurricane

[22]There is a small but growing literature that documents unintended consequences of insurance on housing affordability when areas become designated as high flood risk zones. For example, Blickle and Santos (2022) show that becoming designated as high risk potentially reduces mortgage origination, especially for lower-income borrowers; Sastry (2025) documents that banks are incentivized to shift the burden of risks to federal agencies and optimize their risk exposure by rationing credit through reducing the loan-to-value (LTV) ratio of mortgages, which results in the composition of borrowers shifting towards groups with higher credit scores or higher income.

(before insurance is normally paid), we separate an indicator of 0-12 months following the hurricane from 12-36 months after the hurricane. We first include these indicators individually and then together; all interacted with the index of distance to mangroves (the main effect of the hurricane indicator is absorbed by the time fixed effects). The main effect of distance to mangroves, as well as all property-specific characteristics, are absorbed by property fixed effects. The identification comes from price changes between repeated sales of the same property, relative to the monthly trend. In the last column, we also allow for the annual trend to vary by distance to mangroves.[23] The mangroves distance groups are labeled so that the larger the number, the more distant an individual property is from mangroves. Therefore, a negative coefficient on this measure means that the further the mangroves, the lower the house sale price is.

In the year of the hurricane and the two years that follow we observe that the price decline increases with distance to mangroves. We illustrate this effect in Figure 5 using our benchmark specification in column (4) of Table 2. We find that there are no pre-trends, except when we include mangroves distance-specific trends when we observe a positive pre-trend: that is, in pre-hurricane years, prices are higher for properties that are further away from mangroves. When allowing for trends to vary with mangroves distance, we find that prices grow more slowly for properties that are further away from mangroves. It is possible that persistent negative effects of hurricanes, which are more substantial for properties further away from the mangroves, contribute to these differential trends, as property owners and insurance providers learn about the disaster-protection value of mangroves. While our results show that trends in house prices differ with distance to mangroves, these differences might be reflecting actual effects we are trying to measure, and therefore we do not include them as controls in the rest of our analysis.

An important consideration with our benchmark analysis is a possibility that the effect of the distance to mangroves is contaminated by the effect of distance to the coast. Property fixed effects absorb the direct effect of the distance to the coast, but it is likely that the effect of hurricanes on house prices varies by the distance to the coast, which may bias our estimates of the effects of distance to mangroves. To evaluate the extent of this bias, we decompose the distance to mangroves into a portion that is explained by the distance to the coast and the orthogonal residual. We do so by estimating a regression of the mangrove distance index we use on distance to the coast (in km) for the sample of properties in our regression. We then re-estimate our benchmark regression, in which we replace mangrove distance index interaction with hurricane time indicators $m_i \times H_t$ by the distance to the coast interaction and residual interaction, $dc_i \times H_t$ and $\hat{m}_i \times H_t$. We find that, contrary to

[23]The results are similar if we allow for different trends for different mangrove distance bins rather than an interaction of trend with the categorical mangrove distance measure. Available upon request.

intuition, the prices of properties further away from the coast decline slightly more than for properties close to the coast. The effects of the residual interaction are slightly larger than in our benchmark analysis, have somewhat larger standard errors, but are not statistically different from the benchmark, as shown in Figure 6. Having addressed the concerns about possible contamination of the effects of mangrove distance with distance to coast, we proceed with our benchmark specification going forward.

Properties in counties on and off the hurricane path: property-level analysis. We separate the properties into two groups: those located in counties through which the hurricanes in question (Ivan, Jeanne, or Irma) passed directly, and the rest, as shown in Figure 2. We allow for the effect of the distance to mangroves following the hurricanes to be different for these sets of counties. Since we did not find pre-trends, we do not include them in the analysis.[24] Note that, as before, the main effect of hurricanes on property prices are absorbed by time fixed effects.[25] The results are reported in Table 3. Following the hurricanes, we find that the effects of mangroves protection are substantially larger for the properties located in on-path counties, both immediately following hurricanes and in the following two years. The effects are illustrated in Figure 7. The magnitude of the effect on prices of properties in off-path counties is about 30% smaller in the year of the hurricane and 2.5 times smaller in the following two years than for properties in on-path counties. These findings indicate that housing market participants learn about the protective nature of mangroves when their neighbors are affected by hurricanes, the damages are much more contained and therefore prices hold up much better for the properties that benefit from mangroves protection.

We use the estimated coefficients for the years 2-3 after the hurricane from column (3) in Table 3 to predict the shift of the empirical distribution of price changes due to the presence of mangroves for our pVaR and willingness to pay (WTP) analysis, separately for each hurricane and each county, to allow for the effect to vary based on the hurricane path.

Effect on price dispersion: ZIP code level analysis. Next, we estimate our ZIP code level regressions in equation 3 to obtain estimates of the effect of mangroves on price dispersion following hurricanes. We aggregate our data to ZIP code level for each month taking mean, standard deviation, and median of sale prices for each month and ZIP code, separately for single-family homes and condos. We calculate median distances to mangroves and to the coastline, median elevation, median property size and mean values of building

[24]Including pre-trends does not affect our results.

[25]Including a separate set of time fixed effects for counties on and off hurricane paths for specific hurricanes does not make any difference in the estimates. These results are available upon request.

code indicators in each ZIP code. We include these values as controls in the regressions along with time fixed effects and ZIP code fixed effects. We continue to cluster standard errors on time.

Our dependent variable is the unit-free coefficient of variation of house sale prices in a given month in a given ZIP code. The results are reported in Table 4. In all specifications, we find a positive and significant effect of higher distance to mangroves on the coefficient of variation in the aftermath of the hurricanes. That is, the proximity to mangroves attenuates price dispersion after hurricanes (shorter distance to mangroves means lower price dispersion).

When we break down the effect of hurricanes by counties that are on and off the hurricane path, we find that the increase in price dispersion for properties further away from mangroves is larger for the off-path counties but is also positive and significant for the on-path counties, in the year of the hurricane. In the two years that follow, the effect of mangroves on price dispersion is about the same in the counties on and off the hurricane path. We find that without controls or ZIP code fixed effects, a higher distance to mangroves on average is associated with lower price dispersion, but the sign flips once we include controls, and the coefficient becomes essentially zero once we also include ZIP code fixed effects. Note that the effects of controls also drop when we include ZIP code fixed effects, suggesting these do not vary much over time.

We will use the estimates for the years 2-3 after the hurricane from this last regression (column (4)) to predict the increase in dispersion of the price changes due to the presence of mangroves for our pVaR and WTP analysis. As a robustness test, we also estimated our benchmark price level regression at the ZIP code level and found results that are similar to the property-level regressions (See Table A.7).

To help interpret the results so far, we visualize the mangroves effects across space in Figure 8 of southern Florida, on which our data sample is based. The results from the regressions of the price level and dispersion reported in Tables 2 and 4, without differentiation by the hurricane path, provide the effects across mangrove distance groups: 0-2km, 2-4km, and so on. After hurricanes, the reduction of property sale prices becomes greater if the properties are further from the mangroves. Similarly, there is an increase in price dispersion as the distance to mangroves increases. Thus, the map shows that mangroves proximity has a price level as well as stabilization effects.

5.2 Heterogeneity across the width of the mangrove forest

We have shown that the overall effect of mangroves is to stabilize housing price following hurricanes. We now explore it further by focusing on one dimension of heterogeneity: conditional on the same distance of properties from mangroves, how does the width of the mangrove forest affect price declines following hurricanes? This dimension of heterogeneity is of particular interest because it has been demonstrated that mangroves width is important in providing protection from flooding and wind damage. To evaluate the effect, we are focusing on the interaction terms between the width of the mangrove forest and other key variables.

Estimating equation 6 with additional interaction terms for the flood risk indicators, we compute the marginal effect of different groups of mangrove forest width on the price level properties in medium flood risk areas 2 years following hurricanes, controlling for distance to the mangroves. Figure 9 presents a heat map of the effects of both mangrove distance and width 2 years after a hurricane for properties in the medium flood risk areas.[26] We find that properties near thinner banks of mangroves, such as those less than 20 meters wide, do experience a larger reduction in sale price after a hurricane. As the width of the mangrove forest increases, the price reduction becomes smaller.

In general, price declines following hurricanes are smaller for properties that are closer to mangroves and, holding the distance constant, for properties protected by wider belts of mangroves. In terms of magnitudes, when a property is located within 0-2km from mangroves, and such mangrove forest is between 20-30 meters wide, this property could be sold up to 10% higher in the aftermath of a hurricane than if the distance were 2-4km and the forest width were 10-20 meters. In fact, properties in close proximity to mangroves that are 30 or more meters wide do not experience a decline in housing prices 2 years following hurricane Ivan. As the heatmap shows, the effect of every 10 meters of reduction in mangrove forest width is likely equivalent in magnitude to the effect of an increase in distance to mangroves by 2km.

5.3 Probability Value at Risk

To make further sense of magnitudes and to account for potential benefits of mangroves protection and restoration in terms of the dispersion of housing prices, which is essential to evaluating private financial benefits of mangroves protection, we turn to the concept of value at risk, which is standard in evaluating risk properties of assets.

To illustrate the concept, we compute a change in the sale price of each property from the last transaction before a given hurricane to the first transaction in the 2nd year following the hurricane. Figure 10 shows the distribution of percentage price changes from before to after each hurricane across properties, by county. Given important housing market dynamics

[26] Full regression results on mangrove widths are available upon request.

during our sample, including a rapid increase prior to 2007 followed by the price collapse in 2008-09, we adjust these price changes by Florida-specific Case-Shiller U.S. National Home Price Index. For illustrative purposes, we select a 25% property loss value as a threshold for the value at risk. Red areas indicate the probability of a loss exceeding this 25% threshold, which is known as probability value at risk, or pVaR. For instance, for Charlotte county following hurricane Sandy, which did not even pass through Florida, there was a 41% probability of losing more than 25% of house value relative to the trend.

Next, we ask how this measure varies with the distance to mangroves. We already have the estimates for how the mean of distribution is affected by the distance to mangroves for counties on and off the hurricane path (column (3) Table 3) and also the effect on the second moment, measured by the coefficient of variation (column (4) of Table 4). Thus, we can adjust this empirical distribution of price changes for each hurricane and each county. We calibrate the distribution of price changes based for properties that are more than 16km from mangroves and for properties that are closer than 2km to mangroves. We then compare the difference in the probability of 25% value loss between properties with and without close mangroves protection.

Figure 11 shows the results by counties and hurricanes. It is evident that the presence of mangroves makes a difference in reducing the probability value at risk of property sale prices. In general, because of the flood risk reduction benefits of mangroves, the regions of significant property value losses (25% or more) are smaller for properties near mangroves than for those far away. In the most prominent cases of Collier or Hillsborough counties after Irma, the decline in pVaR is 7 percentage points. Notably, the effects are observed not only in the counties directly hit by the hurricanes but also in counties where perceived flood risk and perceived benefits of mangroves are affected by experience in the neighboring regions. Not surprisingly, these effects are smaller in magnitude.

5.4 Willingness to Pay

How do we translate pVaR estimated in the previous section to the amount of money those who benefit from mangroves protection should be willing to invest in it? We have to make some parametric assumptions.

Assume a Constant Relative Risk Aversion (CRRA) utility function

$$u(x) = \begin{cases} \frac{x^{1-\gamma}}{1-\gamma}, & \text{if } \gamma \neq 1, \\ \ln(x), & \text{if } \gamma = 1. \end{cases}$$

A homeowner who faces a choice of protecting and not protecting mangroves is essentially facing potential hurricane effects that bring the same losses but with different probabilities (lower probability in case of mangroves). We can simplify our analysis by assuming a binary lottery (no loss vs. 25% loss of value) and use our empirical estimates to calculate willingness to pay for the reduction in the probability of a 25% loss.

Thus, without mangroves, the expected utility will be

$$\mathbb{E}[u(W_N)] = (1 - p_N)u(W) + p_N\, u(0.75\, W)$$

W is the value of the property before the hurricane, and p_N is the probability of losing 25% of this value as a result of the hurricane in the absence of mangroves.

The certainty equivalent of this lottery is

$$CE_N = \begin{cases} ((1 - p_N)W^{1-\gamma} + p_N(0.75\, W)^{1-\gamma})^{\frac{1}{1-\gamma}}, & \text{if } \gamma \neq 1, \\ W^{1-p_N}(0.75\, W)^{p_N}, & \text{if } \gamma = 1. \end{cases}$$

Similarly, for the case with mangrove protection,

$$\mathbb{E}[u(W_M)] = (1 - p_M)u(W) + p_M\, u(0.75\, W)$$

where $p_M < p_N$ is the pVaR with mangrove protection.

$$CE_M = \begin{cases} ((1 - p_M)W^{1-\gamma} + p_M(0.75\, W)^{1-\gamma})^{\frac{1}{1-\gamma}}, & \text{if } \gamma \neq 1, \\ W^{1-p_M}(0.75\, W)^{p_M}, & \text{if } \gamma = 1. \end{cases}$$

The willingness to pay for mangrove protection will then be

$$WTP = CE_M - CE_N.$$

The results of these calculations are reported in Figure 12. We can see that for cases such as Hillsborough county following hurricane Irma, where the probability of losing 25% of house value is 22 percent for properties not protected by the mangroves, and drops by 7 percentage points for properties near mangroves, the owner (or the insurer) of the 1-million-dollar property should be willing to pay 80 thousand dollars for mangroves protection and restoration, conditional on the hurricane exposure.[27] On average, we observe 3-4 percentage

[27]We stop short of calculating the present-value, unconditional willingness to pay, because such calculation would require incorporating beliefs about local impacts of various climate scenarios and related beliefs and

points decline in the probability of losing 25% or more of the house value due to the presence of mangroves, which, depending on the initial loss probability, corresponds to 20-40 thousand dollars WTP, conditional on a hurricane occurrence, for a 1-million-dollar property, depending on initial loss probability. As Appendix Figure A.5 shows, the amounts will be higher with a lower CRRA coefficient γ and for a lower loss threshold.

6 Robustness Tests

We have conducted an analysis of alternative specifications to check for robustness of our benchmark analysis.[28]

Disaggregation by individual hurricanes. In the benchmark we use the measure of generalized major hurricane events. As a robustness check, we repeat the estimation in equation 2, but with indicator variables of Ivan, Sandy, and Irma included (instead of the aggregate hurricane variable). The results are generally consistent with Table 2. Table A.5 shows the estimations in which each hurricane is included separately, and we also use 1-year intervals following hurricanes (up to 2 years). We see that our results are primarily driven by hurricanes Ivan and Irma, which is not surprising given that hurricane Sandy did not land in Florida.

Price per square foot. Another concern is heterogeneity of property sizes. So far, we have only considered the effects of mangroves on the overall sale prices of properties. In our benchmark specification, the direct effect of property size on price is absorbed by the property fixed effects, and in the aggregate regressions, we control for the property square footage. That said, it is worth verifying that property heterogeneity is not affecting our results. Table A.6 shows the results of mangroves' effect on the price per square foot. The signs of the coefficients are largely consistent with the specification in which the dependent variable is the overall price.

Specification, subsample, and clustered standard errors. The benchmark results are also robust to alternative specifications and to the analysis of different subsamples. Table A.7 shows that our price level results also hold if we aggregate the data to the ZIP code level and include the same set of controls as we included in the price dispersion equation. Returning

perceptions. We leave this for future research.

[28]In Table A.1 which is a descriptive table of the sample underlying the benchmark estimation, we also show that the results are not driven by after-hurricane composition changes such as the counts of transactions.

to property-level analysis, Table A.8 shows, by including the number of sales as analytical weights, that our results are not driven by properties that are sold more frequently than average.

In our benchmark analysis, standard errors are clustered on time, which allows for cross-section correlation of property prices in each time period. This is necessary given that hurricanes are the shocks that only vary over time. In addition, we estimated regressions in which we allow for over-time and cross-section correlation of property prices for given geographies. The results remain significant if we limit cells to census tracts. However, the precision of estimation drops when we cluster at ZIP code or county level, in addition to time, which substantially reduces degrees of freedom. When we limit correlation to these geographies within a given time period, however, the precision of estimates increases (columns (1)-(4) of TableA.9).[29]

In our benchmark analysis, we include time and property fixed effects. We test whether adding a geography-specific time fixed effects make a difference. We find that as long as the definition of geography is not very broad, at the census tract level, our results remain qualitatively the same, although reduced in magnitude. Adding a broader geography by time fixed effects does alter the results, most likely because these fixed effects absorb the time-varying effects of mangroves, which are spatially concentrated (columns (5)-(6) of TableA.9).

Additionally, since our sample covers years that include the 2008 Financial Crisis, there could be concerns about the sensitivity of the results. To address this, we repeated the benchmark estimation by excluding observations for years 2007 to 2009, and the results are shown in Table A.10. There are no meaningful differences with the benchmark.

Additional controls: insurance and climate beliefs. We also test whether benchmark results may change if we include controls that are not captured by property fixed effects or time fixed effects. We collected data from FEMA's National Flood Insurance Program (NFIP) and from Yale Climate Belief data. Ex ante, it is unclear whether flood insurance, as a tool for climate adaptation, may offset or amplify the effect of mangroves. We have included the variable of ZIP code-level flood insurance coverage (lagged by 1 year) into the benchmark regressions.[30] Table A.11 shows that the inclusion does not change the benchmark results, and the coefficients of NFIP insurance coverage are generally null.

Beliefs have been shown to affect the extent to which nature risks, especially flood risks,

[29] Results for county-level clustering and county-time fixed effects are omitted because they are similar to those with ZIP code.

[30] We cannot merge the NFIP data to our sample at property level, since the public version of NFIP data does not identify specific properties.

are reflected in housing prices (Baldauf et al., 2020). From the Yale Climate Belief data, we have chosen the variable measuring the degree to which people in a county believe that climate change will harm them personally. It is important to note that the belief data we have access to starts from 2014, and the resulting sample is a subset of the benchmark sample. The results are reported in Table A.12. In terms of the mangrove-related coefficients, we do not find significant differences in terms of the direction of impact with the benchmark results. In relation to the belief variable, it does not appear significant in Table A.12. In short, climate beliefs heterogeneity, at least as measured by the Yale Climate Belief survey, does not affect the relationship between mangroves and housing prices.

7 Conclusion

Preserving nature and biodiversity should be one of the foremost concerns of policymakers worldwide. The problem with financing the preservation and restoration of nature and biodiversity, however, is their quintessential public good nature. Unfortunately, governmental and non-profit resources are not sufficient for the needed investments. Thus, it is key to attract private capital to finance the preservation of these resources. Attracting private capital requires quantification of private benefits of natural resources so that a case can be made for structured financial instruments and public-private partnerships as well as public policies and investments. One such benefit of nature is its contribution to reducing climate-related risks.

While nature-based climate adaptation solutions have been shown in natural sciences and engineering literature to have flood risk reduction benefits, there are limited studies that explicitly measure the financial value of such benefits with market-based evidence. In this paper, we help fill the gap by demonstrating the financial benefits of mangroves in stabilizing property values following hurricanes. Using the Florida housing market as the study setting, we identify the mangrove effect by comparing the effect of hurricanes on sale prices of properties close to mangroves versus those that are not. We find that on average, after a major hurricane, properties 2-4km away from mangroves experience a loss of around 3 percentage points larger than properties near mangroves. This difference increases even more (to 17 percentage points) when properties are 8-16km away from mangroves. Moreover, mangrove presence reduces price dispersion following hurricanes. These changes result in 3-4 percentage points on average and as much as a 7 percentage points reduction in the probability of losing more than 25% of the property value following a hurricane. This is a substantial benefit of mangroves presence to property owners and insurers. Conditional on a hurricane hitting the property, this translates into 20-40 thousand dollars on average and as much as 60 thousand dollars on a 1-million-dollar property, depending on the initial risk of value loss. An owner or insurer of a 1-million-dollar property, in this case, would be willing to pay the amount that corresponds to the present value of this amount weighted by their subjective probability of being hit by a hurricane in the future for preserving or restoring mangroves nearby.

Additionally, we take into consideration how the effect can vary by the width of the mangrove forest. In coastal engineering studies, wider belts of mangroves have been found to be important in reducing wave and surge impact. Our analysis finds that properties close to wider mangrove forests experience greater price stabilization benefits after hurricanes. The results demonstrate the financial benefits of restoring mangroves on the intensive margin.

These private financial benefits of mangroves are only one component of their overall benefits to flood reduction, ecosystem services, and biodiversity. We do not conduct a full cost-benefit analysis of mangrove protection and restoration, but our results are important in demonstrating private benefits that may help secure private funding of mangrove protection and restoration efforts, as well as inform policy decisions on the best management of wetlands for homeowners and the funding for wetland conservation and restoration.

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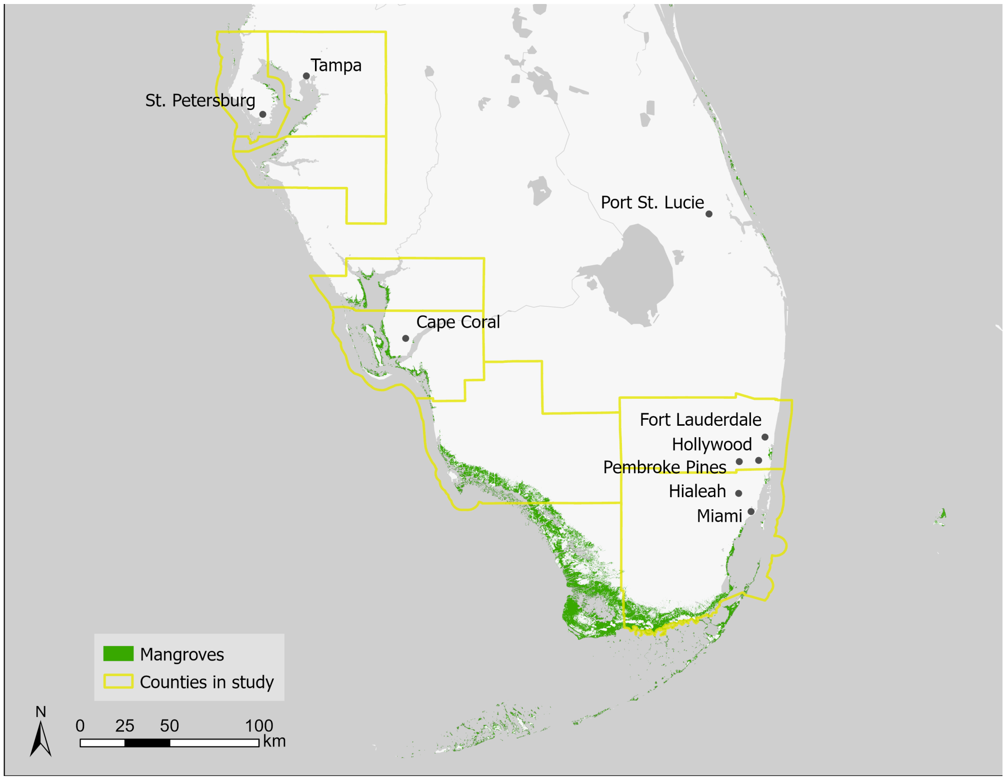


Figure 1: Mangroves Distribution in Florida: select counties in 2020
Source: Global Mangrove Watch (Bunting et al., 2018, 2022).

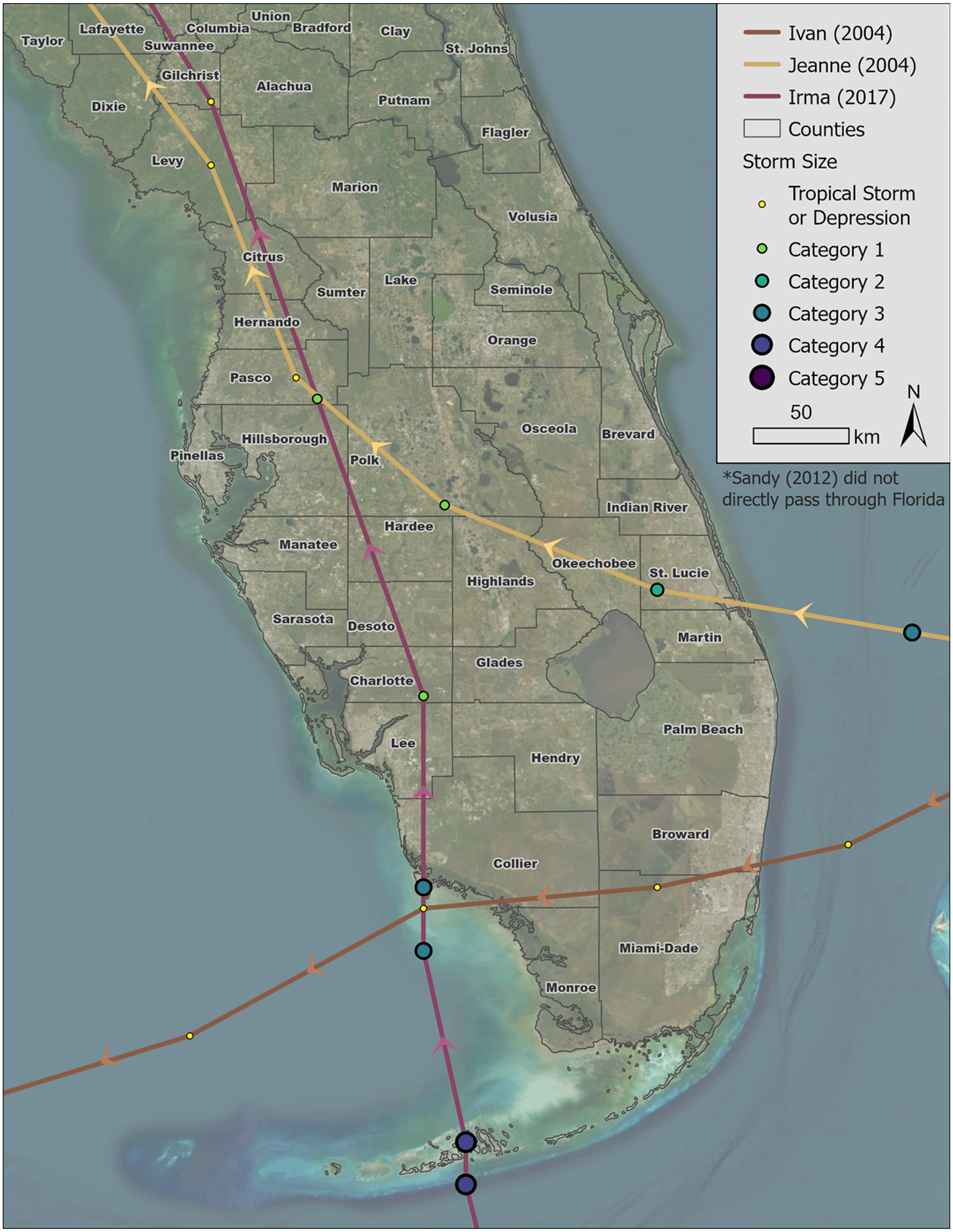


Figure 2: Hurricane Paths during Sample Period
The graph illustrates the paths of hurricanes examined in this paper.
Sources: National Hurricane Center, NOAA; North Carolina Institute for Climate Studies.

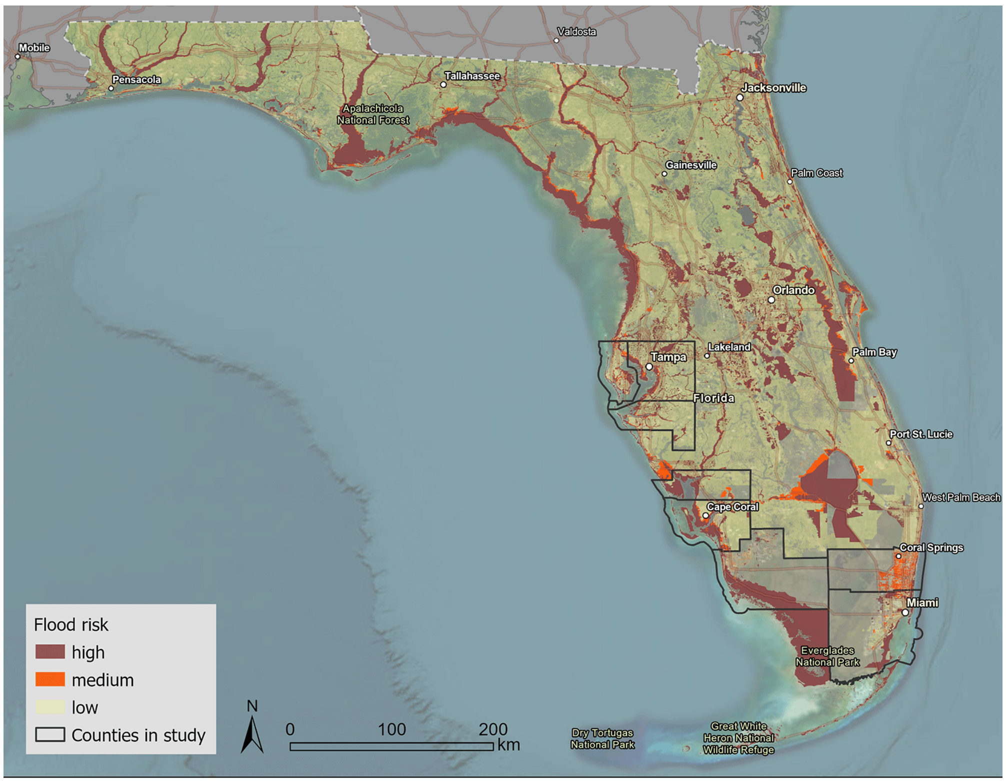


Figure 3: FEMA Flood Risk Map: Year 2020
Risk from the associated flood zones from FEMA Flood Hazard Layer in 2020.

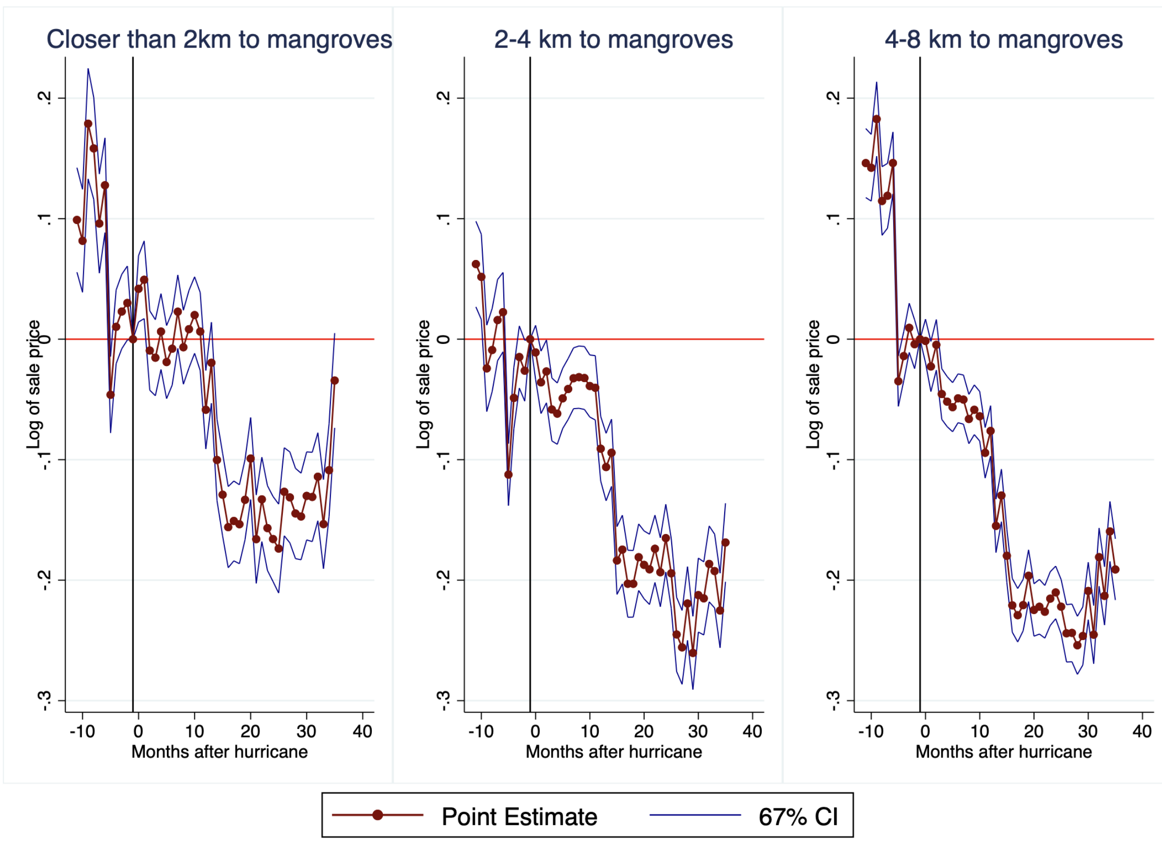


Figure 4: Housing Prices Following Hurricane Season: event study
The figures show the coefficients and 1-standard error bands (67% confidence intervals) for each month of lags and leads of the regression of log property sales prices on Florida HPI, set of lags and leads for the month of each hurricanes in the sample, and property fixed effects (equation 1). The regressions are estimated separately for properties located within 2km of mangroves, 2-4km, and 4-8km. Only properties in medium flood risk area are included. The monthly Florida HPI data are mean values of indices for Miami and Tampa metro areas: S&P CoreLogic Case-Shiller FL-Miami Home Price Index (MIXRNSA) and S&P CoreLogic Case-Shiller FL-Tampa Home Price Index (TPXRSA).

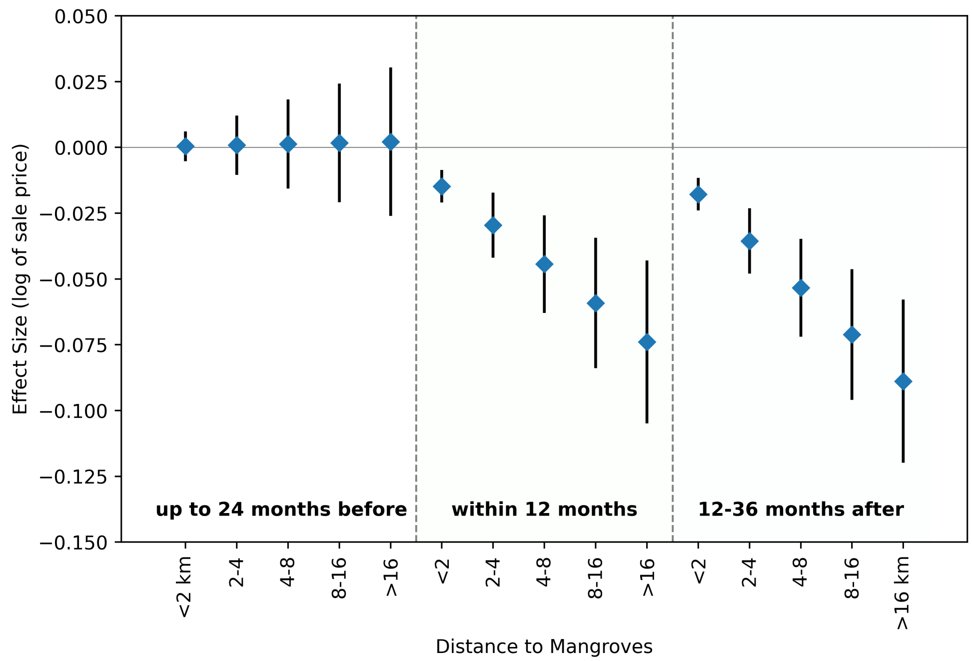


Figure 5: Mangroves Effects on Housing Sale Prices Following Hurricanes
The horizontal axis shows the distance (in kilometers) between properties and mangroves. Plotted are coefficients and standard errors from column (4) of Table 2 that estimates equation 2 multiplied by the values of mangrove distance index m_i, which takes on values of 1 for 0-2km distance, 2 for 2-4km distance, etc.

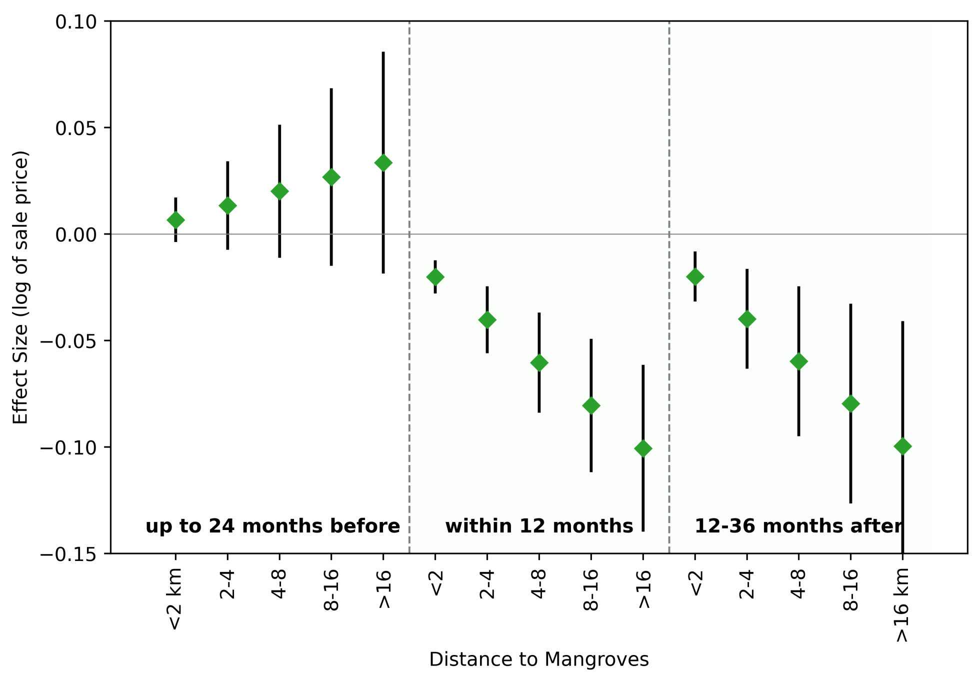


Figure 6: Mangroves Effects on Housing Sale Prices Following Hurricanes: Measure Orthogonal to Distance to Coast
The horizontal axis shows the distance (in kilometers) between properties and mangroves. Plotted are the coefficients and standard errors from the estimations $log(P_{it}) = \beta'(\hat{m}_i \times H_t) + \delta_i + \delta_t + \epsilon_{it}$ multiplied by the values of mangrove distance index m_i, which takes on values of 1 for 0-2km distance, 2 for 2-4km distance, etc.

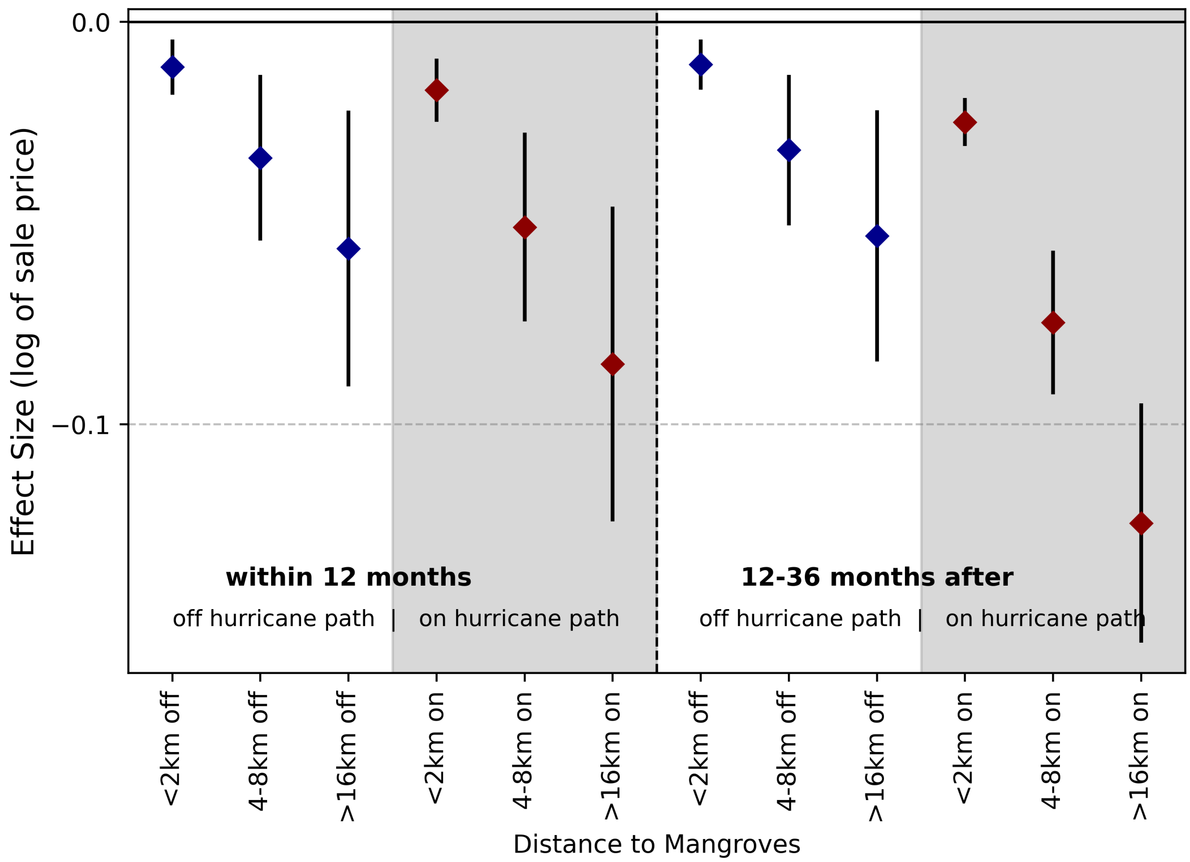


Figure 7: Mangrove Effects on Housing Sale Prices Following Hurricanes, On-/Off-Path
The horizontal axis shows the distance (in kilometers) between properties and mangroves. Plotted are coefficients and standard errors from column (3) of Table 3 that estimates equation 4 and differentiates between counties on and off the hurricane paths, multiplied by the values of mangrove distance index m_i, which takes on values of 1 for 0-2km distance, 2 for 2-4km distance, etc.

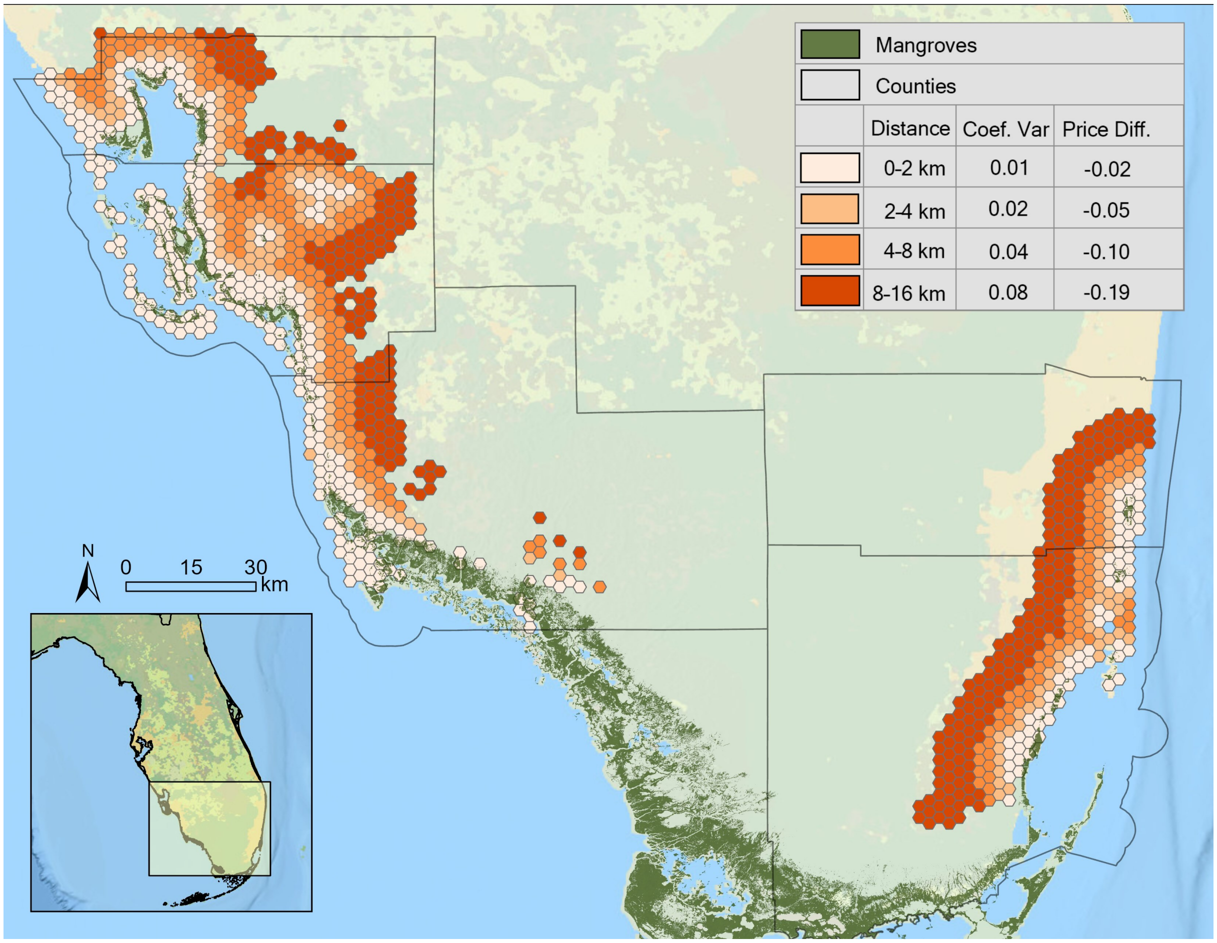


Figure 8: Mangroves Stabilize Housing Sale Prices Following Hurricanes
Each hexagon represents an area with 5km of diameter, in which there are housing transactions as reported by the ZTRAX dataset. We interpolate the effects of distance to mangroves into 1km grid to calculate average effect on price level and dispersion for each hexagon. The numbers are linear interpolations from estimates reported in Table 2 column (4) and Table 4 column (3). Closer proximity to mangroves results in smaller sale price reductions following a hurricane. "Coef. Var" refers the price dispersion reduction effect of mangroves. Closer proximity to mangroves results in smaller sale price volatility following a hurricane. The reference baseline case is a property with nearly 0km distance to mangroves.

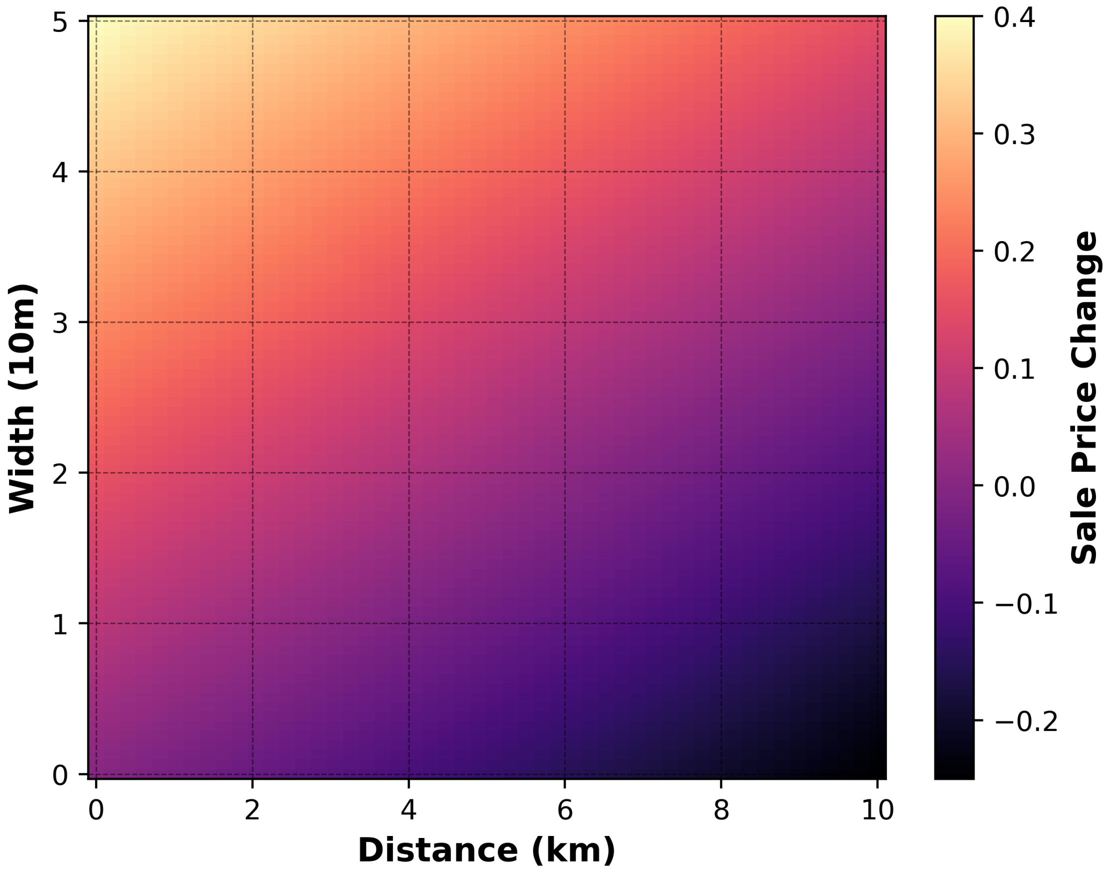
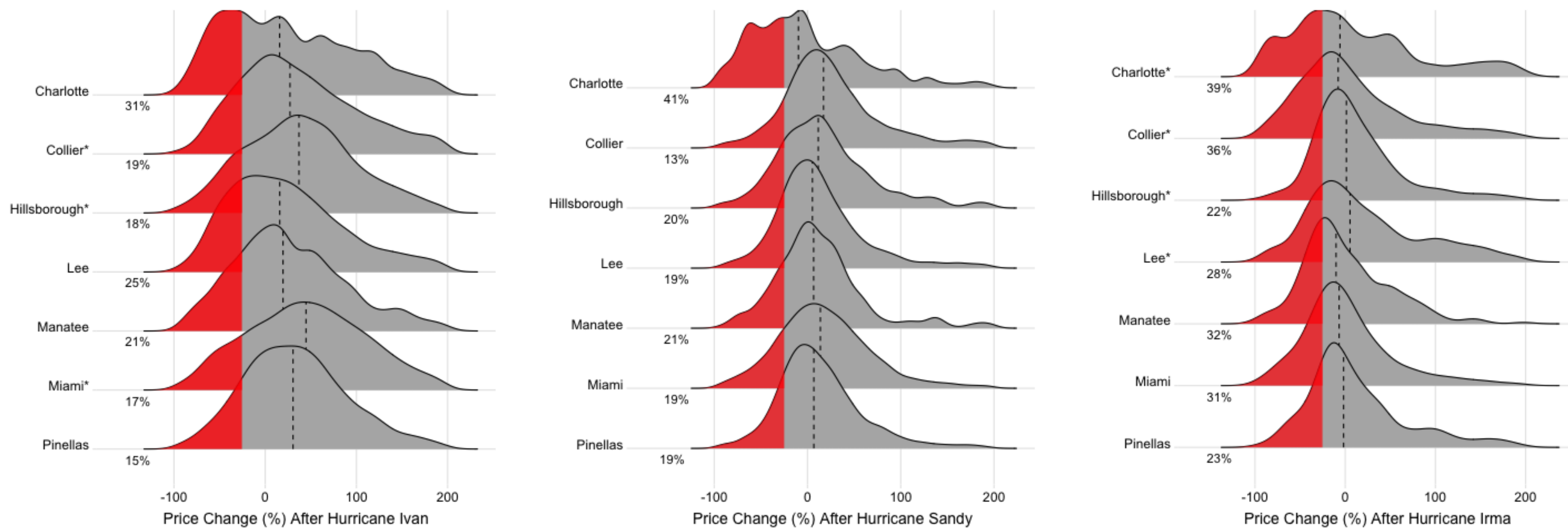
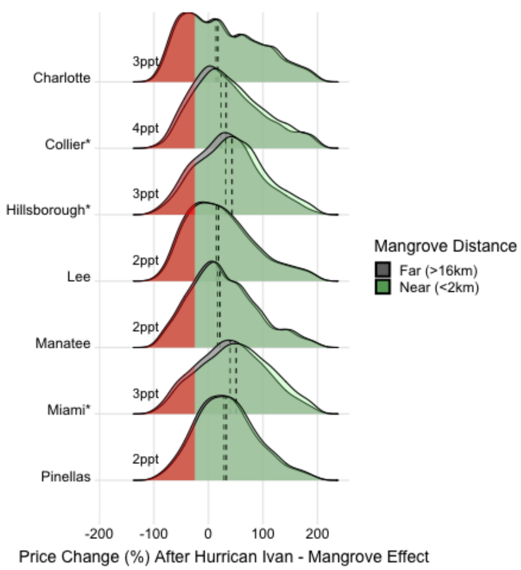


Figure 9: Effect of Mangroves Distance and Width on Sale Price, Medium Risk Areas
Proximity to mangroves in combination with greater mangrove width generally results in more positive sale price changes following hurricanes. Results are based on estimation for Hurricane (year 2) for on-path counties in medium risk areas in Table 3, and a linear combination of mangroves distance (interact with hurricane) coefficient and mangroves width 10m coefficient, estimated from equation 6. We choose coefficient for mangroves with 10 meter width because it is at the lower end of mangroves width empirical distribution, namely a lower threshold to meet in order for the width benefits to take effect. The y-axis is in 10-meter increments. The unit of measurement of effect here is the log of sale price.

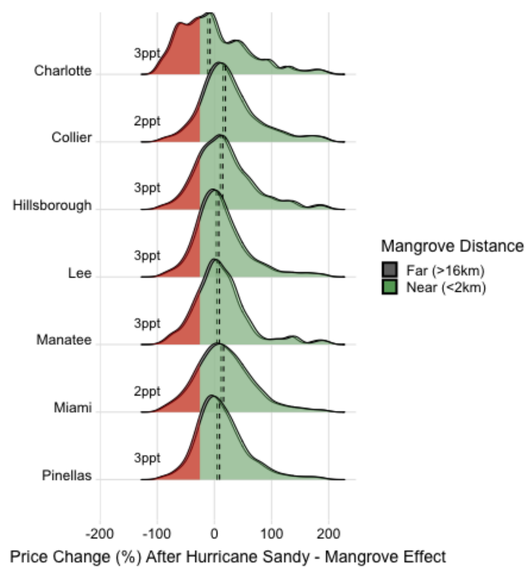


Ivan (2004) Sandy (2012) Irma (2017)

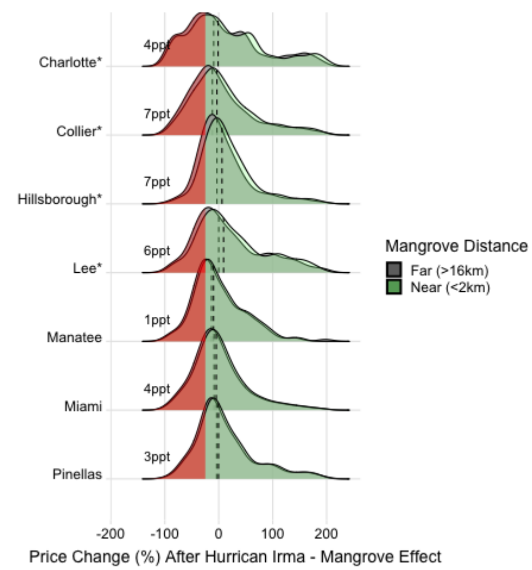
Figure 10: Probability Value at Risk after Hurricanes
County names with asterisks refer to those on the hurricane path. Dashed lines are median values. Price changes of properties in FEMA-designated medium flood risk zones, adjusted using Florida-specific Case-Shiller U.S. National Home Price Index. The effect refers to the 2nd year after the hurricanes. The red region refers to a loss of 25% or more, and numbers underneath show the cumulative density of this region, which is the probability value at risk.



Ivan (2004)



Sandy (2012)



Irma (2017)

Figure 11: Mangroves Reduce Probability Value at Risk after Hurricanes
County names with asterisks refer to those on the hurricane path. Dashed lines refer to median values. Price changes of properties in FEMA-designated medium flood risk zones, adjusted using Florida-specific Case-Shiller U.S. National Home Price Index. The red region refers to a loss of 25% or more. Numbers just above indicate the reduction in the probability value at risk (cumulative density of the area is lower for a distribution of property price changes near mangroves). We shift and rescale the distributions by factoring in the effects from Tables 3 and 4.

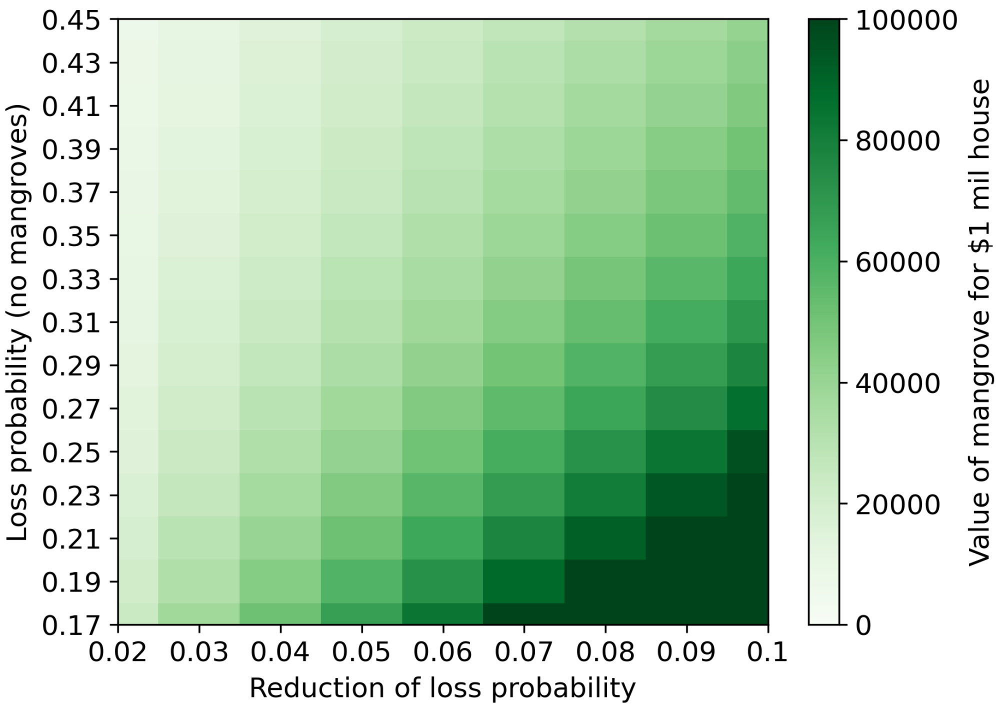


Figure 12: Willingness to pay for mangrove risk reduction
Willingness to pay for reducing the probability of losing 25% of housing value following hurricanes. Calculations assume CRRA utility function with $\gamma = 3$. For instance, as in Hillsborough county following Irma, if the pVaR is 22% (vertical axis), and mangroves reduce the probability of loss (horizontal axis) by 7 percentage points, the willingness to pay for mangrove protection of a 1-million-dollar property is $80,000.

Table 1: Effect of Mangroves on House Sale Prices after Hurricanes

	Dependent variable is Log(Sale Price)			
	(1)	(2)	(3)	(4)
Mangrove Distance	0.036***	0.036***	0.037***	0.043***
	(0.004)	(0.004)	(0.004)	(0.004)
Mangrove Distance ×	-0.006*			-0.008*
I(2 years before hurricane)	(0.003)			(0.004)
Mangrove Distance ×		-0.012***		-0.014***
I(1 year after hurricane)		(0.003)		(0.004)
Mangrove Distance ×			-0.018***	-0.025***
I(2-3 years after hurricane)			(0.003)	(0.004)
Distance to Coast	-0.028***	-0.028***	-0.028***	-0.028***
	(0.001)	(0.001)	(0.001)	(0.001)
Elevation	-0.072***	-0.072***	-0.072***	-0.072***
	(0.003)	(0.003)	(0.003)	(0.003)
Property Age	-0.008***	-0.008***	-0.008***	-0.008***
Property Square Footage	0.000***	0.000***	0.000***	0.000***
Single family house (=1)	0.091***	0.091***	0.091***	0.090***
Condo (=1)	-0.470***	-0.470***	-0.471***	-0.471***
R^2	0.342	0.342	0.342	0.342

The negative coefficients of the interaction variables means that closer proximity to mangroves results in smaller sale price reduction following a hurricane. Results estimated from a specification similar to equation 2 but with property fixed effects replaced with property characteristics: $log(P_{it}) = \beta_0 m_i + \beta_1'(m_i \times H_t) + \gamma' Z_i + \delta_t + \epsilon_{it}$ for medium flood risk properties in the data, where Z_i is a vector of property characteristics, as indicated. This estimation is at property level. Standard errors are in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Number of observations in all regressions is 962529.

Table 2: Effect of Mangroves on House Sale Prices after Hurricanes: Controlling for Property Fixed Effects

	Dependent variable is Log(Sale Price)				
	(1)	(2)	(3)	(4)	(5)
Mangrove Distance ×	0.001			0.000	0.013***
I(2 years before hurricane)	(0.002)			(0.003)	(0.003)
Mangrove Distance ×		-0.009***		-0.015***	-0.013***
I(1 year after hurricane)		(0.002)		(0.003)	(0.003)
Mangrove Distance ×			-0.014***	-0.018***	-0.003
I(2-3 years after hurricane)			(0.003)	(0.003)	(0.003)
Trend × Mangrove Distance					-0.002***
					(0.000)
R^2	0.714	0.714	0.714	0.714	0.714

Equation 2 estimation results for medium flood risk properties in the data. Year × month and property fixed effects are included in all regressions. Robust standard errors clustered on time are in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Number of observations in all regressions is 1171460.

Table 3: Effect of Mangroves on Prices after Hurricanes: Accounting for Hurricane Path

	Dependent variable is Log(Sale Price)		
	(1)	(2)	(3)
Mangrove Distance × I(1 year after hurricane)			
On hurricane path	-0.011***		-0.017***
	(0.003)		(0.004)
Off path	-0.006*		-0.011***
	(0.003)		(0.003)
Mangrove Distance × I(2-3 years after hurricane)			
On hurricane path		-0.021***	-0.025***
		(0.003)	(0.003)
Off path		-0.007**	-0.011***
		(0.003)	(0.003)
R^2	0.714	0.714	0.714

Equation 4 estimated for medium flood risk properties in the data. Year × month and property fixed effects are included in all regressions. Robust standard errors clustered on time are in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Number of observations in all regressions is 1171676.

Table 4: Effect of Mangroves on Price Dispersion after Hurricanes

	Dependent variable is coef. of variation of sales price			
	(1)	(2)	(3)	(4)
Mangrove Distance ×	0.009***	0.003	-0.001	
I(2 years before hurricane)	(0.002)	(0.003)	(0.003)	
Mangrove Distance ×	0.006*	0.010**	0.010**	
I(1 year after hurricane)	(0.002)	(0.003)	(0.003)	
Mangrove Distance ×	0.011***	0.009**	0.008*	
I(2-3 years after hurricane)	(0.003)	(0.003)	(0.003)	
Mangrove Distance × I(1 year after hurricane)				
On hurricane path				0.005
				(0.004)
Off path				0.013*
				(0.004)
Mangrove Distance × I(2-3 years after hurricane)				
On hurricane path				0.008**
				(0.003)
Off path				0.007**
				(0.003)
Mangrove Distance	-0.010***	0.005**	0.002	0.003
	(0.002)	(0.002)	(0.005)	(0.005)
Median distance to the coast		-0.004***	0.002	0.002
Median elevation		0.022***	-0.002	-0.002
Median property age		0.001***	0.000*	0.000*
Median property size		0.000	0.000	0.000
Residence type indicators	Yes	Yes	Yes	Yes
Year × Month Fixed Effect	Yes	Yes	Yes	Yes
Zipcode Fixed Effect	No	No	Yes	Yes
R^2	0.023	0.139	0.226	0.227
Observations	76559	45063	45060	45060

Dependent variables—coefficient of variation of sale prices at ZIP code level. Results estimated from equation 3 for the overall results and equation 5 for the effect by path, and include controls for ZIP code level aggregates of property characteristics. Robust standard errors clustered on time are in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

A Appendix

Appendix A.1 Mangroves Illustrations

Figure A.1: A typical coastal mangrove forest
Photo used under CCL from wikimedia.

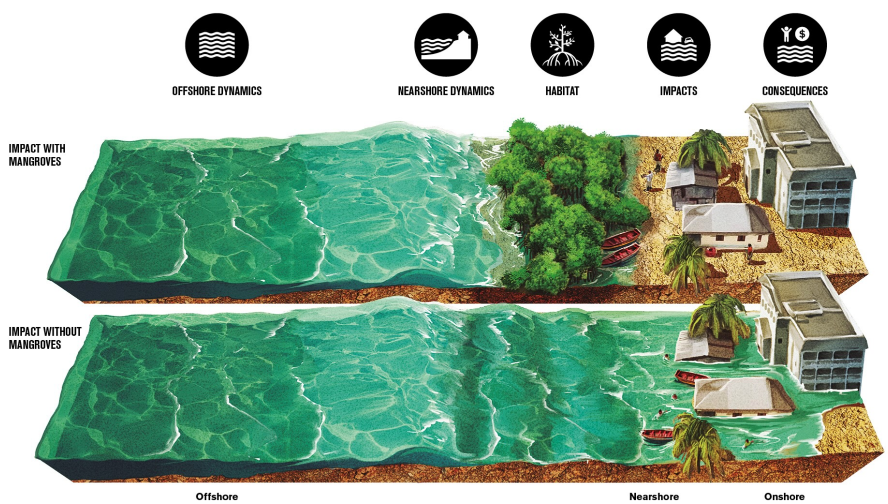


Figure A.2: Illustration of the protective effect of mangroves
Photo used under CCL from ("Forces of Nature: Coastal Resilience Benefits of Mangroves in Jamaica")

Appendix A.2 Descriptive Results

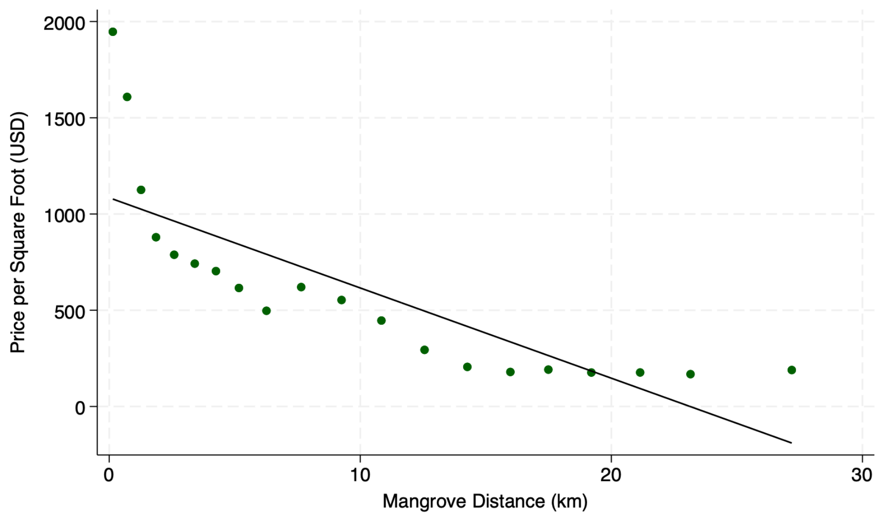


Figure A.3: Bin scatterplot of Housing Price per Square Foot and Mangroves Distance
Controlling for Florida-specific home price index, specifically mean values of S&P CoreLogic Case-Shiller FL-Miami Home Price Index (MIXRNSA) and S&P CoreLogic Case-Shiller FL-Tampa Home Price Index (TPXRSA).

Table A.1: Transactions and Unique Properties by Distance-to-Mangroves Bin and Hurricane Window

	Years 2–3 (Pre)		Year 1 (Post)		Years 2–3 (Post)		Non-hurricane years	
Distance bin	N sales	N props	N sales	N props	N sales	N props	N sales	N props
0–2 km	20,814	13,972	11,329	8,870	16,209	11,621	36,225	19,205
2–4 km	34,807	23,187	19,645	15,070	27,371	19,126	57,932	31,232
4–8 km	52,474	34,347	29,358	22,360	44,830	30,518	91,469	47,030
8–16 km	78,896	54,430	43,336	34,223	69,492	48,610	159,398	85,229
16+ km	84,597	59,651	45,523	36,419	67,497	49,335	180,258	95,118

Notes: Summary table of underlying data in Table 2. Count of number of sales (N sales) and number of properties (N props). "Years 2–3 (Pre)" = sales in the 2–3 years before a hurricane; "Year 1 (Post)" = sales in the year of the hurricane; "Years 2–3 (Post)" = sales in years 2–3 after the hurricane; "Non-hurricane years" = sales outside all defined hurricane windows.

Appendix A.3 Data Details

We have used a variety of data sources to evaluate the effects of mangroves distance and width on housing transaction prices. More specifically, as shown by Table A.2, there are 3 main types of data: 1. housing; 2. mangroves distance and width; 3. flood risk zones. All

Table A.2: Data source table

Data type	Scale or Resolution	Coverage	Years	Source
Houses	Interpolated property address	Florida	1993-2019	ZTRAX
County lines	7.6 foot accuracy	National	2016	TIGER
Elevation map	10 meter cells	Florida	2022	USGS
Coastline	167 foot accuracy	National	2018	USGS
Mangroves	30 meter cells	Global	1996-2020	GMW
Flood risk zones	60 foot accuracy	National	2020	FEMA
Mangroves width	2.22e-4 degree cells	National	2020	GMW

geo-processes are completed in ArcGIS Pro (v3.1.0) using Python. The process is a batch run spatial analysis that adds landscape attributes to each Zillow housing transaction in this study. The attributes gathered include housing elevation, distance to mangroves, and distance to coastlines. The ArcPy library (v3.1) provides functions to convert a table of the transaction data into spatially explicit points based on their latitude and longitude, spatially joining these points to landscape attributes, and export the tabulated results.

Housing. Zillow transactions tables contain sale details and locations for the sold homes in the study area from 1993 to 2019. County geographic data are from the 2020 year Census, and enable us to group transactions by county (U.S. Census Bureau, 2022). Elevation data from the USGS 3D Digital Elevation Program was from U.S. Geological Survey (2020). Housing data was converted into mapped points using the display X, Y data function using their latitude and longitude fields (WGS84). These houses were intersected with county linework using a spatial join between houses that are within a county polygon (U.S. Census Bureau, 2022). Elevation data was joined with the transactions using the raster to points function. For monthly housing price index data, we use the mean values of indices for Miami and Tampa metro areas: S&P CoreLogic Case-Shiller FL-Miami Home Price Index (MIXRNSA) and S&P CoreLogic Case-Shiller FL-Tampa Home Price Index (TPXRSA).

Mangroves Distance. Global Mangrove Watch data included 30-meter resolution mangroves coverage for select years between 1996 and 2020 (Bunting et al., 2022). This mangroves feature describes presence and absence to help researchers identify coverage changes. The National Hydrography Dataset by U.S. Geological Survey (2018) contains detailed information for all records where the parent feature was coastline ($PARENT_FEA$ = Coastline). The distances between each housing transaction and landscape level attributes was calculated with a spatial join. These spatial joins recorded the geodetic distance between a housing feature and the closest mangroves and coastline feature. All this information was exported as a table for subsequent analysis outside ArcGIS Pro using the export table function. An overview of the complete workflow (in diagrams) is available upon request.

Mangroves Width. In the literature, mangrove widths have been calculated as either the length of mangroves covering the shortest distance from a community to the coastline (Del Valle et al., 2020; Das and Vincent, 2009; De Dominicis et al., 2023), the mangroves area normalized by coastline length(Hochard et al., 2021), or the mean cross-shore mangroves width (Heatherington and Bishop, 2012; Montgomery et al., 2018). Engineering studies (De Dominicis et al., 2023) use mangroves width measures between communities and coastline because it predicts storm surge and inundation mitigation. These measures vary according to the direction of the storm to obtain the corresponding mangrove width between a house and the coastline, which can change considerably between events. Our approach focuses on the widths of mangroves closest to a property, as this characterizes width more broadly among all storm events. An overview of the complete workflow (in diagrams) is available upon request.

Flood Zones Flood zones are collected from the FEMA Flood Hazard Layer(Federal Emergency Management Agency, 2020). Properties in this study are classified into three categories of flood risk, low, medium, high, based on their flood zone and its subtypes (as defined by FEMA's flood zone data table). High risk category is 100-year floodzone, as indicated by a flood zone of AE or VE, and low risk areas is designated as a zone of "Area of Minimal Flood Hazard". Medium areas contain all other flood zones in the sample.[31]

Appendix A.4 Temporal Variation of Mangroves

Table A.3: Change (%) in Property-Mangroves Distance (1996 through 2020)

Percentile	Max year to year change (%)	Longitudinal Change (%)
5th Percentile	0	0
25th Percentile	0	0
50th Percentile (Median)	0	0
75th Percentile	0.08	0.02
95th Percentile	2.5	1.9
Mean	1.1	1

[31] Other flood risk data sources are available, but regulation relies on FEMA classification, which is why we chose FEMA classification for our analysis.

Appendix A.5 Effect by Flood Risk

In this section, we present estimation results by flood risk zones and provide motivation for our focus on medium risk areas for the benchmark analysis. We account for the *ex-ante* flood risk using National Flood Hazard Layer (NFHL) data.[32] The NFHL flood risk data not only provides information on the underlying flood risks, but it is likely to affect housing sale prices due to a variety of regulatory implications.

Table A.4: Effect of Mangroves on Prices by Flood Risk

	Low flood risk	Medium flood risk	High flood risk
	(1)	(2)	(3)
Mangrove Distance ×	-0.033***	0.000	-0.052***
I(2 years before hurricane)	(0.004)	(0.003)	(0.004)
Mangrove Distance ×	0.001	-0.015***	0.002
I(1 year after hurricane)	(0.005)	(0.003)	(0.003)
Mangrove Distance ×	-0.013***	-0.018***	-0.041***
I(2-3 years after hurricane)	(0.003)	(0.003)	(0.004)
R^2	0.774	0.714	0.806
N	2078400	1171460	798326

Dependent variables: log of sale prices. Results estimated from equation 2. We estimate for each flood zone separately. Standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

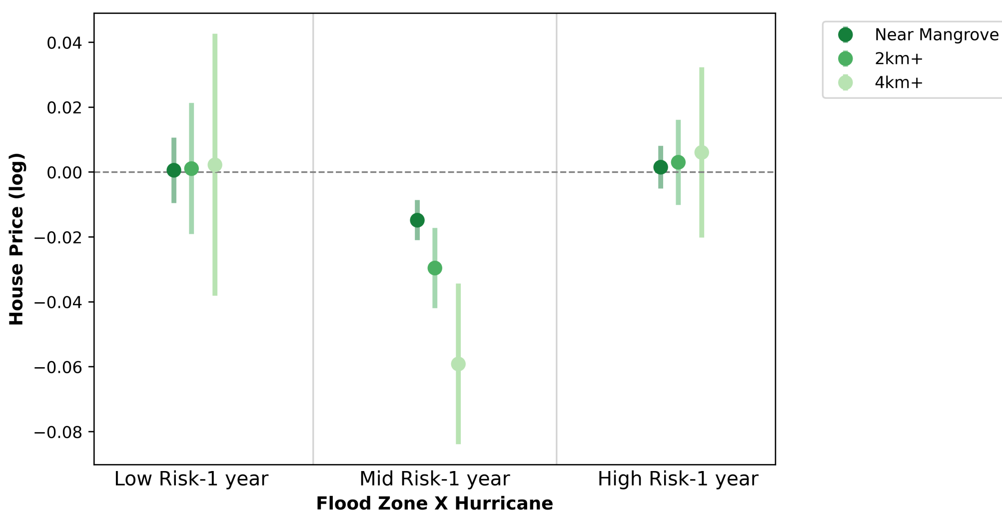


Figure A.4: Mangroves and Price, by Flood Risk Zone
Results are a linear combination of hurricane effect, mangroves distance effect, and their interaction terms. The results are from 1 year after hurricane coefficients in Table A.4.

[32]See Appendix A.3 for the detailed discussion of the floodzone definitions we use.

Appendix A.6 Robustness test tables and charts

Table A.5: Effect of Mangroves on Prices after Hurricanes by Individual Hurricane

	(1) Sale Price (log)	(2) Sale Price (log)	(3) Sale Price (log)	(4) Sale Price (log)
Mangrove Distance ×	0.010^{***}			0.014^{***}
I(2 year before Ivan)	(0.003)			(0.004)
Mangrove Distance ×	-0.002			-0.010^{***}
I(2 year before Sandy)	(0.002)			(0.003)
Mangrove Distance ×	-0.012^{***}			-0.013^{***}
I(2 year before Irma)	(0.003)			(0.003)
Mangrove Distance ×		-0.009^{***}		-0.028^{***}
I(1 year after Ivan)		(0.003)		(0.006)
Mangrove Distance ×		0.000		0.006^{*}
I(1 year after Sandy)		(0.003)		(0.003)
Mangrove Distance ×		-0.024^{***}		-0.018^{***}
I(1 year after Irma)		(0.005)		(0.006)
Mangrove Distance ×			-0.020^{***}	-0.024^{***}
I(2 year after Ivan)			(0.004)	(0.004)
Mangrove Distance ×			-0.001	-0.002
I(2 year after Sandy)			(0.002)	(0.003)
Mangrove Distance ×			-0.054^{***}	-0.059^{***}
I(2 year after Irma)			(0.004)	(0.004)
R^2	0.714	0.714	0.714	0.714

The negative coefficients of the interaction variables means that closer proximity to mangroves results in smaller sale price reduction following a hurricane. Results estimated from equation 2 for medium flood risk properties in the data but separately by individual hurricane. Time and property fixed effects are included in all regressions. Standard errors are in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Number of observations in all regressions is 1171460.

Table A.6: Effect of Mangroves on House Sale Prices (per Square Foot) after Hurricanes

	Dependent variable is Log(Sale Price) per Square Foot				
	(1)	(2)	(3)	(4)	(5)
Mangrove Distance ×	-0.012			-0.028*	-0.040**
I(2 years before hurricane)	(0.013)			(0.015)	(0.018)
Mangrove Distance ×		0.002		0.006	0.005
I(1 year after hurricane)		(0.018)		(0.020)	(0.020)
Mangrove Distance ×			-0.033**	-0.045***	-0.059***
I(2-3 years after hurricane)			(0.015)	(0.017)	(0.020)
Trend × Mangrove Distance					0.002
					(0.001)
R^2	0.817	0.817	0.818	0.818	0.818

The dependent variable—price per square footage—is rescaled by multiplying by 100. equation 2 estimation results for medium flood risk properties in the data. Time and property fixed effects are included in all regressions. Robust standard errors clustered on time are in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Number of observations in all regressions is 848916.

Table A.7: Effect of Mangroves on Prices after Hurricanes at ZIP code level

	Sale Price (mean)	Sale Price (median)
	(1)	(2)
Mangrove Distance ×	0.001	-0.001
I(2 years before hurricane) (max)	(0.005)	(0.005)
Mangrove Distance ×	0.002	-0.004
I(1 year after hurricane) (max)	(0.006)	(0.006)
Mangrove Distance ×	-0.002	-0.006
I(2-3 years after hurricane) (max)	(0.005)	(0.005)
Mangrove distance group (median)	0.021*	0.019
	(0.009)	(0.010)
Distance to coast (median)	-0.035***	-0.040***
Elevation meters (median)	0.012	0.011
Property Age (median)	-0.010***	-0.010***
Property Square Footage (median)	0.000**	0.000**
Single family house (=1)	0.129***	0.176***
Condo (=1)	-0.532***	-0.425***
R^2	0.502	0.497

The negative coefficients of the interaction variables means that closer proximity to mangroves results in smaller sale price reduction following a hurricane. Results estimated from a specification similar to equation 2 but at ZIP code level $log(P_{zt}) = \beta'(m_z \times H_t) + \delta_z + \delta_t + \epsilon_{zt}$ for medium flood risk properties in the data. Standard errors are in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Number of observations in all regressions is 58868.

Table A.8: Effect of Mangroves on Prices after Hurricanes: Weighted Regression

	Dependent variable is Log(Sale Price)				
	(1)	(2)	(3)	(4)	(5)
Mangrove Distance × I(2 years before hurricane)	-0.002 (0.002)			-0.003 (0.003)	0.012*** (0.003)
Mangrove Distance × I(1 year after hurricane)		-0.011*** (0.002)		-0.016*** (0.003)	-0.014*** (0.003)
Mangrove Distance × I(2-3 years after hurricane)			-0.016*** (0.003)	-0.022*** (0.003)	-0.005 (0.003)
Trend × Mangrove Distance					-0.002*** (0.000)
R^2	0.739	0.739	0.739	0.739	0.739

Observations are weighted by the inverse of the number of sales for each property so that each property has the same weight in the regression. Results estimated from equation 2 for medium flood risk properties in the data with time and property fixed effects. Standard errors are in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Number of observations in all regressions is 1171460.

Table A.9: Effect of Mangroves on Prices after Hurricanes: Standard Errors and Fixed Effects

	Dependent variable is Sale Price (log)					
	(1)	(2)	(3)	(4)	(5)	(6)
Mangrove Distance × I(2 years before hurricane)	0.000 (0.007)	0.000 (0.012)	0.000 (0.002)	0.000 (0.002)	0.005** (0.002)	-0.006** (0.003)
Mangrove Distance × I(1 year after hurricane)	-0.015** (0.007)	-0.015 (0.011)	-0.015*** (0.002)	-0.015*** (0.003)	-0.008*** (0.003)	-0.001 (0.003)
Mangrove Distance × I(2-3 years after hurricane)	-0.018* (0.010)	-0.018 (0.017)	-0.018*** (0.002)	-0.018*** (0.002)	-0.007** (0.003)	-0.000 (0.003)
Cluster	Time, Census	Time, ZIP code	Time× Census	Time× ZIP code	Time	Time
Fixed effects	Property Time	Property Time	Property Time	Property Time	Property Time×Census	Property Time×ZIP code
R^2	0.714	0.714	0.714	0.714	0.728	0.752

Results estimated from a specification similar to equation 2 but differ by fixed effect and clustered standard errors. $log(P_{zt}) = \beta'(m_z \times H_t) + \delta_z + \delta_t + \epsilon_{zt}$ for medium flood risk properties in the data. Standard errors are in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Properties with missing census tract information are assigned identical dummy census tract number. 1171460 observations in all cases.

Table A.10: Effect of Mangroves on Prices after Hurricanes: hurricane main and path effects, excluding Lehmann Crisis

	Dependent variable is Log(Sale Price)	
	(1)	(2)
Mangrove Distance ×	-0.001	
I(2 years before hurricane)	(0.003)	
Mangrove Distance ×	-0.015***	
I(1 year after hurricane)	(0.003)	
Mangrove Distance ×	-0.018***	
I(2-3 years after hurricane)	(0.004)	
Mangrove Distance × I(1 year after hurricane)		
On hurricane path		-0.037***
		(0.005)
Off path		0.008
		(0.004)
Mangrove Distance × I(2-3 years after hurricane)		
On hurricane path		-0.028***
		(0.004)
Off path		-0.009*
		(0.004)
R^2	0.717	0.718
N	1066842	1066842

The negative coefficients of the interaction variables means that closer proximity to mangroves results in smaller sale price reduction following a hurricane. Results estimated from equation 2 and from equation 4 for medium flood risk properties in the data. Standard errors are in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A.11: Effect of Mangroves on Prices after Hurricanes, Controlling for Insurance Coverage

	Dependent Variable is Sale Price (log)				
	(1)	(2)	(3)	(4)	(5)
Mangrove Distance ×	0.001			0.001	0.013***
I(2 years before hurricane)	(0.002)			(0.003)	(0.003)
Mangrove Distance ×		-0.009***		-0.015***	-0.013***
I(1 year after hurricane)		(0.002)		(0.003)	(0.003)
Mangrove Distance ×			-0.014***	-0.018***	-0.003
I(2-3 years after hurricane)			(0.003)	(0.003)	(0.003)
Trend × Mangrove Distance					-0.002***
					(0.000)
NFIP Insurance Coverage	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
R^2	0.714	0.714	0.714	0.714	0.714

The negative coefficients of the interaction variables means that closer proximity to mangroves results in smaller sale price reduction following a hurricane. Results estimated from equation 2 for medium flood risk properties in the data and include NFIP as control variables. Time and property fixed effects are included in all regressions. Standard errors are in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Number of observations in all regressions is 1171460.

Table A.12: Effect of Mangroves on Prices after Hurricanes, Controlling for Climate Belief

	Dependent Variable is Sale Price (log)				
	(1)	(2)	(3)	(4)	(5)
Mangrove Distance ×	-0.003			-0.253	-0.042
I(2 years before hurricane)	(0.006)			(0.248)	(0.260)
Mangrove Distance ×		-0.025**		-0.032***	-0.019*
I(1 year after hurricane)		(0.008)		(0.009)	(0.008)
Mangrove Distance ×			0.002	-0.263	-0.053
I(2-3 years after hurricane)			(0.006)	(0.248)	(0.259)
Trend × Mangrove Distance					-0.009***
					(0.002)
Belief about climate damages	0.001	0.004	0.001	0.002	0.010
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
R^2	0.822	0.822	0.822	0.822	0.823

Results estimated from equation 2 for medium flood risk properties in the data and include county-level climate beliefs as control. Time and property fixed effects are included in all regressions. Standard errors are in parentheses: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Number of observations in all regressions is 53374. The number of observations is smaller than benchmark due to the belief data merge.

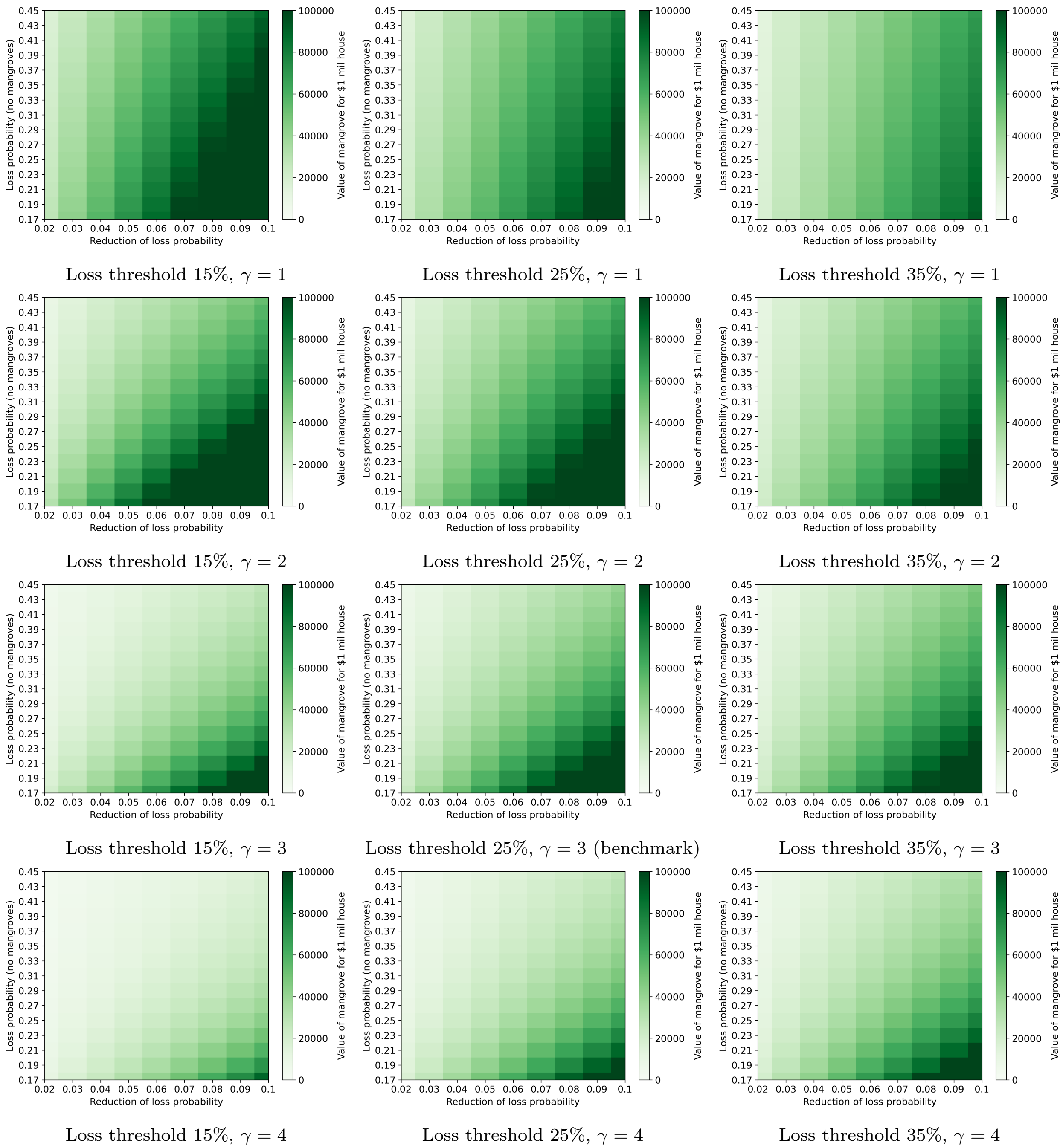


Figure A.5: Sensitivity of willingness to pay calculations to the loss threshold and CRRA parameter γ.